USING NONDESTRUCTIVE TESTING METHODS TO CHARACTERISE PRODUCTION-INDUCED DEFECTS IN A METAL-CFRP HYBRID STRUCTURE

Michael Schwarz[1(*)], Jannik Summa[1], Hans-Georg Herrmann[1,2]
[1]Chair for Lightweight Systems, University of Saarland, Saarbrücken, Germany
[2]IZFP Fraunhofer Institute for Nondestructive Testing, Saarbrücken, Germany

ABSTRACT: In this work different nondestructive testing methods, such as active and passive thermography as well as ultrasonic with special probes, so-called EMAT`s (ElectroMagnetic Acoustic Transducer) will be applied for the characterisation of a metal-CFRP (Carbon Fibre Reinforced Polymer) hybrid structure. To validate these testing methods, different kinds of artificial defects are inserted into the hybrid structure. It is shown that active thermography is very suitable to detect the artificial inserted defects not only in the hybrid structure but also in the CFRP structure itself. Furthermore the bonding between metal and the polymer is characterised very well. Likewise CFRP samples are investigated by passive thermography while being mechanically loaded through tensile or fatigue tests to give a predication about the influence of the defects on the mechanical properties (effects of defects).
Finally an outlook on an optimised geometry of the hybrid structure as well as on further excitation methods for active thermography is given.

KEYWORDS: Nondestructive testing, thermography, EMAT

1 INTRODUCTION

Through the worldwide regulations concerning CO_2 the topic lightweight design is becoming more and more important. To achieve a significant decrease in weight, lighter materials as aluminium, magnesium and CFRP have to be used increasingly. However a complete substitution of existing materials by expensive CFRP cannot be economically used for series production. Thus, an intelligent hybrid structure consisting of an aluminium and a CFRP component turns out to be an alternative solution. To overcome the gap in stiffness between aluminium and CFRP a polymer is inserted. But through this polymer two interfaces are created where defects occur most likely [1].
By using nondestructive testing methods possible process-induced defects should be detected at these interfaces and in the CFRP itself. In order to validate the used testing methods, artificial defects (e.g. delamination, missing rovings, pleat, misorientation of the fibres and gapping) are implemented in the hybrid structure and the CFRP.
The used nondestructive testing methods are thermography and ultrasonic. To detect defects at the interface CFRP-polymer and in the CFRP itself thermography is used. For the investigation of the interface aluminium-polymer an ultrasonic testing method with special transducers is used, the so-called EMAT which is characterised by couplant-free testing. This method has been used only for metals and bondings so far, so the utilisation for hybrid structures gives new interesting areas for an application.

2 THERMOGRAPHY

There are two general methods of measurement in thermography: passive and active thermography.
To achieve a thermal contrast active thermography needs an external excitation. Excitation sources can be therefore halogen lamps, ultrasonic, eddy current, laser or flash generators. The excitation method in this case is a flash generator. An infrared camera with Stirling cooler is capturing the thermal radiation after the sample is excitated (see Fig. 1). Since defects act like thermal barriers they are depicted as bright areas in the infrared image.
No external excitation is needed for passive thermography. The detected temperature-contrast is generated by internal heating due to deformation and friction processes, for example within destructive testing like tensile or fatigue tests.
Commonly applied methods are MIDA (mechanical induced dissipated heat analysis) or TSA (thermal stress analysis), which enable the identification of weak spots or defects by local temperature hot spots [2].
By choosing thermography as nondestructive testing method there is the possibility to detect defects

* Corresponding author: University of Saarland, Saarbrücken, Germany, Michael.Schwarz@izfp-extern.fraunhofer.de

at the interface of the hybrid at the end of production process. However, it is not only possible to execute the measurements before and after destructive testing (by active thermography), but also to perform insitu tests (by passive thermography). Finally, there is the strong possibility to compare the different thermography methods to achieve the best characterisation of defects.

