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ScienceDirect

Procedia CIRP 62 (2017) 15 – 20

www.elsevier.com/locate/procedia

10th CIRP Conference on Intelligent Computation in Manufacturing Engineering - CIRP ICME '16

Experimental investigation of clamping systems and the resulting change of cutting conditions while drilling carbon fiber reinforced plastics

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Abstract

Drilling is one of the most frequently applied processes for machining carbon fiber reinforced plastics (CFRP). The clamping distance influences the bending of a plane specimen when using a 4-point clamping system. In this paper, an empirical model for CFRP based on the plate theory is presented which describes the bending behavior of the specimen during the drilling process. Additionally, the influence the bending behavior exerts on the cutting thickness during drilling CFRP is described. The results show that the cutting thickness varies while drilling the material depending on the acting axial force and the current bending of the specimen.

Peer-review under responsibility of the scientific committee of the 10th CIRP Conference on Intelligent Computation in Manufacturing Engineering

Keywords: Fiber reinforced plastic; Drilling; Bending; Clamping system

1. Introduction

Fiber reinforced plastics (FRP) are suitable for multifarious applications, e.g. in the aerospace and automotive industry as well as in the leisure segment. The main reason for this lies in the high specific stiffness and strength. In addition, fiber reinforced plastics (FRP) provide design freedom for the component. Compared to the same metallic structure, the specific energy absorption capacity of carbon fiber reinforced plastics (CFRP) is between four and five times higher [1]. FRPs are usually produced in a near-net-shape process. Nevertheless, machining processes are necessary and in this case, milling and drilling are the most common ones [2].

Post-processing such as drilling leads to a weakening of the composite [3]. Moreover, the phenomenon of delamination at the upper side “peel-up” and at the underside “push-out” of the component caused by drilling is quite frequent [4]. Reducing the axial force at the entrance side and at the exit side presents one option for avoiding delamination in FRP composites [4,5]. With the combined process of circular and spiral milling and wobble milling, Schulze et al. showed that directing process forces toward the center of the workpiece decreases delamination [6]. The influence of the axial force caused by different drill geometries on delamination was investigated [7,8,9,10] as well as preventing delamination with predrilled pilot holes [11]. Drilling with a dynamically adapted feed rate was developed by Klotz et al. and shows a reduction of workpiece damage and allows a longer tool life [12].

Only little research has been executed on examining of clamping systems during machining of FRP. Uhlmann et al. investigated the influence while drilling metallic tubes with different cantilever distances. They found out that the acceleration of the beams as well as the edge layer hardness increase with rising cantilever distance [13]. The company Schmalz developed a clamping system for the variable clamping of complex workpiece geometries [14]. An optimization method for finding clamping points which held the static resilience and oscillation amplitude within some predefined boundaries was developed by Eisseler et al. [15]. A reduction of the maximum axial force during drilling cantilever beams can be observed as well as a reduction of the real feed force during the entrance of the drill tool. This leads to an increase of the total processing time. At the exit of the drill tool, the feed force temporarily increases. The use of ultrasonic assisted drilling results in a reduced deflection and

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doi:10.1016/j.procir.2016.06.089

in a decrease of forces by 30-40%. Conversely, the surface damage increases [16,17]. Heberger et al. investigated different supports at the top layer and the bottom layer. The best results could be observed when a support plate with a predrilled hole of the same diameter as the final hole was used [18]. When a backup plate and saw or core drills are applied, higher critical feed forces can be achieved until delamination occurs [19]. The same results can be observed when using a twist drill [20]. An active backup force can reduce the surface damage at the bottom layer by about 60-80%, compared to unsupported drilling [21]. For drilling holes in FRP tubes, magnetic colloids with an applied magnetic field are pressed against the inner wall of the tube. That also leads to a reduction of damage of around 60-80% [22]. When drilling FRP metal stacks, the metallic part can be regarded as a backup plate. Qi et al. investigated the critical feed force for delamination depending on the thickness of the metal plate [23]. Capello examined the influence of supported drilling and developed a damping system which avoids a drastic increase of the feed force when the drill exits the workpiece [24]. A device which presses a plate against the upper layer leads to the reduction of peel-up delamination [25]. Luo et al. developed a model for predicting the feed force depending on the influence of workpiece stiffness and the feed rate. They divide the drilling process into three phases: The entrance phase, the full engagement phase and the exit phase of the drill. During these three phases, the feed rate changes dynamically taking into account the actual deflection of the workpiece. As a result, the uncut thickness of the material increases at the entrance and in the full engagement phase when drilling specimens with low stiffness [26]. However, the authors did not calculate the actual feed rate which occurs at the different phases of the drilling process. Klotz et al. investigated different clamping systems regarding the damage at the top and the bottom layer and showed that the tool breaks through the component and causes push-out delamination [27]. The same investigation was performed for edge milling of planar specimens with variable clamping distances [28].

