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NDT investigations on C/SiC samples from different manufacturing steps

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Abstract
This paper is focused on eddy current measurements of C/SiC samples in different status of the manufacturing process. The measurements are compared with results of X-Ray, Scanning Acoustic Microscope (SAM) and optical images and discussed.

Keywords: C/SiC, eddy current, NDT, X-Ray, carbon fiber composite

1. Introduction

Using of eddy currents is state of art for nondestructive testing of electrical conductive materials [1]. The developed high-frequency eddy current technology “EddyCus®” (with frequency ranges up to 100 MHz) made it even possible to extend the classical fields of application towards less conductive materials like CFRP [2]. More details to this technology can be found in [3], [4].

C/SiC is ceramic matrix composite (CMC) and belongs to a class of materials developed for aeronautics and space applications, in a domain where superalloys cannot be used anymore [5]. In comparison to metallic structures C/SiC-composites have many advantages as excellent thermal and mechanical properties by lower weight, high and stable friction coefficient, long life, low wear rate, and lower sensibility to surroundings and oxidation [6]. They have potential applications in structures (air intakes, structural panels with stiffners, etc.), in turbines and for brakes [5].

EddyCurrent (EC) testing was already performed on C/SiC samples in [7]. In this paper are provided NDT examinations for three C/SiC manufacturing process steps. The idea is to transfer the collected experience by investigations on CFRP to up-and-coming C/SiC.

2. Experimental Setup and Practice

2.1 Samples

The samples, shown in Figure 1 represent different steps of the manufacturing process of C/SiC and are numbered with 99, 100 and 101. These samples were provided by the working group of Ceramic Matrix Composites at the Universität Bayreuth.
Samples dimensions are presented in Table 1:

<table>
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<tr>
<th></th>
<th>99</th>
<th>100</th>
<th>101</th>
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<tbody>
<tr>
<td>99</td>
<td>100,1<em>81,5</em>(3,3-4,1) mm³</td>
<td>99,7<em>81,1</em>(3-3,7) mm³</td>
<td>99,9*(81-81,7)*(3-3,3) mm³</td>
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Sample "99" is a pure CFRP (carbon fiber reinforced plastic). In "100" the resins were burned out, so carbon fibres and carbon particles remain. In “101” the cavities were filled with Si and after that the sample was sintered. Thus all samples have different states with different properties and different defects (if existent).

### 2.2 Nondestructive Test Methods

#### 2.2.1 Optical evaluation

There was a digital photo performed. Displays in photos and surface optical review were evaluated and documented. The inconstant illumination intensity of the test and the subjectivity of the assessment must be mentioned as disadvantages.

#### 2.2.2 Eddy currents

Eddy current testing is a well-established nondestructive method for the characterization of surfaces or materials by analyzing conductivity and permeability variations [3].

Alternating current passing the excitation coil induces a primary magnetic field. It excites eddy currents in a specimen. They create a secondary magnetic field that opposes the primary magnetic field. Changing the specimen material properties leads to changing the path of eddy currents and correspondingly complex signal changing at the pick-up coil.

Measurements were done with EddyCus® MPECS – Multi Parameter Eddy Current Scanner. A semi-transmission coil with middle frequency 4 MHz was used. All eddy current images in this paper are done with 2.3 MHz.
According to axes on Figure 3, coil angles were defined: 0° along the x-axis, 90° along the y-axis and 45° was the position, as in the Table 2.

<table>
<thead>
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<th>Table 2: Coil angle definition</th>
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<td>0°</td>
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Almost all eddy current measurements in this paper were done in contact-mode because of better resolution. To prevent wearout of coil, samples were coated with polyethylene film. By choosing (rotating) a Complex Phase Angle (CPA), noise signals can be filtered out.

2.2.3 X-Ray radiography

The use of X-rays for nondestructive testing is widely spread and offers numerous different methods for the characterization of chemical and structural properties of the samples. The X-ray radiation has wavelengths of about $10^{-6}$ m to $10^{-12}$ m and therefore belongs to the high-energy, ionizing radiation, which can penetrate a large number of substances. The simple X-ray transmission is most widely used in the NDT because it is simple and fast to perform. In the case of radioscopy, the structures of the sample are imaged as a function of their attenuation, with objects lying one behind the other in the beam direction overlaid. Defects within structure can thus be made visible [8]. For X-Ray radiography was used a phoenix nanomex (Figure 4).

