AICC – AUTOMATIC INSPECTION OF CUT CARBON

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Abstract

In this article, measurement methods and an optical test device for determining the quality of machined components are introduced. Until now, catalogues of limiting samples are commonly used for this and visual quality assessments are carried out without technical aid, so they are not reproducible. In the article, an optical measurement procedure is presented. This procedure evaluates special machining errors on drill holes and edges that can occur during the manufacture of fiber components. The measuring method was implemented in terms of a handset with the name AICC (Automatic Inspection of Cut Carbon). With the help of AICC, the subjective and error-prone assessment of a worker is avoided and reproducible measurement results are created. Further, there is the possibility to file all measurement results in a database, what allows to draw conclusions about process flows and stability.

1 Introduction

Due to the outstanding mechanical properties and the possibility of near-net-shape fabrication, the amount of components which are made from carbon fibre reinforced plastic (CFRP) is highly increasing. As an example, CFRP comes into focus of attention in the automotive industry due to constantly rising requirements concerning emission levels of vehicles. Higher material costs and the need of additional processing technologies are raising the costs of the whole CFRP process chain. Using this kind of material in batch production requires a significant reduction of costs along the production of CFRP components. Thereby, a special demand exists in machining of CFRP, which represents an important step of the mentioned process chain. It is necessary to adapt conventional tools and process parameters due to the different material behavior of CFRP and metal (anisotropic and isotropic) during machining.
As a result of the differing machining processes and the typical characteristics of fibre materials, also the damage patterns in machining differ from those of metals. Because of this, new strategies of quality measurement and -rating are necessary in the production and processing of CFRP.

2 Damage mechanism in CFRP-processing

2.1 Influence of cutting tools

Besides the adjustment of process parameters, the tool wear is enormously influencing the expected quality when machining CFRP components. The structure of CFRP-suited tools will always have to find a compromise: On the one hand, the machining of the soft plastic requires a sharp cutting edge and therefore a small cutting edge radius to keep the heat input as low as possible. The sharp edge whereas will be strongly stressed by the very abrasive working carbon fibre, so the cutting edge radius increases (Figure 1). This influences the processing of the matrix in return.

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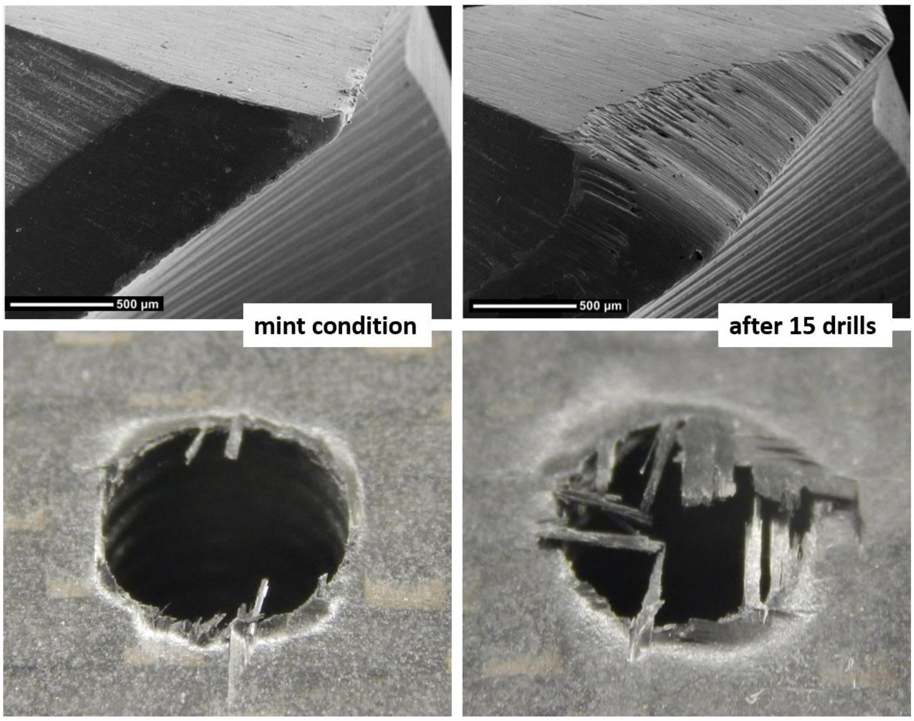

Figure 1. Comparison of hole quality in CFRP processing by HSS drilling tool

The lifetime of CFRP-suited tools is therefore not reaching the lifetime of metal-suited tools. The higher process forces due to abrasion are also increasing the possibility of occurring defects.

