Diagnosing of the Glass Fiber Reinforced Polymer Material High Performance Drilling Process State

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Abstract. The article presents the results of works on the analysis of using cutting forces and torque measurements to determine the state of dry fiberglass matrix polyester resin composite high performance drilling process. The research and analyzes were carried out for the different states of tool state and the process state itself. GFRP - Glass Fiber Reinforced Polymer was used to perform the experiment. As a result of the conducted analyzes, it was determined that booth the forces and torque generated in drilling process can constitute a good diagnostic signal, on the basis of which it is possible to conclude about the state of the process and tool.

1 Introduction

Making holes in polymer composite materials, in particular those reinforced with various types of fibers, is a significant technological problem due to the occurrence of unfavorable processing conditions; highly abrasive properties of reinforcing fibers, poor heat dissipation, limitations in the use of cutting fluids lead to accelerated tool wear or damage to the workpiece. A common problem when drilling in materials such as GFRP or CFRP (and other fiber-reinforced composite materials) is the occurrence of delamination [8, 12]. An important problem during the machining of composite materials is the tool wear process, its monitoring and modeling of the cutting edge condition [2,4,5,6], especially in terms of its wear [14,19]. The drilling process in composite materials and fibrous composite materials has been the subject of various scientific studies, e.g. in the field of determining trust forcee and torque [1,2,20], modeling temperature or forces occurring in the process [3,7,9,11,15, 18] as well as testing the material itself, in particular its abrasive properties or abrasion resistance [10]. Based on the review of the literature in the field of the study, it was found possible to diagnose and monitor the state of the removal process of fiber-reinforced polymer composites on the basis of forces and acoustic emission (AE) [4, 13, 17].

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2 Characteristics and diagnosing of drilling processes state

An attempt was made to determine the suitability of the trust force and rorque generated in the tool-holder-workpiece system for drilling process of fiber composite material (GFRP - Glass Fiber Reinforced Polymer) state determine. Original results were alco compared to cutting edge state.

2.1 General set-up, methodology and technique of experiment

The article presents the results of original studies using the Kistler 9257B dynamometer with the 5017 signal amplifier. The acquired and processed signal was sent to a data acquisition system for force measurements (DAQ) Type 5697A module. During the measurement of forces and torque, the proprietary software Dynoware 2825D-02, supplied by the manufacturer of the dynamometer was used. The software had a database structure, which made possible to conduct collected data without the need to record the obtained results. Before making the tests, the dynamometer was programmed in Newtons (based on the attached calibration card - the values are given in Table 1.) and checked by applying a force with a known value.

Table 1. 3-component Kisler 9257B dynamometer technical data.

Range Fx , Fy , Fz Fz for Fx and Fy≤0.5 Fz	Fx , Fy , Fz Fz	kN kN	-5 ... 5 -5 ... 10
Threshold	-	n	<0.01
Sensitivity (calibrated)	fx , Ph Fz	PC /N PC /N PC /N	- 7.92 - 7.90 - 3.69
Hysteresis , all ranges	-	%FSO	≤0.5
cross-talk	-	%	≤±2
natural frequencies	fn (x ,y,z)	kHz	≈3.5
natural frequencies (mounted on flanges	fn (x ,y) fn (z)	kHz kHz	≈2.3 ≈3.5

Polymer material drilling conditions were:

- Glass Fiber Reinforced Polymer material, 8mm thickness,
- 8mm HSS EI 13 W ü rth drill bit, standard geometry,
- cutting speed v_c = 150 m/min, feedrate v_f = 300 mm/min,
- dry drilling (no fluid coolant an compressed air were used),
- straight drilling cycle.

The tests were carried out on a DMG DMU50 5-axis machining center, the workpiece was clamped in a vice attached to a force gauge. Orientation axis force gauge was consistent with the orientation axis machine tools.

Optical analysis of the drills was performed using a Keyence VHX-7000 digital stereoscopic microscope. The photos were captured at x100 magnification.