2.2.4 Scanning acoustic microscopy (SAM)

Ultrasound refers to sound waves with frequencies above 20 kHz. It can be applied for material nondestructive investigations. An acoustic microscope uses the ultrasound propagation possibility in solids and liquids. An ultrasonic pulse is generated in a transducer using a piezoelectric material. The generated sound wave, focused via a lens, passes through the coupling medium water into a sample. The interaction at interfaces between different materials (including inclusions or defects) is investigated. Using the focusing lenses allows receive higher resolution as normal ultrasound testing. Scanning method makes it possible to get a two-dimensional image. A scanning acoustic microscope assembled at Fraunhofer IKTS-MD was used for measurements (Figure 5).
3. Results

Some of measuring effects are marked with *number* in text and with correspondent number in figure.

3.1 Sample 99

Sample 99 is a pure CFRP (carbon fiber reinforced plastic). The X-ray image on Figure 6 shows material particles that have a higher density *1* (dark spots). They could not be seen with other tested methods. Also regions with smaller densities can be observed *2* e.g. less filled. These areas were also seen visually on Figure 8 – “areas with hollows”. They were not visible in the eddy current images due to an edge effect.

In the eddy current image on Figure 9 can be seen fiber structures. Noticeable spots are marked on the picture. Two dark spots *3* resemble two hollow spots in the photo. Other abnormalities couldn’t be captured with other methods.

In the optical view can be seen slightly swollen areas. One of them is also to see on Figure 7 (EC-image).

Different semi-transmission coil angles or other complex phase angle by eddy current testing can influence a result image. You might get new signals, as *4* on Figure 10. Different phase angles allow some signals to be displayed more clearly.
3.2 Sample 100

In Sample 100 the resins were burned out, so carbon fibres and carbon particles remain.

With X-Ray radiography on Figure 11 can be seen similar indications as in sample 99. At the bottom right is marked a dark area *5*. It means greater weakening. In the optical view on Figure 13, this area looks as if metal was infiltrated there. The area is also visible on Figure 16 from the back side. It has to be discussed, why the area is not visible in the eddy current image. Some displays in the eddy current image on Figure 12 match optical view, some are new.

Depending on the angle of the semi-transmission coil, different displays appear more clearly (compare Figure 12, Figure 14 and Figure 15). Optimization of the image contrast allows most favorable image for the eyes.
3.3 Sample 101

In “101” the cavities were filled with Si and after that the sample was sintered.

![Image](image1.png)

**Figure 17**: Sample 101, X-Ray image

**Figure 18**: Sample 101, EC image: 2.3 MHz; 45°; 0° CPA

**Figure 19**: Sample 101, optical view, front side

**Figure 20**: Sample 101, SAM image: 1 MHz; 20mm focal length

**Figure 21**: Sample 101, EC image, with Lift-off: 2.3 MHz; 45°; 180° CPA

**Figure 22**: Sample 101, EC image: 2.3 MHz; 90°; 180° CPA

Scratch, that visually can be seen on Figure 19, is also visible in X-Ray image on Figure 17. With eddy current it was not detected. It is supposed that big circular indication *6* in eddy current images (see Figure 18, Figure 21, Figure 22) is silicon infiltration border. This border is partly in SAM image on Figure 20 visible. In X-Ray image can be seen two parts: the darker in the middle *7* and ring-shaped brighter left *8*. The second part is barely visible. On Figure 18 at the bottom in the middle are circular measurements-artefacts *9* visible. Such artefacts were visible only by this sample in contact mode. By measurement with minimal Lift-off (Figure 21) they were not detected. This artefact comes from illustration of coil itself on surface irregularities. On Figure 22 marked displays come clearly.

4. Conclusion and Outlook

C/SiC samples from three manufacturing steps were investigated with eddy current testing and compared with X-Ray, SAM und visual images of the samples. Eddy current is promising solution for material controlling during C/SiC manufacturing steps. Supposedly a silicon infiltration border was seen by sample 101.
Direction of semi-transmission coil has big influence on defects detectability with eddy current testing.
In future are planned systematic defect inductions during production of the same sample and evaluations with nondestructive testing. In this way has to be proven suitability of NDT-methods for detection of specific defects.

Acknowledgements

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References

1. 'Non-destructive testing – Eddy current testing – General principles', ISO 15549, 2008