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ULTRASONIC LOSS ANGLE WITH SPECKLE INTERFEROMETRY

A. Salerno, S. Danesi, D. Wu, S. Ritter, G. Busse

Institut für Kunststoffprüfung und Kunststoffkunde, Universität Stuttgart,
Pfaffenwaldring 32, D-70569 Stuttgart,
Germany

ABSTRACT

Defect detection is performed by injecting ultrasound into a sample: Locally increased losses (stress concentration and/or defect enhanced loss angle) of elastic energy result in heat generation and subsequent local thermal expansion which is imaged by electronic speckle pattern interferometry (ESPI) at video frequency. The obtained lines of equal deformation indicate the selectively activated heat sources that are correlated with hidden defects. Therefore remote inspection of loss angle heating allows for rapid and non-destructive evaluation in the quality management of structures.

INTRODUCTION

Quality control requires the detection of defects that are caused by the production process or later by deterioration. If such defects are detected early enough the production process can be improved or unsafe components can be exchanged to avoid failure.

Under this aspect one is interested in inspection methods that do not affect the performance of intact components and which allow to inspect large areas in a short time with a high reliability. Therefore those methods are most attractive which respond selectively to defects and which can be applied in a remote way.

If one is looking for a mechanical defect then a straight forward method would be based on the local changes of properties related with the defect (and not on secondary effects like changes of e.g. electrical properties). A mechanical defect is generally characterized by local stress concentrations or enhanced mechanical losses. So any method responding to those effects is suited for selective imaging of defects.

PRINCIPLE

Cyclic loading of a component together with the hysteresis loop results in heat generation. This is the base for vibrothermography [1] where a sample is loaded periodically and the resulting temperature field is monitored: defects reveal themselves by excessive production of heat and by the resulting local increase of temperature.

The relevant quantity is the hysteresis area generated per unit time. Therefore, instead of using a big machine where the sample is clamped, one can attach an ultrasonic transducer to it. The ultrasound propagates through the whole sample, and in defect areas the energy of the acoustic wave is converted more efficiently into heat. This local increase of heat production may be due to stress concentration at the same loss angle or to an increased loss angle (e.g. caused by friction in cracks) at the same stress level.

Instead of detecting the generated hot spots with lockin thermography [2] we investigated the mechanical effect of the local thermal expansion which can be monitored in a sensitive way by interferometric equipment. In that case one observes the bending generated by the defect-induced "thermal wedge".

EXPERIMENTAL ARRANGEMENT

We used a 3D real-time electronic speckle-pattern interferometer [3] where the image of the inspected component is superposed by a grainy structure ("speckles") that is due to interference effects. Therefore these speckles move already when wavelength-sized deformations of the object occur. The analysis of the speckle motion or of speckle displacement between two deformation states of the inspected object results in a fringe pattern that displays lines of equal deformation of the surface (instead of the equal-height-lines on a map). If the deformation component perpendicular to the surface is analyzed, then the distance between two fringes is half the wavelength of the laser source ($\lambda/2 = 0.4\ \mu m$). Usually the small deformation of the inspected component is induced either by heating the sample with irradiation or with a mechanical load. In our arrangement the deformation source is located inside the sample itself. As these fringe patterns (observed after the initial reference image has been taken) are updated at video frequency, one has an efficient tool to observe the development of thermal bumps induced by the absorption of ultrasound in defect areas.

Ultrasound at 20 kHz was fed into the sample by clamping a transducer to one edge of it. The nominal power issued by the ultrasonic generator was varying from case to case between 200 and 400 watts, but the real power injected into the sample was much lower, reaching 10-20% of the nominal power. The resulting setup is shown in Fig. 1. Surprisingly enough the correlation between the reference image and the image taken 3 - 30 seconds later was not affected by the ultrasound. The reference image could be taken before the transducer was activated, during sound generation or thereafter.