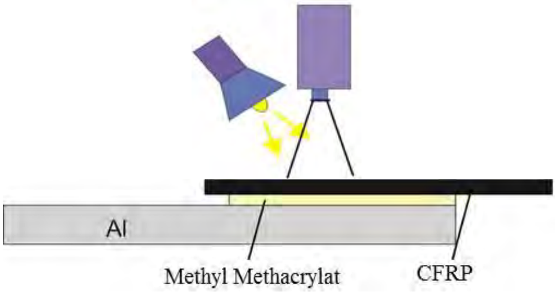

Fig. 1 *Measurement configuration of thermography testing*

3 EMAT

The ultrasonic testing method with EMAT gives the advantage of couplant-free testing. Therefore more advantages are created like fast and cheap testing. However, the sample either has to be conductive or ferromagnetic. Because of that fact the suitability of CFRP is limited.
The ultrasonic testing with electromagnetic acoustic transducers is excitated either by the Lorentz force or by magnetostriction. To achieve the effect of magnetostriction, the analysed material has to be ferromagnetic. While applying an external magnetic field, the ferromagnetic material creates a mechanical deformation, similar to the piezoelectric effect. This deformation occurs parallel to the external magnetic field. Despite the occurring eddy current in the material, dynamic magnetic fields are also induced, which create dynamic forces. These forces are parallel to the external magnetic flux.
To get the effect of the Lorentz force, the used material has to be conductive. In this case special induction coils are used. These induction coils are passed by a current impulse and generate eddy currents in the windings by induction. By overlapping these generated eddy currents with a magnetic field perpendicular to the surface, periodic alternately Lorentz forces will occur. These Lorentz forces induce particle deflection acting as sources of ultrasonic waves in the material [3] (see Fig. 2). By using surface acoustic waves with this kind of ultrasonic testing the interface between the metal and the polymer can be investigated. Especially the quality of the connection between the two components and also defects can be characterised.

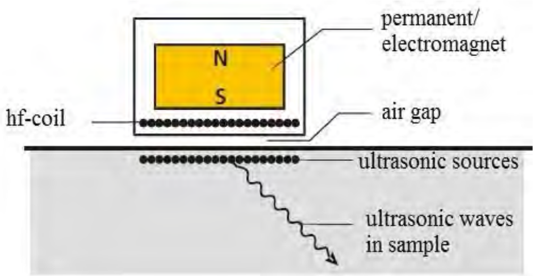

Fig. 2 *Principle of an EMAT-probe [Quelle: F. Niese, Dissertation, 2010]*

4 MECHANICAL TESTING

Mechanical testing was carried out on [0°/90°, ±45°]$_s$ CFRP samples containing 30 vol% of a 3K plain weave (Torayca FT300B) embedded in the epoxy matrix (Biresin CR170/CH150-3).
According to [DIN EN ISO 527-4:1997] sample type 2, the geometrical parameters were chosen to be 120 mm length, 20 mm width and 1 mm thickness. The clamping length was chosen 25 mm on each side.
The specimens were mounted with wedge grips on an Instron 8500 with a 100 kN load cell. An Axial clip-on extensometer was used measuring longitudinal strains.
The tests were carried out displacement controlled. Tensile tests with 2 mm/min cross-head speed and fatigue tests with 5 Hz frequency and a displacement ratio R = 0.1. Different maximum relative displacements were chosen ranging from 40 % to 70 % of the fracture displacement of the defect-free reference, which is 1.16247 mm.
Mechanical experiments were complemented with an InfraTec VarioCAM® HD head bolometer camera with a resolution of 1024 x 768 pixels. The cameras interval of spectral sensitivity ranges from 7.5 to 14 µm and its temperature resolution lies beneath 0.05 K (at T = 303.15 K).

5 RESULTS

In Fig. 3 the front and rear side of a sample with an artificial implemented gapping defect is shown. Both figures are recorded after mechanical testing. In the left picture the front side of the sample is shown and the gapping defect can be seen in the middle of the sample. Around this gapping, there can be detected bright areas, which are an indication for delamination that occurred during the mechanical testing. In the right picture the rear side of the sample is shown. Similar to the picture of the front side you can see many bright areas which are also an indication for delamination.