2.2 Damage Mechanism

Possible processing errors:

- Delamination
- Fraying
- Feathering
- Fibre breakage and fibre rupture
- Geometrical defects

Due to their influence on for example holes for rivet connections in aircraft manufacturing, where delaminated drills can affect the function of the joint, the focus in this article is particularly put on delamination. On top of that, the method is demonstrated at the example of faying.

Definition delamination:
Because of the layer-by-layer structure of CFRP-components, several layers can be peeled away during machining. This happens either because of machining errors or because of too high machining forces. Thereby normally the surface layers are peeled away. It is differentiated between the separation of layers at the inlet (Peel-up) and at the outlet (Push-out) of the drill bit. This is presented graphically in figure 2.

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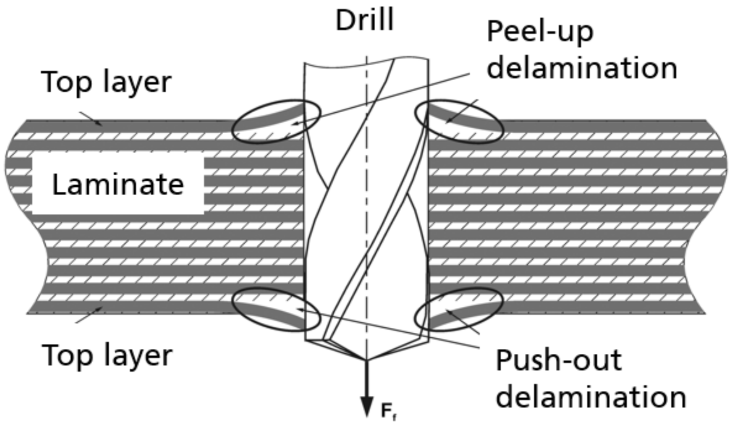

Figure 2. Delamination at drill holes of fiber composite components

In contrast to metal and wood machining where in several decades of experience, evaluation criteria and measurement techniques for the quality assessment of drill holes already exist, lacking in fiber composites hitherto uniform evaluation criteria. Present approaches often are only factory standard or, due to measurement technique, manual procedures and devices. In the meantime, however various approaches for an objective calculation of delamination were published. In the following three of these approaches are listed.

The diameter-related delamination factor by Chen: [1]

$$F_d = D_{max} / D \tag{1}$$

Area-related delamination factor:

$$F_{d,area} = A_d / A \tag{2}$$

Enhanced delamination factor by Davim: [2]

$$F_{da} = (1 - \beta) \times D_{max} / D + \beta \times A_{max} / A \;\; \text{mit} \;\; \beta = A_d / (A_{max} - A) \tag{3}$$

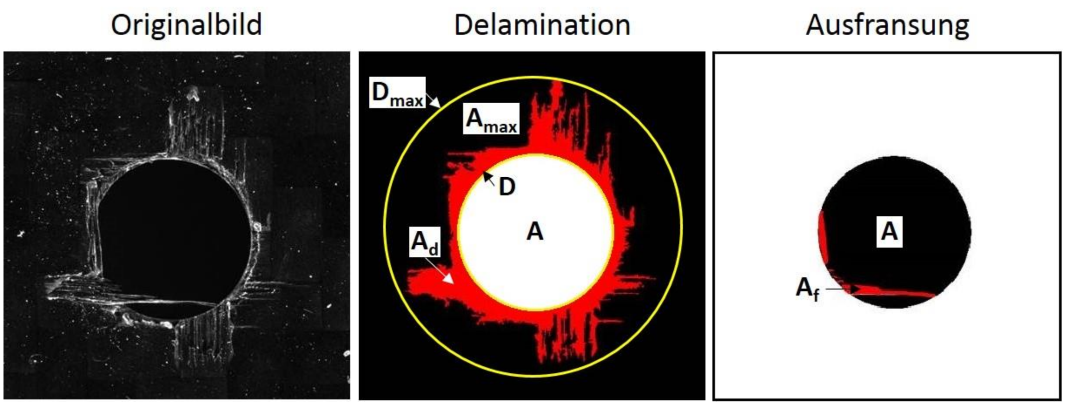

Figure 3. Overview of the variables for the calculation of delamination and fraying (A = circular area of the drill hole [mm²] ; Ad = area of delamination [mm²] ; Amax = maximal delaminated area [mm²] ; A_f = area of fraying [mm²] ; D = drill hole diameter [mm] ; D_{max} = maximal delaminated diameter)