2.2 Results measurements

Cutting force measurement results; F_x, F_y, F_z and torque M_z were depicted in the form of selected graphs of forces and torque values changes during drilling (fig. 1-4). Digitally unfiltered values were analyzed; a hardware low-pass filter of the amplifier 10 Hz and sample rate100 Hz was used. The results of the changes in the values of forces and torque were also presented on two summary charts (Fig. 5 and Fig. 6). The machining conditions were selected on the basis of the analysis of the available literature and previous own work so as to obtain high process efficiency and accelerated tool wear. The obtained volumetric machining efficiency for the assumed parameters was 15000 mm^3/min and the time of making a single hole was about 2 s.
Fig. 1 shows forces and torque values changes F_x, F_y, F_z and torque M_z during drilling hole #1 with a drill bit with the correct condition of the cutting edges; the obtained courses of changes are consistent with those obtained by other research teams, e.g. [16]. Marked characteristic zones changes values as: A – drill entry zone, B – full drill diameter entry zone, C – completely entered tool drilling zone, D – drill tip leaving zone, E – toll backward zone. The maximum value of the axial cutting force (trust force) was 256.3 N and the maximum recorded cutting torque was 0.56 Nm.

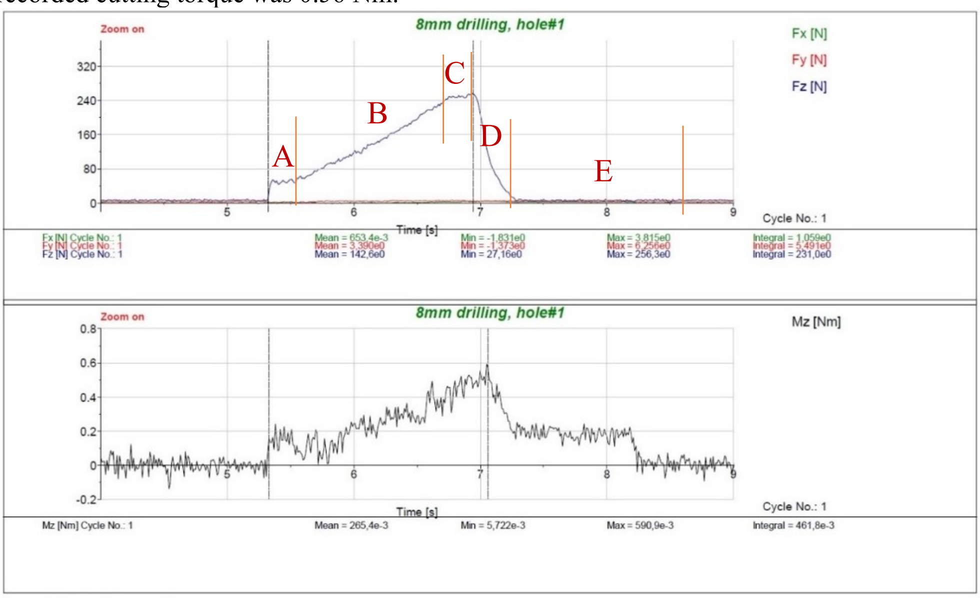

Fig. 1. F_x, F_y, F_z and M_z values changes during GFRP drilling, hole #1, A – drill entry zone, B – full drill diameter entry zone, C – completely entered tool drilling zone, D – drill tip leaving zone, E - toll backward zone

Cutting force measurement results; F_x, F_y, F_z and torque M_z for a drill with an incorrect cutting edge condition are shown in the figures below (fig. 2÷4). Fig. 2 shows the changes in the character of the course of forces during the drilling of hole #4; lack of a clear zone A, zone B with a clearly larger slope of the change curve, zone C strongly elongated by a quasi-constant value. The maximum value of the axial cutting force (trust force) was 768.1N and the maximum recorded cutting torque was 0.54 Nm.

