NONDESTRUCTIVE CHARAKTERIZATION OF ADHESIVE JOINTS USING LOCK-IN THERMOGRAPHY

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Abstract: The present work investigates the possibility of detecting defects in adhesive joints using Lock-In Thermography. The major objective of the present work was the ultrasonic Lock-In Thermography. The ultrasonic excitation is coupled with IR imaging. The technique uses ultra-low amplitude modulation of the ultrasonic excitation and then uses Lock-In techniques to extract phase and amplitude. At present mainly two different procedures of active thermography are being used: Pulse and Lock-In Thermography. With pulse thermography the examined material is warmed up with a short energy pulse (light, eddy current or ultrasonic pulse) and the heat response is recorded after a certain time. The result is an infrared image which indicates material defects in different depths.

This paper presents a variety of images showing the capability of ultrasonic Lock-In Thermography to image subsurface defects in adhesive joints. Several examples of adhesives joints qualifies the ultrasonic Lock-In-Thermography for the in-process quality control for adhesive bonded components. It is shown that for steel and for aluminium substrates bonded with high-modulus structural adhesives it is possible to detect several different defects in the interfacial region between the adhesive and the adherend.

Introduction: The increasing use of adhesively bonded structures and adhesive joining technology in all fields of industrial manufacturing as an alternative to the traditional methods of fastening materials involves an increasing demand on quality control. Quality is again of special value and in-process quality control will become more interesting for a lot of manufacturing processes.

Because of the vast variety of materials employed there is evidence of need for adequate non-destructive techniques. Many different nondestructive evaluation techniques have been used to detect cracks and other adhesive defects such as delaminations in composite structures. Non-destructive testing by means of thermal methods is based on detection of different thermophysical material properties.

Defects in bonded structures are a barrier to thermal diffusion. Thus, these defects are detectable with thermal methods. The most common kinds of damage include: inhomogeneities due to the presence of spurious materials, delaminations, porosity, localized lack of or excess of resin and debonding.

Results: A schematic diagram of the experimental set-up of the ultrasonic Lock-In Thermography is shown in figure 1. At present mainly two different procedures of active thermography are being used: Pulse and Lock-In Thermography. With Pulse Thermography the examined material is warmed up with a short energy pulse (light, eddy current or ultrasonic pulse) and the heat response is recorded after a certain time.