Romoli [4] and Faraz [5] define further approaches that use such Davim at the extended delamination factor the delaminated area as the basis of quality assessment

<u>Definition fraying</u>
Become fibers not cut off in the processing area and in standing after the machinability operation in the processing zone, this is referred to in the mechanical processing of fiber composite components as fraying. These fiber protrusions are problematic in downstream processes because the frayings are inferring contours, for example by the insertion of a dowel pin or painting. In contrast, the influence of fraying on the mechanical properties of a component is considered to be low.

Area-related fraying factor

$$F_{f,area} = A_f / A \qquad (4)$$

All evaluation criteria for delamination and fraying are implemented and can be used with the optical quality measurement approach that is introduced in this article.

3 Procedures for quality control for fiber reinforced plastics

The special structure and damage mechanisms of fibre composite components lead to new challenges in quality management. Especially finding a suitable test procedure in quality management for safety critical components is an important task. Comparing metal-components to CFRP-components, the reinforced plastic is vulnerable to damages in the machining process thus strict test procedures are needed. Because of high test-rates destructive test methods are in many cases uneconomical. Therefore different non-destructive testing methods are available for CFRP-components. These include for example thermography, ultrasound or testing with computer tomography (CT). Due to little investment costs of measuring equipment, visual inspection is still one of the most popular methods for quality control in industrial processing.

4 Partly automated optical test procedure AICC

The Fraunhofer IPA is dealing with the economic finishing of CFRP and is thereby using an optical solution for automated quality management of drill holes and edges. As a result, a manual device was designed which is able to inspect and approve the machining quality fast and simple. No special qualified worker is needed to judge the quality. Furthermore the mobile device guarantees maximum flexibility in quality control. The optical approach was chosen, because processing errors can be detected efficiently with this variation and this is best realized as opposed to the test methods described in Chapter 3. Furthermore the test duration per part is longer with the other. On top of that, these techniques are suitable for a mobile use only conditionally.

The use of „Automatic Identification of Cut Carbon“ (AICC) enables the waiver of the often used catalogues of limiting samples and hence improves the quality of testing significantly. The AICC is also applicable as a stationary test bench for measurement laboratories.
AICC enables measurements of free-form shapes of nearly any orientation. The evaluation of the component happens after machining or even at the same time as machine-integrated solution. The evaluation also works with quantitative figures as well as categorizing the components in usable and waste parts. The results are filed in a database which are accessible for complete documentation and process monitoring.
These features make AICC practicable for manual control of incoming goods, in-house documentation at the suppliers as well as automated process monitoring and optimization.