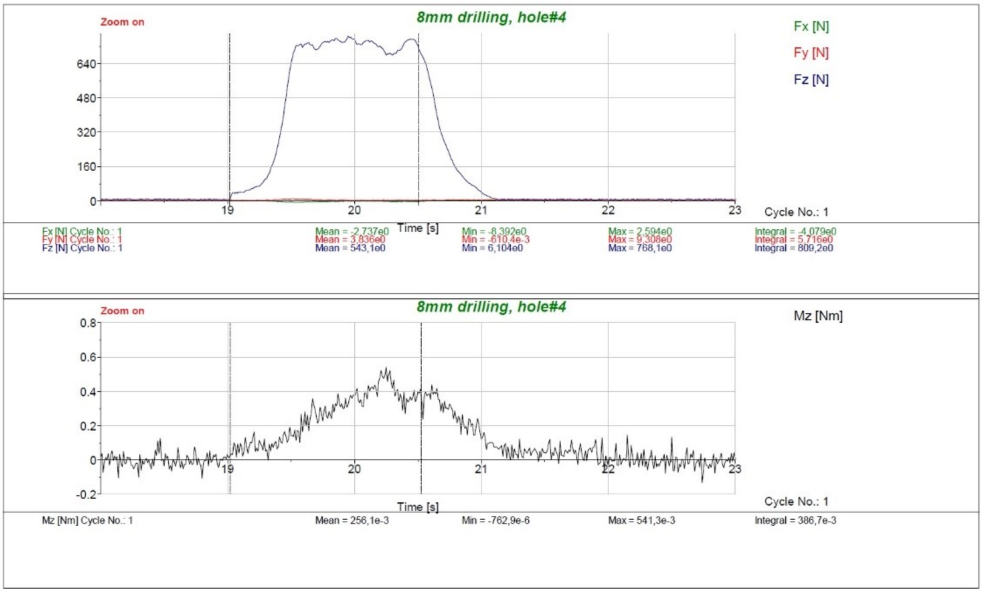

Fig. 2. F_x, F_y, F_z and M_z values changes during GFRP drilling, hole #4

Fig. 3 shows the changes in the nature of the course of forces during the drilling of hole #8; as in Fig. 2. no clear zone A, zone B with a clearly smaller slope of the change curve than in Fig. 2, zone C strongly elongated initially increasing and then rapidly decreasing in value. The maximum value of the axial cutting force (trust force) was 985.7 N and the maximum recorded cutting torque was 0.75 Nm

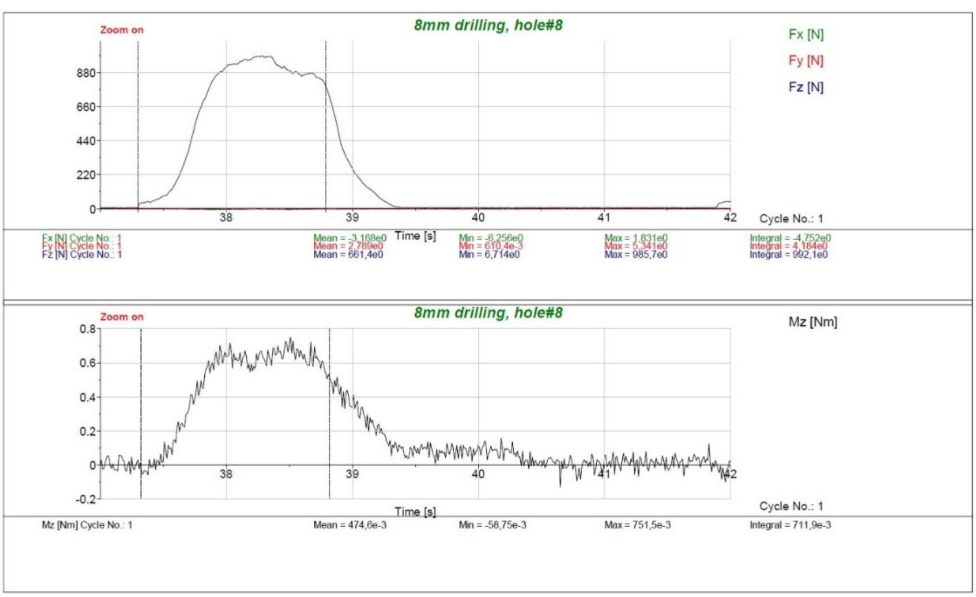

Fig. 3. F_x, F_y, F_z and M_z values changes during GFRP drilling, hole #8

Fig. 2 shows the changes in the character of the course of forces during the drilling of hole #27; no clear zone A, zone B with a clearly larger slope of the change curve, zone C strongly elongated with a quasi-constant value , as in Fig. 2. The maximum value of the axial cutting force (trust force) obtained increased significantly and amounted to 1404 N. The maximum recorded cutting torque was 0.94 Nm