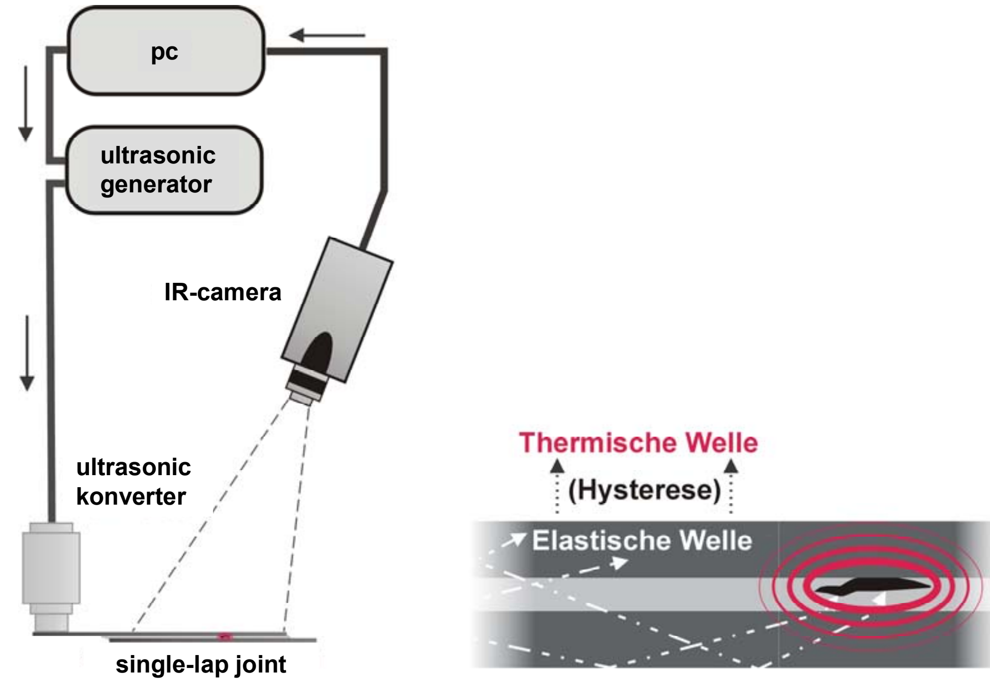

Figure 1: Experimental set-up for the ultrasonic Lock-In Thermography

For example, a low- frequency ultrasonic (e.g. 20 kHz) burst infuses the sample for about 300 ms. With ultrasonic waves the defects in material and joint are excited into oscillation and the absorbed energy by plastic deformation or friction is transformed into heat energy. The two surfaces of the defect do not move in unison when ultrasound penetrates into the sample. A defective joint differs from an intact one by its reduced loading capacity. Defective joints show for example voids, delamination, porosity or cracks in the joint. The result is an infrared image which indicates material defects in different depths. This paper presents a variety of images showing the capability of Lock-In Thermography to image subsurface defects.

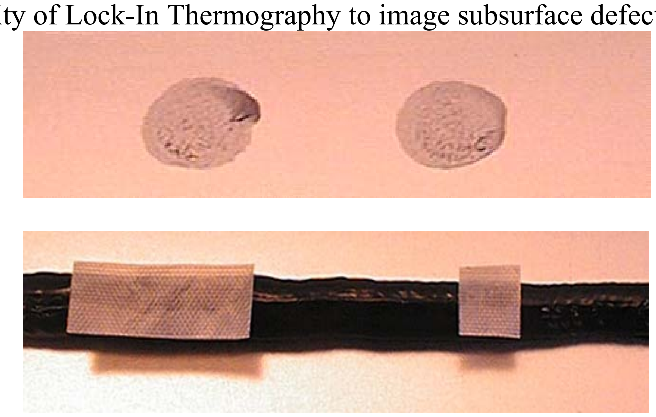

Figure 2: Fingerprint contamination with lubricating oil and simulation of defects with thin PTFE-layers

Figure 3 shows the infrared images of 3 examples of peel joints. The adherents were stainless steel and measured 250 x 25 x 0.8 mm and the bondlines were 0.3 mm in thickness. The surfaces had been prepared with Methylethylketon. All joints were contaminated with 3 points of lubricating oil as figure 2 shows.

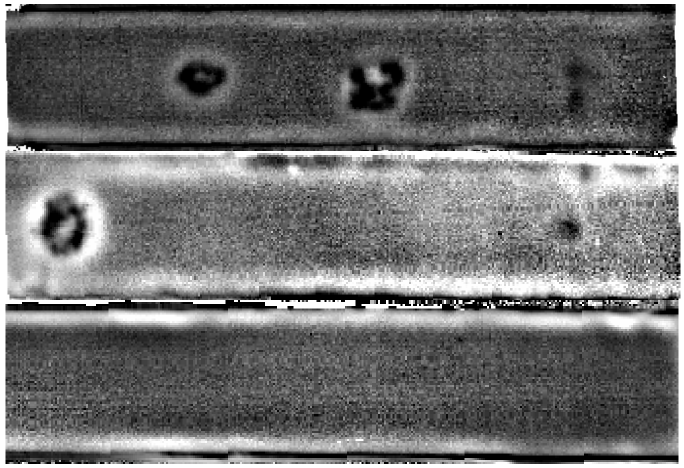

Figure 3: Infrared images of contaminated specimen using 3 different adhesives.
(From top: 2K-EP, 2K-PUR, 1K-PUR)

The contaminated area was applied as thin layers with 10-mm diameter comparable with fingerprints placed on the stainless steel sheets. Figure 3 shows the infrared images of the ultrasonic Lock-In Thermography for three different adhesives (2K-Epoxy adhesive, 2K-Polyurethane and 1K-Pulyurethane).
It is worth noting that the detectability of the contaminant layers in the 1K-Polyurethane specimen is much lower than in the 2K-Epoxy.