The samples that we used to investigate the applicability of this technique were laminates or layered materials with known areas of disbonds. So all areas where ultrasound was absorbed were parallel to the surface. Sample size was typically around 20 x 30 cm^2, thickness ranged from 4 mm (in the case of carbon fiber reinforced laminates) to about 30 mm for wood coated with veneer or polymer material.

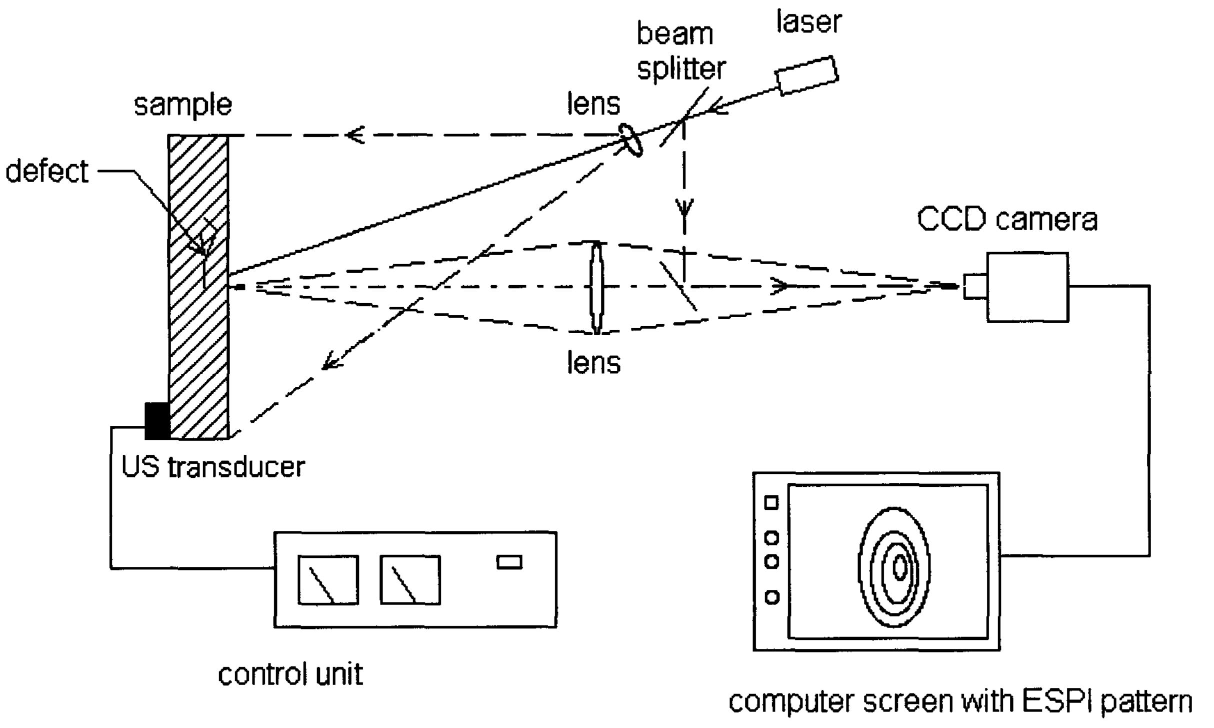


Fig. 1 - *Experimental setup: ESPI equipment for out-of-plane imaging of loss angle induced absorption of ultrasound emitted by transducer attached to sample*

RESULTS

Carbon fiber laminates

Fig. 2 shows the pattern observed on a laminate after two different levels of ultrasound power (on the right image the power is increased by factor 2) had been injected over 3 seconds. The left lower corner shows in both images a circular section which is the transmitter head. At the lower power level (left) one delamination is clearly visible, the other one barely. At the higher level (right) a weak third defect emerges. The relation between the change of power and the resulting time dependence of surface deformation should allow to investigate the nature of the defect and the depth where it is located.