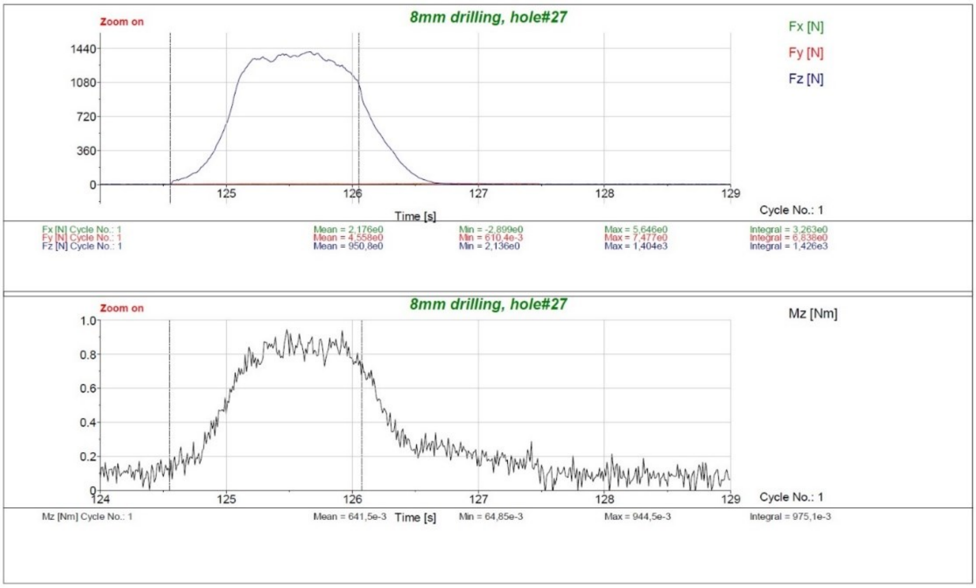

Fig. 4. F_x, F_y, F_z and M_z values changes during GFRP drilling, hole #27

In Fig.5. and Fig.6. the obtained waveforms of changes in the values of cutting forces and cutting torque for all the holes made were depicted. The holes were made in 3 rows of 10 holes (fig. 8), 2 GFRP boards were used. The rows of holes are schematically separated by red lines.

A visual verification of the state of the cutting edge was carried out after making a series of holes; Fig. 7 b) and c) and compared with a new blade; Fig. 7a). The state of the main cutting edge, visible from the side of the rake plane - Fig. 7 a) and b) and the flank surface - Fig. 7 c). The places of the greatest tool wear, resulting in a change in its geometry, are marked - indicated by red arrows, as well as the direction of wear and its form; abrasive wear – indicated by yellow lines.

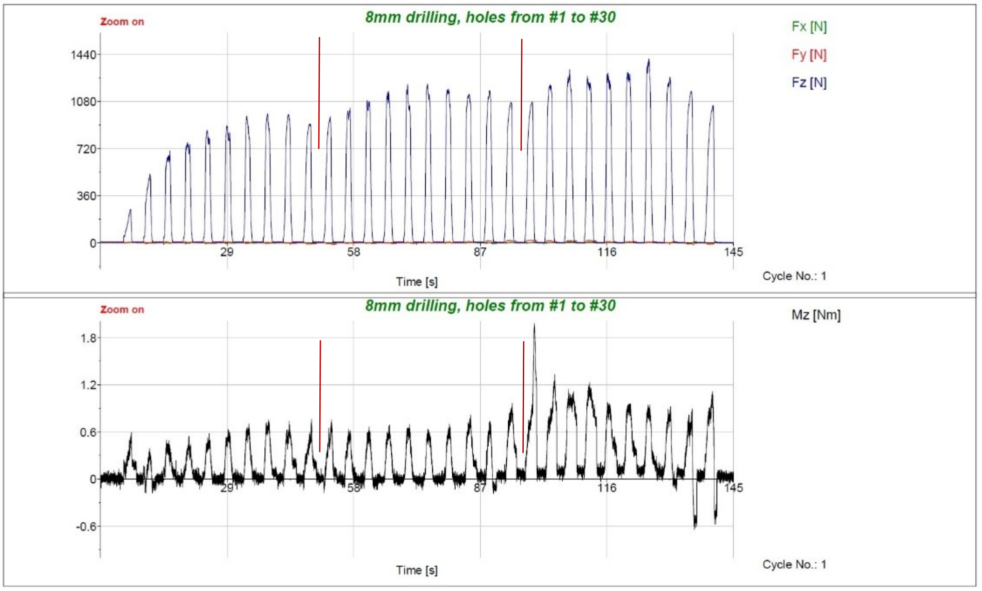

Fig. 5. F_x, F_y, F_z and M_z values changes during GFRP drilling, holes from #1 to #30