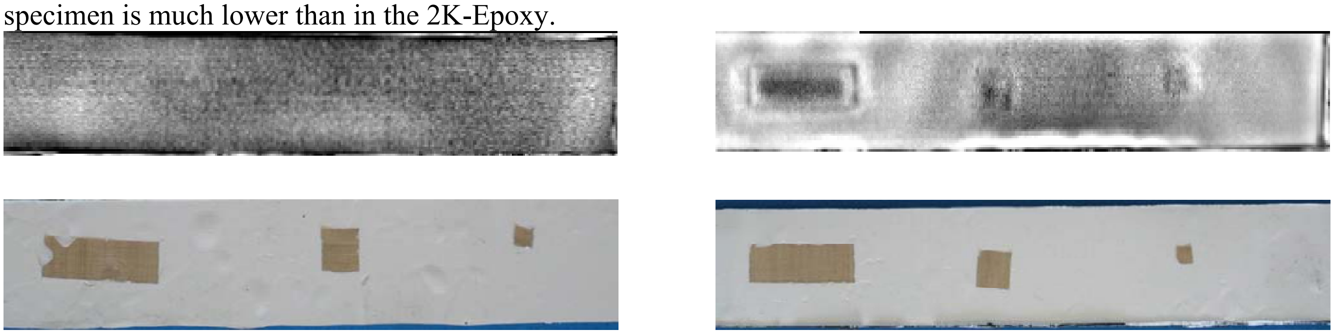

Figure 4: Infrared images (top) and fracture pictures of specimen with aluminium (left) and stainless steel substrates and 1K-PUR adhesive

Figure 4 and 5 shows another possible model for the defect simulation. With the help of very thin PTFE-films with different sizes it is possible to simulate delamination or "kissing bonds" with two connecting interfaces. The prepared specimens shown in figure 4 and 5 shows the influence of the different substrates (aluminium / stainless steel) and the influence of different adhesives.

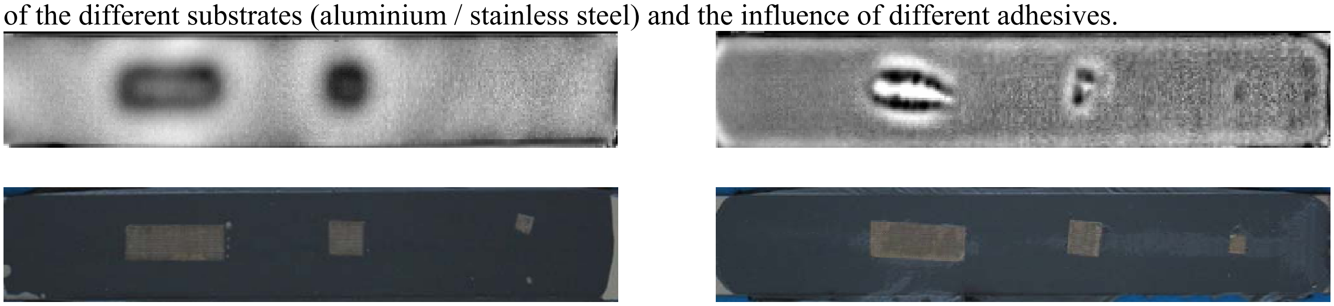

Figure 5: Infrared images (top) and fracture pictures of specimen with aluminium (left) and stainless steel substrates and 2K-EP adhesive

Figure 4 and 5 shows the results and the infrared images of the ultrasonic Lock-In Thermography. Again the difference between the sample with the 2K-Epoxy and the 1K-Polyurethane is obvious and it seems to be difficult detecting "kissing bonds" in specimens with adhesives with high dissipation factor.

Conclusion: The infrared images of the ultrasonic Lock-In Thermography show that the measurement principle shown in figure 1 enables the detection of defective areas with higher hysteresis loss. We have presented a variety of images showing the capability of the ultrasonic IR technique. Exciting the sample with power ultrasonic can lead to local heating possibly caused by friction of crack edges or plastic deformation, which is detected by the IR-camera. One of the most important factors affecting the detectability of delaminations or "kissing bonds" with this measurement principle and for the simulated defects is the dissipation factor of the used adhesive and the material of the substrates.

