1.9.9. COMPUTED TOMOGRAPHY AND PULSED THERMOGRAPHY OF CARBON REINFORCED CARBON/COPPER COMPONENTS FOR THERMONUCLEAR FUSION

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Introduction. Thermonuclear fusion seems to be one possibility to overcome the lack of energy in the future. One of the key components of a nuclear fusion reactor is the so called divertor, the component facing the high temperature plasma and bearing the highest heat load. For the ITER (International Thermonuclear Experimental Reactor) in France a maximum loading of 25 MW/m^2 is planned. This task can be solved by using coolable cooper-alloys, which are bonded to carbon fibre reinforced carbon (CfC) or wolfram as plasma facing material. The extreme heat loading during operation requires stable processes for the production of such components and a comprehensive concept for quality assurance. Special attention is given to the material joint between fibre reinforced carbon and CuCrZr as material for the cooling system. Various non-destructive testing (NDT) methods like X-ray computed tomography (CT) and thermography testing (TT) have been adopted for different inspection tasks of CfC and the whole divertor. CT enables the precise size measurement of defects and structures in the CFC and at the CFC-CuCrZr interface. Pulsed Thermography can be also used at any stage of production and leads to very useful information. For the interpretation of the TT results finite element modelling (FEM) was performed where the effect of different defect shapes at the interface on the TT can be studied.

Results. The left picture in fig. 1 shows a scanning electron microscope picture of the CFC-surface structured by laser machining. A periodic structure can be seen. The central picture of fig. 1 shows an optical cross section of the bonding between the CFC and the CuCrZr-tube. The bonding of the CFC monoblocks to the CuCrZr tube consists of two production steps. At first a Cu layer is attached to the CFC monoblock by active metal casting. Afterwards the joint between the active metal casted layer of the monoblock and the CuCrZr tube is established by hot isostatic pressing. The right picture in fig. 1 shows a cross-sectional CT-picture along the bonding interface of CFC and CuCrZr. The CT-measurements were performed at a cone-beam CT-system with a micro-focus tube. There are clearly regions visible, where the Cu has fully penetrated into the

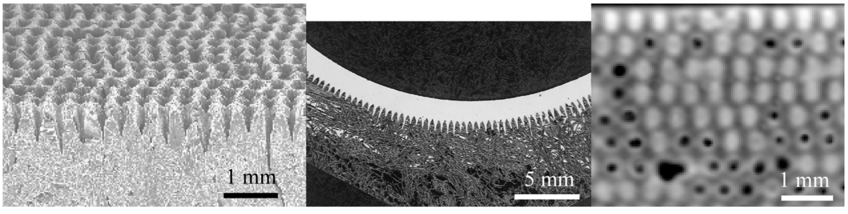

Fig. 1. Scanning electron microscope picture of CFC surface structured by laser machining (left picture)**. Optical cross sectional picture of copper-CFC interface clearly showing the Cu-needles** (middle picture)**. Cross sectional CT-picture along the Cu-CFC-interface showing the copper needles and pores** (right picture)

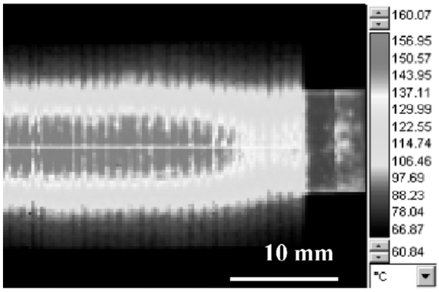

Fig. 2. Thermogram of the surface of a monoblock component

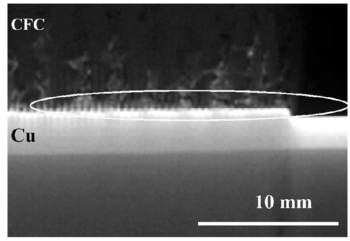

Fig. 3. CT of the same monoblock component as depicted in fig. 2

CFC-needles (bright spots) but there are also pores with almost no Cu (dark spots) revealing a bad connection.

Figure 2 shows a thermogram of the surface of a monoblock component. The TT-picture shows temperature gradients originating from the design of the component and from defects. Therefore, the interpretation should be supported by modelling and/or by comparative investigations. In fig. 2 the fibre structure of CFC leads to vertical stripes in the picture. The gradient along the white line indicates a bonding defect. This was verified by computed tomography. Figure 3 shows a CT-cross-sectional picture of the same part as in fig. 2. The position and the length of the crack, which gave a special feature in the TT signal, can be determined by computed tomography. A good correspondence between CT and TT can be stated.

Finally FEM analyses were done by using the FE-package ABAQUS/Standard V6.4 at PLANSEE. The FEM results were used for interpretation of the TT-results. Via FEM the effect of the relevant defect sizes according to the acceptance criterion on the results of TT was investigated. The simulation results enable the estimation of the defect size from the TT phase image.

Summary

– We applied computed tomography and pulsed thermography for the characterisation of carbon reinforced carbon/copper components which are used as divertor in nuclear fusion reactors.

– CT is very useful to get high resolution 3-dimensional information about the structure, the geometry, the interfaces and the defects of the various components. This information can be used for improving the production processes and for the interpretation of thermography testing.

– Pulsed thermography can be applied to the components in any stage of production. For the performance of the test no reference element is needed which enables a simple data treatment for defect analysis. Therefore pulsed thermography is a cost effective method for serial application.

– By finite element analysis the defects sizes can be derived from the TT phase image.

– A good correspondence between CT, TT and finite element analysis was found.

– The results shown here are the base for the definition of the acceptance criterion for the ITER prototypes by means of thermography testing.