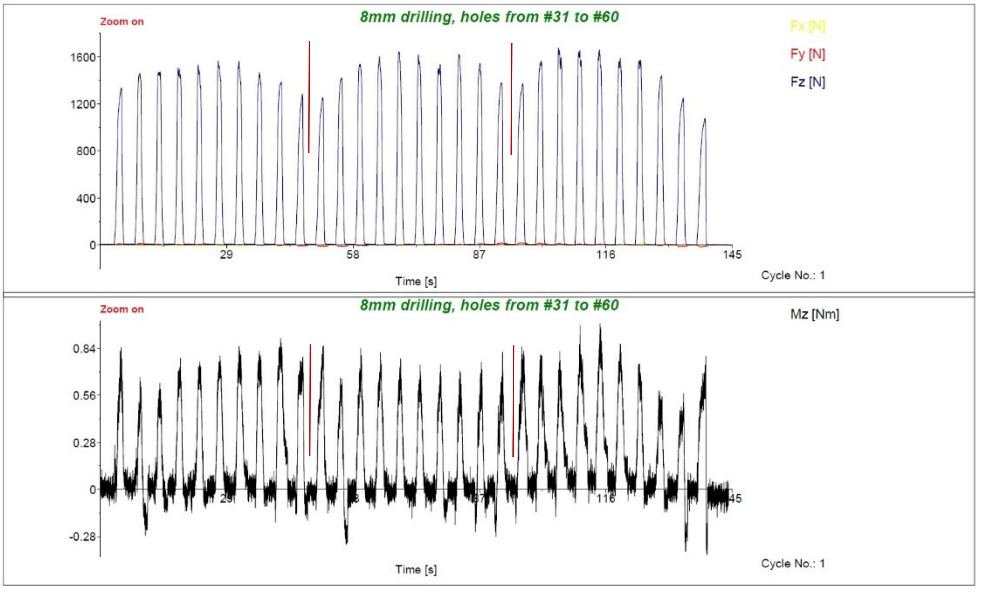

Fig. 6. F_x, F_y, F_z and M_z values changes during GFRP drilling, holes from #31 to #60

Fig. 7. Main cutting edges and surfaces view; a) new drill; b) and c) - worn drill

3 Discussion and conclusions

The tests of high-performance GFRP material drilling resulted in intensive tool wear and rapid changes in the values of the measured quantities, i.e. cutting forces and torque, which were diagnostic signals of the state of the process. As in the previous study [13], the determined changes in the value of cutting forces were a good diagnostic signal of the process status. During the experiment, it was found that a large amount of heat was generated (measurements of temperature changes were not the subject of the study), which was manifested by the formation of smoke in the place where the hole was made and glowing of the machined surface. This indicates a highly abrasive nature of the reinforcing fibers, as a result of which very high abrasive wear of the cutting tool was observed, which, despite this, had good cutting properties until the end of the experiment. As a result of the conducted machining, a new geometry of the cutting edge was formed, which enabled the drilling process to be carried out without any problems, however, it resulted in strong increases in the maximum trust force and maximum torque and a change in the course of changes in the values of forces and torque. The obtained machining effects, especially in terms of delamination, were at a similar level, and often drilling holes with a partially worn tool was sometimes obtained better than in the initial phase of the test - Fig. 8.

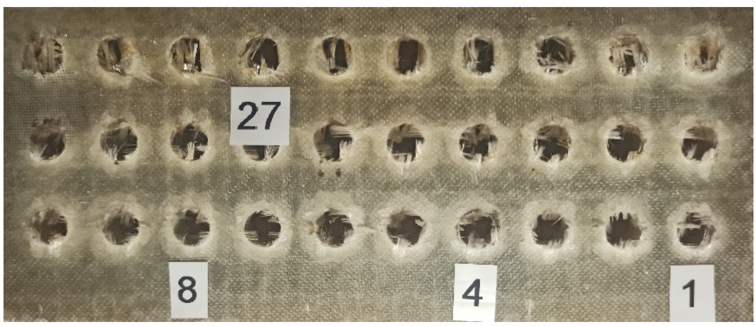

Fig. 8 Sample back side view; holes #1, 4, 8 and 27 marked

Based on the literature review and the results of own work, the following conclusions were drawn:

- The machining force or force components values and its changes, generated in the process of workpiece machining, are good as diagnostic signals. The biggest disadvantage of this solution is the necessity to interfere with the tool-holder-workpiece system and the high price of measuring set-up. The solution to this inconvenience may be the integration of the measuring system, e.g. with the machine tool table, using cheaper components of the measuring system (e.g. strain gauge systems).
- The obtained maximum increase in the value of the cutting force for the worn tool compared to the new tool amounted from 256 to 1674 N. i.e. 653.9% and the torque from 0.39Nm to 1.98 Nm , i.e. 507.7%.
- The state of the process diagnosing on the basis of the cutting force value changes seems to be a convenient solution, while diagnosing the occurrence of critical states should rather be based on the torque value changes analysis.

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