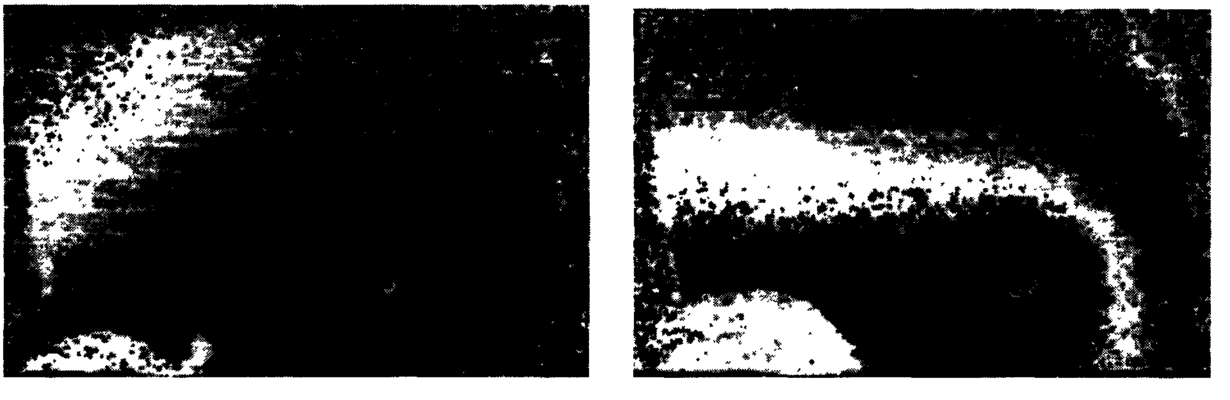


Fig. 2 - *Detection of delaminations in carbon fiber laminate at two different levels of acoustic power. Arrows indicate defects.*

Veneered wood

The sample used for Fig. 3 was a wood plate of 2.5 cm thickness with a 3 mm thick wood veneer on top. There was a bonding defect in the upper left corner which is clearly revealed by the development of a bump (less than 0.4 µm height, because there is only one fringe) after ultrasound excitation during 30 seconds. The structure in the center of the bottom edge is the clamp keeping the transducer in place at the rear surface of the plate.

The sample in Fig. 4 was a 3 cm thick wood plate veneered with a 0.7 mm thick polymer foil. In this image we demonstrate how the appearance of the defect (located in the center of the plate, while the circular ultrasound transmitter was attached again to the center of the lower edge) depends on the experimental conditions though the power level and the duration (10 seconds) is the same: Image 4 a was generated by correlating two images taken while the transmitter was active. The three fringes indicate a bump height of 1.2 µm. The plate itself is not bent. Image 4 b was generated from two images taken 5 seconds and 10 seconds after the transducer had been switched off. First of all one sees that the fringes appear less noisy. The reason is that the sample was not oscillating. Though the fringe pattern looks similar there is one important difference: While the gradual transition from white to black is directed towards the outside of the fringes in image 4 a, this has reversed in image 4 b. As the pattern does not display the bump itself but rather its change between two deformation states, image 4 a shows how the bump is generated on an otherwise flat plate while image 4 b shows its decay and simultaneously the overall bending of the whole plate due to heat diffusion. Image 4 c was generated from the reference image taken before ultrasonic excitation and an image taken 5 seconds thereafter. Therefore this image displays the total deformation during this time. The sign of contrast change is the same as in Fig. 4 a, so the defect induced bump is generated with a total height of 7 fringes (2.8 µm). In addition one sees that the coupling area of the transducer has heated up as well. Also overall bending of the plate is more obvious.