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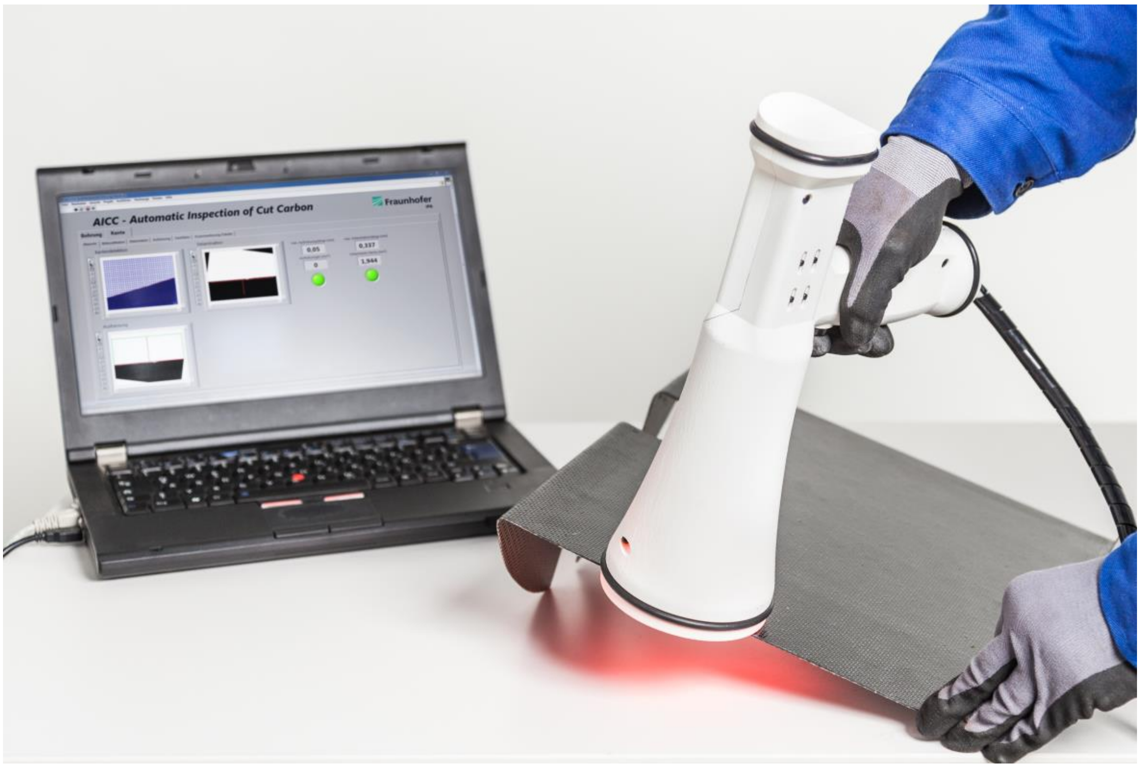

Figure 4. Use of the AICC measuring system during testing

4.1 Structure

A high-resolution camera, which is controlled and electrically supplied by a gigabit-ethernet (GigE) hub, is used for testing the components. The camera contains a high-resolution CCD-sensor and is operated on a black-white mono 8-video format.
An objective, which is especially suitable for a short distance, is used in combination with the area scan camera. A connecting ring for a c-mount objective supply connects the area scan camera with the objective. Before the image recording, the work piece is there for illuminated with a dark field illumination, consisting of a ring light with a small illumination angle. The ring light provides a uniformly a homogeneous lighted surface where unevenness on the work piece cause more significant differences in brightness. Thereby it should be noted that the illumination doesn´t cause reflections on smooth materials like carbon and glass-fiber reinforced plastics. The expensive illuminating with a flat illumination angle will later support the image processing so that even smaller processing errors can be detected after processing and thus the resolution can be improved.
Since the objective has no zoom function, the distance between objective and workpiece, the so-called object distance, has to be observed precisely. It is furthermore important that the orientation and mounting of the described components is ensured. To comply with these geometrical criteria an individual housing was especially designed and produced with 3D-printing technology.

4.2 Function

Under consideration of the background and the brightness around, drill holes and milling edges can be captured with the described structure. With the help of algorithms the quantification of various damage patterns like delamination, fraying, spalling and feathering can be carried out within one ROI (region of interest) step by step.

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The ambient light in the area of application as well as the surface condition of the specimen can affect the measurement results. This may happen when the ambient light influences the measuring spot during the measurement or when the lightning is reflected on a smooth surface. To perform an optimal measurement even in such problematic cases, the upper and lower threshold value for the detection of drills and for determination of delamination can be adjusted freely.

4.3 Excitation and presentation

The handset contains a single button for starting the process. By pressing the button the dark field lightning is switched on and simultaneously the camera takes a photo. When holding the button still only one image is evaluated until the complete program has been passed. By further pressing the button the program starts new and an additional image is recorded. The process takes about a second if a drill hole or cutting edge was recognized and the evaluation starts. Otherwise the camera takes up to 20 images per second which are displayed in the LabVIEW program to better locate the spot to be evaluated (figure 5).