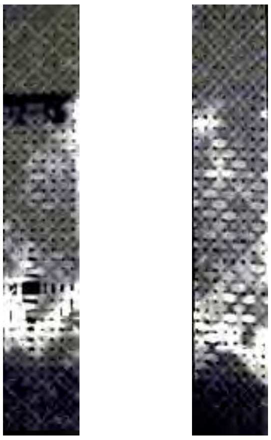

Fig. 3 *Front and rear side of a sample with delamination and gapping defect after mechanical testing*

In Fig. 4 the front and rear side of a sample with a missing roving defect which has been removed artificially is shown. In the left picture on the right side you can see where the vertically roving has been removed, also you can see some bright areas in the middle of the sample. These bright areas are, like in Fig. 3, a hint for delamination that occurred due to mechanical testing.

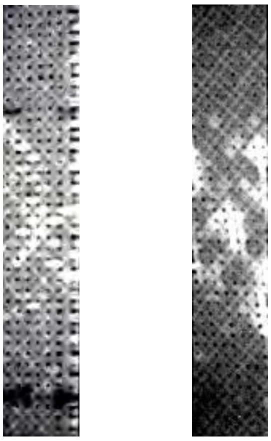

Fig. 4 *Front and rear side of a sample with delamination and missing roving defect after mechanical testing*

In Fig. 5 two thermographic pictures of aluminium-CFRP bonding are shown. The aluminium and CFRP components are linked through a methyl methacrylate adhesive. In one case there is a perfect bonding between the aluminium and CFRP component and in the other case there is an artificial delamination between the two components. In the left picture there is a specimen with almost perfect bonding and in the right picture there is a specimen with a delamination in the middle of the bonding area. The bright areas at the edge of the picture represent the CFRP component, the dark area in the middle stands for the used adhesive. In the right picture there is also a bright area in the middle of the adhesive area, which is a sign for the artificial delamination in the bonding.

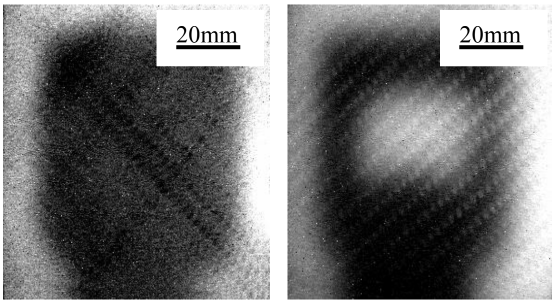

Fig. 5 *Bonding of aluminium-CFRP components without and with delamination*

In Fig. 6 an aluminium sample with and without bonding has been characterised by ultrasonic testing methods with special probes, the so-called EMAT`s. In the picture the ultrasonic signal is depicted. The signal for the sample without bonding is coloured red and the signal for the sample with bonding is coloured black. The three signals are the same for the two samples. Thereby the leftmost amplitude is the excitation signal and the next two signals are the direct signal transmitter-receiver and the signal with reflection at the "short" end, number 1 and 2, respectively, concerning Fig. 7. The signals 3 for the reflection at the "long" end, 4 for a complete circulation and 5 for a complete circulation plus direct signal transmitter-receiver are only present for the sample without bonding (red). For the sample with bonding (black) the signals 3, 4 and 5 are completely damped.