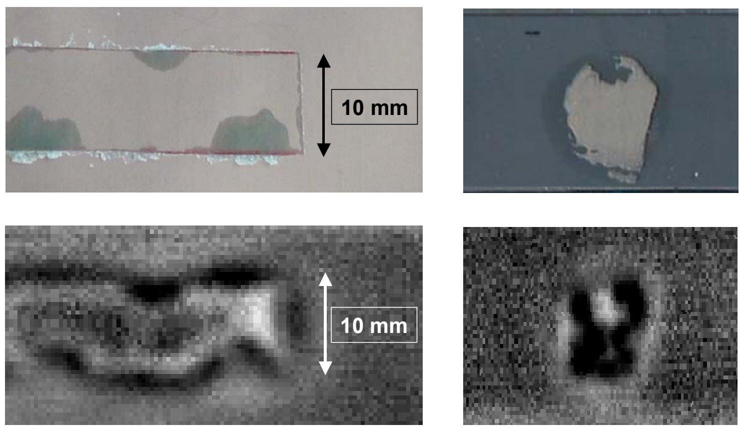

Figure 5: Detail of two defects showing the failure picture (top) and the infrared image

The higher the dissipation factor of the adhesive, the more difficult is the detectability of "kissing bonds". The infrared images show that we get much better results with stiff structural adhesives than, for example, with soft filler and sealant type adhesives. Figure 5 shows two details from a specimen bonded with a stiff structural adhesive. The infrared images show the defect position very clearly and, above all they show the form and contour of the defects. Several examples of adhesive joints qualify the ultrasonic Lock-In-Thermography for the in-process quality control for adhesive bonded components.

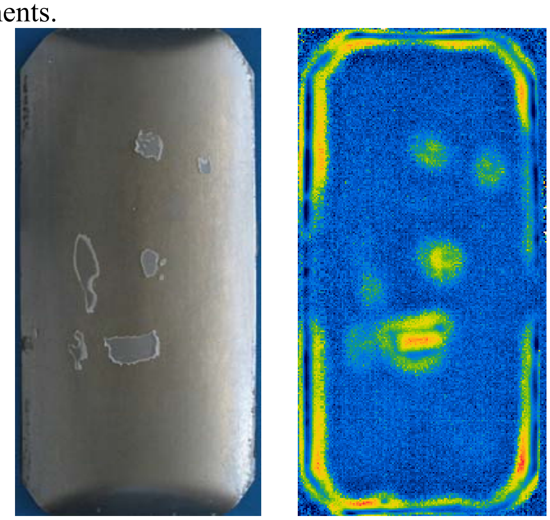
Figure 6: Failure picture (left) and the infrared image

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References: 1. BUSSE, G.; WU, D.; SALERNO, A.: Neue Möglichkeiten der Früherkennung von Beschichtungsfehlern, Berichtsband DFO, Band 35 (1997), S. 17-23
2. A. Dillenz, D. Wu, K. Breitrück and G. Busse, Lock-In Thermography for depth resolved defect charakterisation, 15th WCNDT, 2000
3. R.L. Sierakowski, S.K. Chaturvedi, Dynamic loading and characterization of fiber-reinforced composites, Wiley, New York, 1997, pp. 137-139.
4. R.L. Sierakowski, G.M. Newaz, Damage Tolerance in advanced composites, Technomic, Basel, 1995, pp. 115-130
5. ABBÉ, S.; DEGAIT, A.; HONORAT, P.; RENON, J. M.: Industrial non destructive testing of composite materials by stimulated infrared thermography, Non-Destructive Testing 92, Proceedings of the 13th World Conference, Vol. 2 (1992), S. 703-707
6. Youssef, Y.; Fahr, A.; Roy, C.: NDE of adhesively bonded joints using acousto-ultrasonics and recognition, Nondestructive Characterization of Materials IV, Plenum Press, New York,1991, S. 345-353
7. Freemantle, R.J.; Challis, R.E.: UTonline Application Workshop, May 1997