International Journal of Machine Tools & Manufacture 51 (2011) 740–744

Contents lists available at ScienceDirect

International Journal of Machine Tools & Manufacture

journal homepage: www.elsevier.com/locate/ijmactool

Short communication

Evaluation of drilling parameters on thrust force in drilling carbon fiber reinforced plastic (CFRP) composite laminates using compound core-special drills

C.C. Tsao*, Y.C. Chiu

Department of Mechatronic Engineering, Tahua Institute of Technology, Hsinchu 30740, Taiwan, ROC

A R T I C L E I N F O

Article history:
Received 7 March 2011
Received in revised form
14 May 2011
Accepted 18 May 2011
Available online 30 May 2011

Keywords:
Carbon fiber reinforced plastic
Compound core-special drill
Cutting velocity ratio
Delamination
Drilling
Thrust force

A B S T R A C T

Drilling is the mostly used secondary machining of the fiber reinforced composite laminates, while the delamination occurs frequently at the drill exit in the workpiece. In the industrial experiences, core drill shows better drilling quality than twist drill. However, chip removal is a troublesome problem when using the core drill. Conventional compound core-special drills (core-special drills and step-core-special drills) are designed to avoid the chip removal clog in drilling. But the cutting velocity ratio (relative motion) between outer drill and inner drill is null for conventional compound core-special drills. The current study develops a new device and to solve the problems of relative motion and chip removal between the outer and inner drills in drilling CFRP composite laminates. In addition, this study investigates the influence of drilling parameters (cutting velocity ratio, feed rate, stretch, inner drill type and inner drill diameter) on thrust force of compound core-special drills. An innovative device can be consulted in application of compound core-special drill in different industries in the future.

1. Introduction

Carbon fiber reinforced plastic (CFRP) is a composite material commonly applied for various structural parts to near-net shape due to its high specific strength, high fracture toughness and excellent corrosion resistance. However, the machinability and cutting behavior of CFRP differ from metals because it is anisotropic, inhomogeneous and abrasive. In conventional machining, drilling is the most commonly applied method, accounting for as much as 40% of all materials removal processes [1]. With CFRP, the most frequent defects are delamination, fiber pull-out, interlaminar cracks and thermal degradation after drilling. Drilling-induced delamination tends to reduce the structural strength and in-service life under fatigue loads.

Several studies have been reported that drilling-induced delamination correlates closely with the thrust force during exit of the drill [2,3], and it is believed that there is a "critical thrust force" below which no damage occurs [2]. Reducing thrust force depends on the geometry and materials of the tool, workpiece materials, drilling parameters and coolant use. It is the tool geometry that is the most significant factor in the choice of cutting tool in drilling composite materials. Improper usages of tooling and cutting conditions can damage the composite laminate by chipping and cracking at the exit plane of the drill. Some studies have pointed out new concepts of tooling different realms of cutting conditions to reduce the drilling-induced damages in drilling composite materials [4,5]. Mackey [5] showed that using a tubular drill bit could improve the quality of hole finish in drilling.

The core drill is a hollow grinding drill with bonded diamond cutting surface and reduced thickness. With much smaller thrust and much better hole quality than the twist drill [6,7]. However, chip removal is a troublesome problem when using the core drill. To resolve this problem of chip removal, conventional compound core-special drills are designed to avoid the chip removal clog in drilling. Conventional compound core-special drills can be considered as composed of an outer drill (core drill) and an inner drill (twist drill, saw drill or candlestick drill). Various types of the conventional compound core-special drills are shown in Fig. 1.

To analyze their action, Hocheng and Tsao [8,9] developed a series of analytical models, based on the linear elastic fracture mechanics (LEFM) and energy conservation for the core-special drills to correlate the thrust force with the onset of delamination. But the cutting velocity ratio (relative motion) between outer drill and inner drill is null for conventional compound core-special drills. Therefore, the current study develops a new device to solve the problems of relative motion and chip removal between the outer and inner drills in drilling CFRP composite laminates. Langella et al. [10] specified the action of the chisel edge for the twist drill on thrust increases with

* Corresponding author.
E-mail addresses: aetcc@thit.edu.tw, aetcc@et4.thit.edu.tw (C.C. Tsao).

0890-6955/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ijmachtools.2011.05.004