For a quick control and graphical presentation of the measurement results the program LabVIEW by National Instruments was used. For a better review all measurement results for a drill hole or milling edge are presented on one side of the monitor in each case. With two tabs (figure 5) it can be switched between the two surfaces. At a glance the user gets graphical information about the position and scale of:

- A drill hole or a milling edge
- Delamination
- Fraying stick

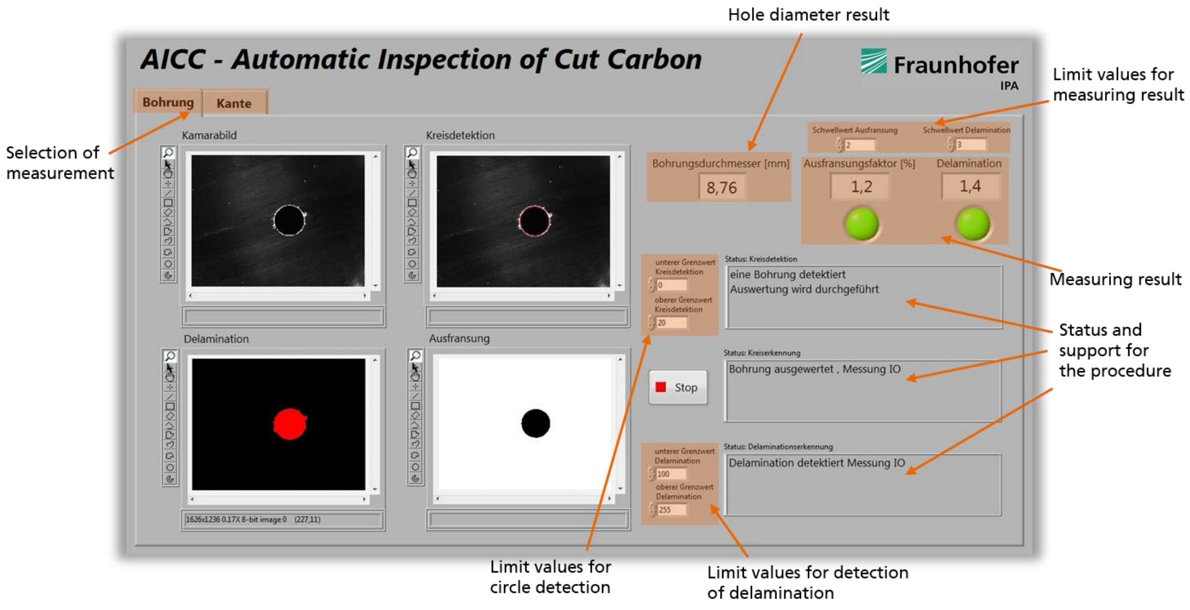


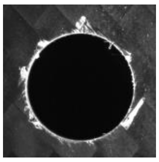
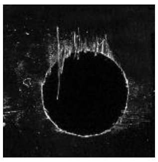
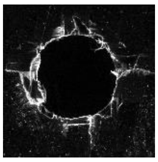
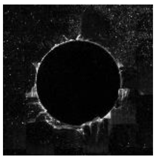
Figure 5. User interface and display surface of the measurement program

Furthermore, the machining errors are shown to the user as key figures and for drill holes the diameter is displayed. For a simpler visualization a tolerance limit can be defined before with the help of a threshold. Therefore an LED just has to show if the measurement lies within or outside the specification.

4.4 Measurement results

The following table shows drill holes with different machining quality and the associated measurement results for delamination and fraying.

Table 1. Measurement results for drill holes with different machining quality

	Delamination factors	Fraying factor
	F_d = 1,37 $F_{d,area}$ = 0,27 F_{da} = 1,53	F_f = 0,19
	F_d = 1,14 $F_{d,area}$ = 0,11 F_{da} = 1,20	F_f = 0,22
	F_d = 1,71 $F_{d,area}$ = 0,17 F_{da} = 1,81	F_f = 2,87
	F_d = 1,66 $F_{d,area}$ = 0,26 F_{da} = 1,83	F_f = 5,39
	F_d = 1,21 $F_{d,area}$ = 0,12 F_{da} = 1,27	F_f = 0,34

Conclusions

In this article, an optical measurement procedure for the evaluation of drill holes and milling edges with particular machining errors that occur on the mechanical processing of fiber materials was introduced. The method was implemented in form of a handset, which can perform location-independent measurements of free-form parts in almost any orientation. Machining errors like delamination and fraying are expressed in key figures to waive catalogues of limiting samples and thus, significantly improve the inspection quality.

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