Within this work, the clamping of planar specimens with a 4-point clamping system is examined. Its purpose constitutes in generating knowledge on the behavior of CFRP under uniquely defined clamping conditions and the force induced by the drilling tool. The deflection of the specimen is predicted with a specifically developed model and the local change of feed per tooth is calculated and analyzed.

2. Experiments

2.1. Experimental setup

For the drilling experiments, a 4-point clamping system is used which is comparable to the system which was shown in [27]. As can be seen in Figure 1, the specimen is clamped with four ball pressure screws on the upper side and four aluminum pins on the underside of the specimen. The clamping points are located at a distance of 10 mm to the specimen edges. The length of l_x and l_y are variable whereby different clamping distances can be configured. All drillings are located in the middle of the specimen. The distance between the drilling and clamping points was stated by l_{max}. All ball pressure screws are fixed with a tightening torque of 0.5 Nm.

In the drilling experiments, the same procedure as shown in the previous work [27,28] is used. Between each drill at the 4-point clamping system, a drill with ideal clamping condition is conducted. For these reference drills, the specimen is supported by two plates on the upper side and underside with a hole of 15 mm in diameter [27].

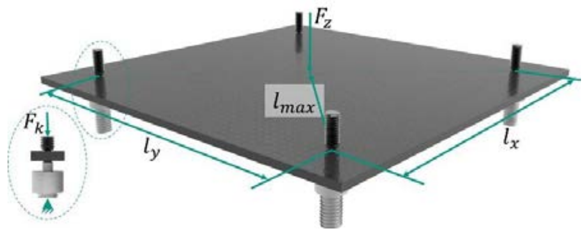

Fig. 1. Schematic drawing of the 4-point clamping system

The experiments are conducted on a Heller MC16 machining center. The multi-component dynamometer (Kistler Type 9255C) and three signal conditioner (Kistler Type 5015) are used for measuring the three orthogonal forces F_x, F_y, F_z which affect the specimen. The axial force $F_{z,Dyn}$ and torque M_z are measured with a rotating multi-component Kistler dynamometer Type 9125A at the drill. For measuring the bending moment, a potentiometric position sensor Novotechnik TR25 is used.

2.2. Material data, drill tool and process parameters

The specimens used for the experiments have the same attributes as the material used in [27]. The thickness of the plates is $h=2.5mm$. The fiber is named T620SC 24K 50C produced by Toray company. CFRP plates are pressed by the injection resin transfer molding process and consist of eight plies of endless quasi-isotropic compositions [0°/90° and +45°/-45°]. Fiber content lies at 60% and the elastic modulus at 46,100 MPa. The drilling tool for these experiments has a diameter of 10 mm and a geometry according to DIN 6539. The number of teeth is 2, the helix angle 30° and the point angle 118°. The feed rate was fixed to $v_f=300$ *mm/min* and the drill speed was fixed to $n=3{,}000$ min^{-1} [27].

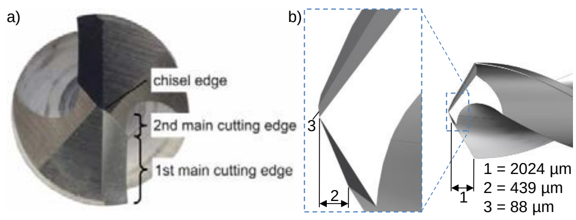

Fig. 2 a) Geometry of the drill tip; b) Height of the cutting edge at the drill tip

As Figure 2 (a) demonstrates, the main cutting edge can be divided into two sections, the first main cutting edge and the