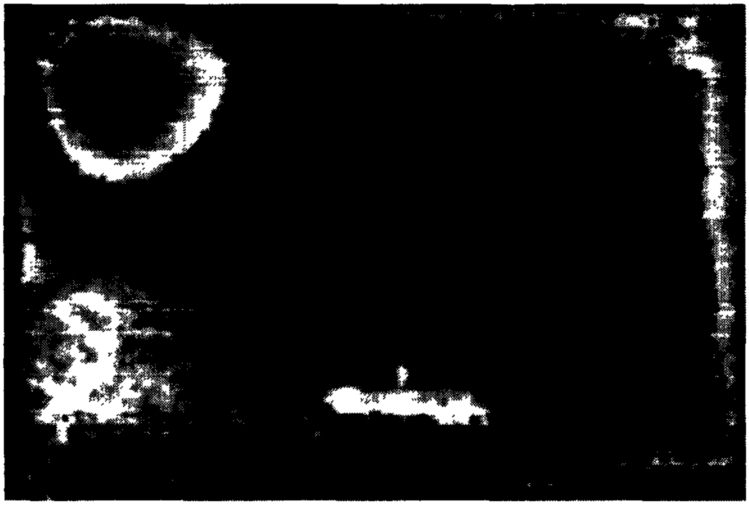
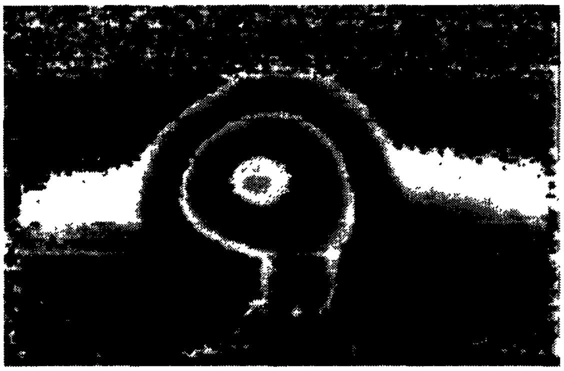
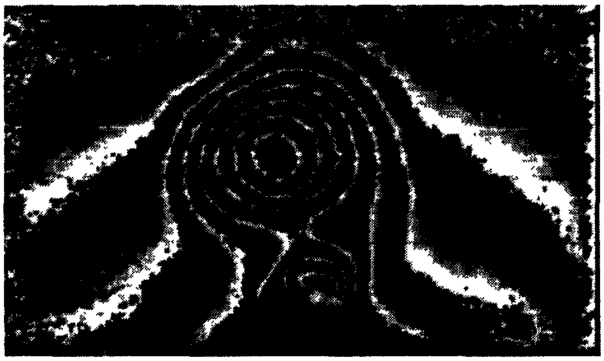


Fig. 3 - *Detection of delamination (upper left corner) between two glued wood plates with 3 mm and 25 mm thickness, respectively.*

a)



b)



c)

Fig. 4 - *Detection of central delamination between wood substrate provided with polymer layer. Different conditions of detection: Both images taken during acoustic excitation (4a), both thereafter (4b), or one image before and one image after excitation (4c)*

CONCLUSION

We have shown that delaminations in layered structures reveal themselves in a non-destructive way by their thermal expansion caused by defect-selective absorption of ultrasonic energy. From investigations on other kinds of material we know that this method works also on defects with other geometries, the reason is multiple reflection of elastic waves where the average directionality is almost eliminated. The interferometric fringe pattern appearing around defects after ultrasonic excitation therefore allows for rapid identification of defects which is of interest in the quality management of safety-relevant structures (e.g. aerospace applications).

ACKNOWLEDGMENTS

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REFERENCES

[1] HENNEKE, E.G., REIFSNIDER, K.L. and STINCHCOMB, W.W.: *Thermography - An NDI method for damage detection.* Journal of Metals, Sept. 1979, p. 11-15

[2] RANTALA, J., WU, D., BUSSE, G.: *Lockin-vibrothermography applied for nondestructive evaluation of polymer materials*. 7th Intern. Symposium on Nondestructive Characterization of Materials, 19-23.06.95, Prag, in print

[3] RITTER, S., BUSSE, G.: *3D-electronic speckle-pattern-interferometer (ESPI) in der zerstörungsfreien Werkstoff- und Bauteilprüfung*. Deutsche Gesellschaft für Zerstörungsfreie Prüfung e.V. (Jahrestagung 17.-19.05.93, Garmisch-Partenkirchen), p. 491-498