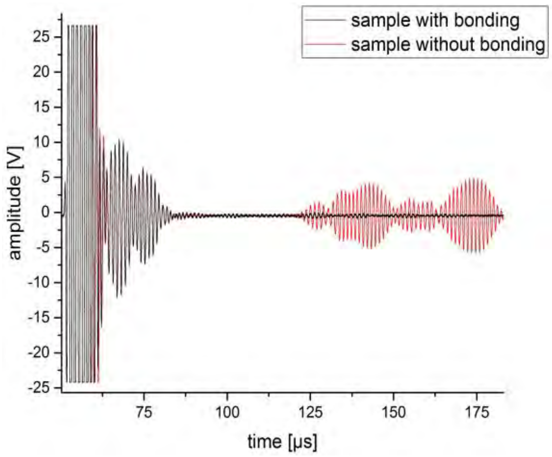

Fig. 6 *EMAT-measurement of sample with and without bonding*

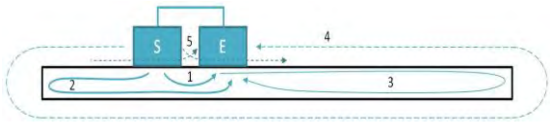

Fig. 7 *Signals for EMAT-measurement*

In Fig. 8 and Fig. 9 the sample with a gapping defect is shown with passive thermography during a tensile test. Fig. 8 shows the sample at a number of cycles of 10^3 and Fig. 9 at a number of cycles of 10^6. After 10^3 cycles the temperature is evenly distributed over the whole sample. After 10^6 cycles the temperature is concentrating on the area where the artificial gapping defect is. Concerning to this aspect it can be said that the weakest point of the sample is where the artificial defect is implemented.

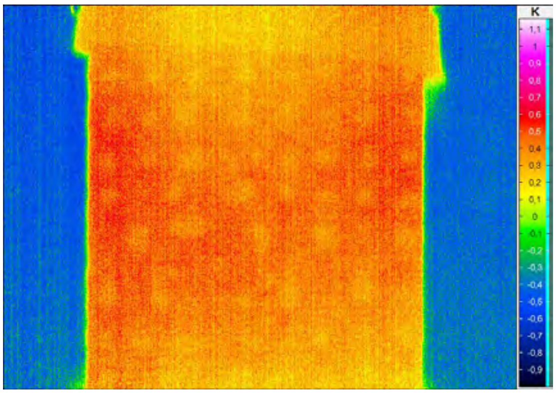

Fig. 8 *Passive thermography picture of sample with gapping after 10^3 cycles*

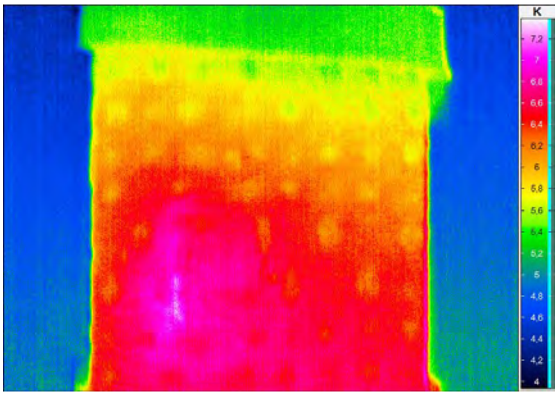

Fig. 9 *Passive thermography picture of sample with gapping after 10^6 cycles*

6 CONCLUSIONS

As described in this paper the nondestructive testing methods thermography and ultrasonic are suitable to detect and characterise different defects. Thermography has been used to detect different defects like gapping, missing roving and delamination, in the CFRP samples and the bonding samples. With the ultrasonic testing method the difference of the signal between an aluminium sample with and without bonding has been demonstrated. By combining them more information about the condition of the sample can be generated. Especially the bonding can be characterised.

Furthermore the combination of active and passive thermography gives insights into the behaviour of the sample during mechanical testing and the effect on the structure. It has been shown that the weakest point is around the area of defects. Therefore it is very important to detect possibly all flaws in the used hybrid structure.

In further works an optimisation of the aluminium-CFRP sample will be performed. Additionally other excitation methods for active thermography will be validated and compared to the already used ones for a better characterisation.

7 ACKNOWLEDGEMENT

The authors gratefully acknowledge the funding by Deutsche Forschungsgemeinschaft and also thank their colleagues from Fraunhofer IZFP Saarbrücken and their research partners from wbk at Karlsruher Institute of Technology and LKT at TU Dortmund.

REFERENCES

[1] Casas-Rodriguez J.P., Ashcroft I.A., Silberschmidt V.V.: *Delamination in adhesively bonded CFRP joints: Standard fatigue, impact-fatigue and intermittent impact*, Composites Science and Technology 68: 2401–2409, 2008

[2] Rösner H., Netzelmann U., Hoffmann J., Karpen W., Kramb V., Meyendorf N.: *Thermographic Materials Characterization*. In Nondestructive Materials Characterization 67, Springer, Berlin-Heidelberg, pp. 246-285, 2004

[3] Salzburger H.-J., Niese F., Dobmann G.: *Emat Pipe inspection with guided Waves*, Welding in The World 56: 35-43, 2012