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Effect of ultrasonically-assisted drilling on carbon-fibre-reinforced plastics

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ABSTRACT

This research focuses on the effect of ultrasonically-assisted drilling (UAD) on carbon fibre-reinforced plastics. High-frequency vibration was used to excite a drill bit during its standard operation. An extensive experimental study of drilling forces, temperature, chip formation, surface finish, circularity, delamination and tool wear was conducted using ⌀3 mm drill and presented here. UAD showed a significant improvement in drill quality when compared to conventional drilling processes. A finite-element study was also conducted to understand the nature of drilling-force reduction in UAD.

1. Introduction

Carbon-fibre-reinforced plastic (CFRP) composites have strong but brittle carbon fibres embedded into a weaker plastic matrix. The carbon fibres support the load, while the matrix serves to hold and protect the fibres and transmit the load to them. CFRP composites have many superior properties including low density (lower than aluminium), high strength (as high-strength steels), high stiffness (stiffer than titanium), good fatigue and creep resistance, and excellent dimensional stability (close to zero coefficient of thermal expansion). Thus, it is of no surprise that CFRP composites are widely used as structural and functional components in aerospace, biomedical, sports, automotive and defence applications amongst others.

Though every attempt is made to manufacture CFRP components to near-net shape, in order to facilitate their assembly, machining of CFRP is unavoidable. For example, to join structures, holes need to be drilled to facilitate riveting and bolting. Thus, drilling in composites is indispensable. However, this process leads to various damage modes in composites, such as delamination, fibre pull-out, hole-roundness errors and inter-laminar crack propagation. Amongst these, delamination is a major threat, as it leads to a loss of mechanical and fatigue strength in the drilled-hole area [1]. Hocheng and Tsao [2,3] explored the possibilities of delamination-free drilling in composite materials via an exhaustive study of drill types and defining the level of critical thrust force at the onset of delamination. Apparently, reduction of this force can diminish the extent of drilling-induced damage. Hence, it was realised that vibration assisted drilling has potential as a viable non-traditional drilling method for damage free drilling in heterogeneous composites [4–7].

In the recent past [8,9,11], ultrasonically-assisted drilling (UAD) techniques, in which high-frequency (typically >18 kHz) and low-amplitude (<20 μm) vibration was superimposed on a movement of a standard twist drill bit in the axial direction,

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have been used to improve the overall machinability of advanced materials. These studies were typically performed using ⌀6 mm and wider drills in a variety of workpiece materials including metals and woven composites. Several studies performed over the last few years indicated that vibrating the drill bit in the axial direction yielded the maximum reduction in drilling-induced damage. There are several well-documented advantages of UAD over conventional drilling (CD) techniques such as reduction in thrust forces and torque, better surface finish, low tool wear and elimination/reduction in burr formation [8–11]. The thrust force has a direct effect on drilling-induced damage in composites; hence, it is considered to be the main parameter affecting quality of a drilled hole.

The paper is organised as follows. In Section 2, descriptions of the experimental setup including various characterisation instruments used are presented along with details of a workpiece material and cutting tools used. Section 3 comprises measurement results followed by discussions in Section 4. The paper ends with some concluding remarks in Section 5.

2. Experimental work

2.1. Experimental setup

A universal lathe (Harrison M-300) was modified to accommodate an ultrasonic transducer (Fig. 1), and the modified system offered flexibility of conducting UAD and CD experiments using the same setup. It comprises a Langevin-type piezoelectric ultrasonic transducer that uses a high-frequency alternating voltage to create mechanical vibration by employing piezoelectric effects.

A typical transducer consists of a stack of peizoceramic elements, a front wave-guide and a backing mass. The vibration amplitude generated in the piezoelectric element is too small for viable applications; hence, geometry of the transducer's components needs to be appropriately designed with the aid of eigenmode analysis to amplify the amplitudes [12]. Thus, a commercially available transducer was appropriately modified using an improved design of its waveguide to accommodate a ⌀3 mm drill bit. The waveguide design was carried out based on the modal analysis with a commercial finite-element software Abaqus v6.11 [13] in order to maximise the amplitude of the longitudinal (axial) mode of vibration.

The waveguide was made of aluminium as it provides a fair degree of acoustic coupling between a carbide drill bit and a steel transducer horn. The transducer was fastened in an aluminium tube and mounted on the headstock of the lathe using a four-jaw universal chuck (see Fig. 1a). The conical waveguide was screwed on the transducer horn. Precautionary measures were taken during the overall assembly of the system to ensure its rigidity. Thus, the headstock of the lathe accommodated the transducer assembly; whereas, the tail stock of the lathe was prepared to accommodate a workpiece and a force-measuring dynamometer. In UAD experiments, the frequency was tuned and set at a particular resonance level with the help of GW Instek™ (model SFG-2110) functional generator.

Langevin transducers usually have one or two resonant frequencies, for which substantial vibration amplitudes can be achieved. In this work, the transducer was designed to resonate at frequencies in excess of 20 kHz. Only one resonance frequency was observed for the developed transducer with the attached drill bit at a frequency of 27.8 kHz.

2.2. Workpiece material

The workpiece material used in the drilling studies was a M21/T700 CFRP provided by Airbus™. This quasi-isotropic composite was composed of 34 plies with the stacking sequence of $[(0^\circ/45^\circ/90^\circ/-45^\circ)_{4s}/0^\circ]_s$, shown in Fig. 2. The plates of CFRP (thickness: 10 mm) were cut into pieces with a length of 200 mm; and width of 10 mm. The composite material was tested and mechanical properties were evaluated via a series of experiments conducted at the in-house materials-testing facility in Loughborough University, UK. The mechanical properties of the unidirectional 0° ply (all the fibres in loading direction) are given in Table 1; further details are available in [14].

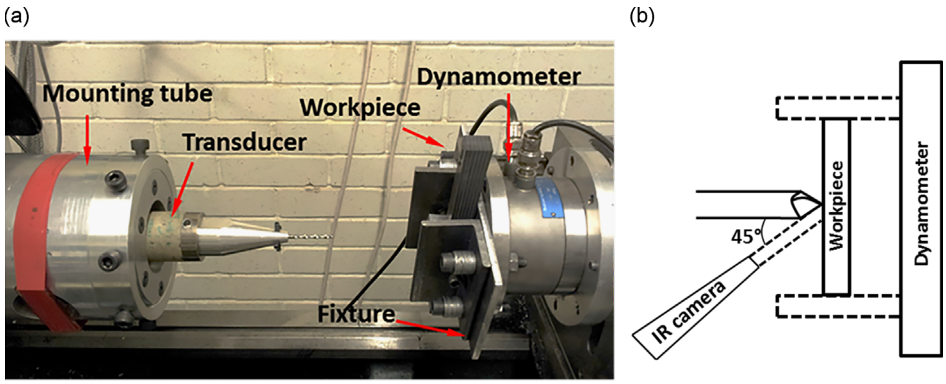

Fig. 1. Experimental setup (a) and schematic for temperature measurements (b).