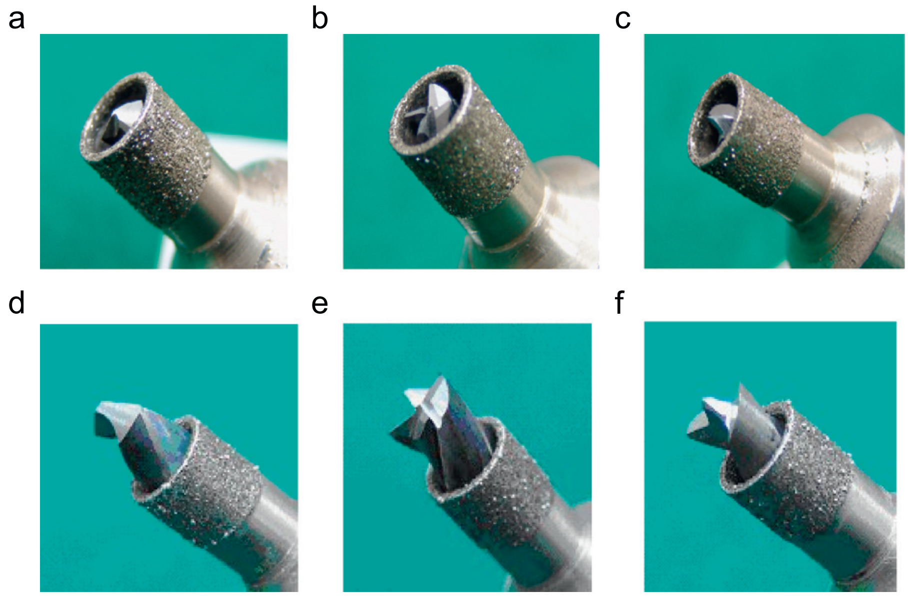

Fig. 1. Photograph of various types of the conventional compound core-special drills. (a) Core-twist drill, (b) core-saw drill, (c) core-candlestick drill, (d) step-core-twist drill, (e) step-core-saw drill, and (f) step-core-candlestick drill.

the feed rate and may account for over 80% of the total force required to drill a hole. Khashaba et al. [11] showed that increased cutting speed reduces the associated thrust force and torque, especially at high feed values. Tsao [12] showed that diameter ratio and feed rate have the most significant influence on the overall performance of step-core special drills, and the diameter ratio may be a viable alternative for the step-core special drills in terms of drilling thrust. The thrust force of various step-core drills increase with decrease in diameter ratio and increase in feed rate. Gaitonde et al. [13] found that the tendency of drilling-induced delamination decreases with increased cutting speed in drilling of CFRP composite materials. A combination of lower feed rate and lower point angle with higher cutting speed to reduce drilling-induced delamination using a K20 twist drill was suggested. In addition, DiPaolo et al. [14] pointed out that the spalling occurred at the drill exit through the Mode I (opening) and Mode III (tearing) damage mechanism. Mode III was subjected to the peripheral drilling moment and a twisting due to the combination of the downward thrust force and the back rake angle along the cutting lips. Tsao and Hocheng [15] reported that the effects of peripheral drilling moment on delamination using special drill bits could be ignored under mild drilling conditions.

On the other hand, Taguchi method has been widely used to investigate the effects of the entire machining parameters through small number of experiments in drilling CFRP composite materials. Davim and Reis [16] found that the delamination factor increases with both cutting speed and feed rate. Tsao and Hocheng [17] showed that the feed rate and drill diameter are seen to make the largest contribution to the overall performance in drilling CFRP composite materials. Although significant efforts have been made to reduce the drilling-induced delamination caused by various drill bits and process conditions, there have been few papers reporting the effects of cutting velocity ratio (considered rotational direction) and stretch between outer drill and inner drill on the thrust force of compound core-special drills in drilling CFRP composite materials.

2. Experimental setup

The carbon/epoxy composite materials were drilled in this study. Composite laminates are being prepared in the laboratory

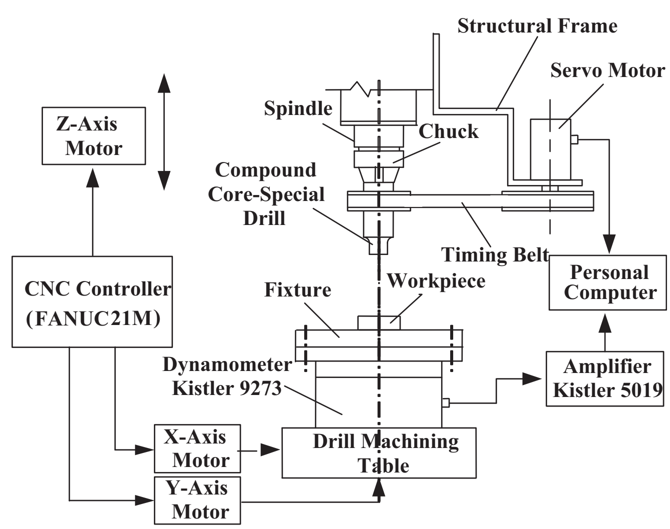

Fig. 2. Schematic of experimental setup.

from woven WFC200 fabric carbon fiber prepregs. The laminates are cured in an autoclave at 150 °C and 600 KPa for 90 min. The composite was a 16-ply ($[0°/90°]_{8S}$) laminate approximately 4 mm thick. The plates are cut into coupon specimens of 60 mm × 60 mm using diamond-edged saw. A LEADWELL V30 vertical machining center with a 5.5 kW power and an additional servo motor with a 0.4 kW power were employed to drive inner drill and outer drill in drilling tests, respectively, as shown in Fig. 2. The thrust forces during drilling were measured using a Kistler type 9273 piezoelectric dynamometer and the signal was transmitted and converted by a Kistler type 5019 controller unit and recorded on a Pentium IV personal computer. The amplifier has to stabilize for at least an hour. Each test was replicated twice. The outer drill diameter and core tool thickness of the compound core-special drills are 10 and 1 mm, respectively, the end of the core tool plated with a #60 diamond grits, and its length is 12 mm. The internal parts of the compound core-special drills are the twist drill, saw drill and candlestick drill, respectively. Tungsten carbide twist drills, saw drills and candlestick drills of