01 Jul 1994

Detection Optimization of Disbond in Layered Composites with Varying Thicknesses using an Open-Ended Rectangular Waveguide

Stoyan I. Ganchev

Nasser N. Qaddoumi

R. Zoughi
Missouri University of Science and Technology, zoughi@mst.edu

Recommended Citation

S. I. Ganchev et al., "Detection Optimization of Disbond in Layered Composites with Varying Thicknesses using an Open-Ended Rectangular Waveguide," *Proceedings of the Conference on Precision Electromagnetic Measurements (1994, Boulder, CO)*, pp. 69-70, Institute of Electrical and Electronics Engineers (IEEE), Jul 1994.
The definitive version is available at https://doi.org/10.1109/CPEM.1994.333287

DETECTION OPTIMIZATION OF DISBOND IN LAYERED COMPOSITES WITH VARYING THICKNESSES USING AN OPEN-ENDED RECTANGULAR WAVEGUIDE

S. Ganchev, N. Qaddoumi, and R. Zoughi
Applied Microwave Nondestructive Testing Laboratory
Electrical Engineering Department
Colorado State University
Fort Collins, CO 80523

Abstract

The detection of air disbond in layered dielectric composite, which is an important practical issue in many industries, is studied both theoretically and experimentally. Sensitivity of disbond detection depends on certain parameters, like the frequency of operation, the distance between the sensor and the first dielectric layer, and the layered composite geometry (conductor backed or terminated by an infinite half-space of air). The impact of all these parameters is investigated theoretically and then verified experimentally.

Introduction and Considered Geometries

An air disbond between dielectric layers of a composite is a common problem in many industries such as aerospace, construction, rubber industries, etc. The disbond is usually between the metal plate and a dielectric coating or between dielectric layers. Based on this, the geometries considered are depicted in Fig. 1. Case (a) and (b) pertain to multi-layered composites backed by a conducting plate, and (c) is a multi-layered composite terminated by free-space. These cases cover important practical geometries, namely disbond (d_3) between coating and metal base (a), disbond (d_3) between the dielectric layers in conductor backed case (b), and disbond (d_3) between the dielectric layers in infinite half-space case (c). In all geometries d_1 denotes the airgap between the rectangular waveguide sensor and the first dielectric layer, which makes these measurements inherently noncontact.

Theoretical Simulations and Measurements

The theoretical simulations for an open-ended rectangular waveguide radiating into a multilayered dielectric composite has been developed in [1]. Here, only calculations and measurements of the phase of the reflection coefficient are considered, since this parameter has shown to be more sensitive (than the modulus of the reflection coefficient) with respect to geometry variations [1-3].

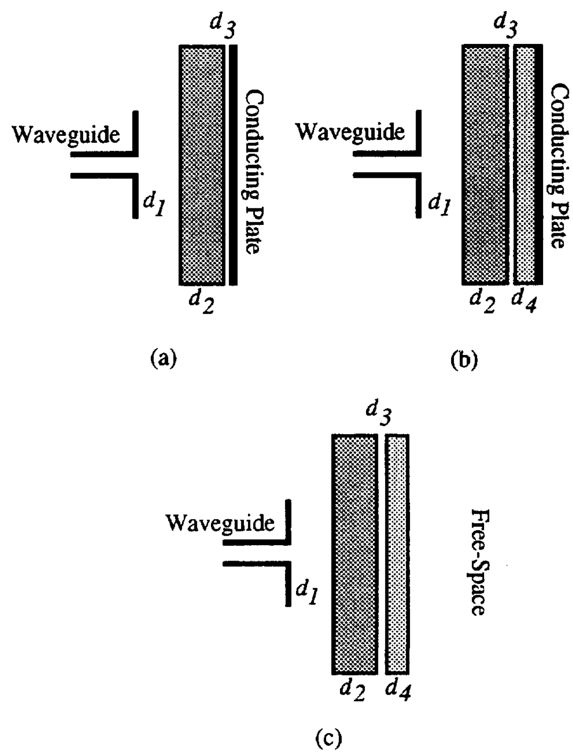

Fig. 1: Open-ended rectangular waveguide sensor radiating into different layered dielectric composite geometries: (a) a three-layer conductor backed, (b) a four-layer conductor backed, and (c) a four-layer backed by an infinite half-space of air.

To illustrate the frequency dependence on the detection sensitivity for a disbond between two dielectric layers backed by conductor (Fig. 1(b)), the following theoretical simulation was carried out. The dielectric layers have dielectric constants of $\varepsilon_r = 9 - j1$. Referring to Fig. 1(b), the air gap is $d_1 = 5.5$ mm, $D = d_2 + d_3 + d_4$ is 7.2 mm or 8.2 mm, the air disbond d_3, takes values of 0 mm, 0.076 mm, 0.127 mm, and 0.178 mm. The disbond is always in the middle, so the two dielectric layers (d_2, d_4) have equal thicknesses, and the disbond thickness increase is compensated with equivalent decrease of dielectric layer thicknesses. For each case (no disbond, and the three disbond thicknesses) phase vs. frequency in X-band region (8.2 - 12.4 GHz) is calculated. Fig. 2 depicts the absolute value of the phase differences for each disbond value and the no disbond case.

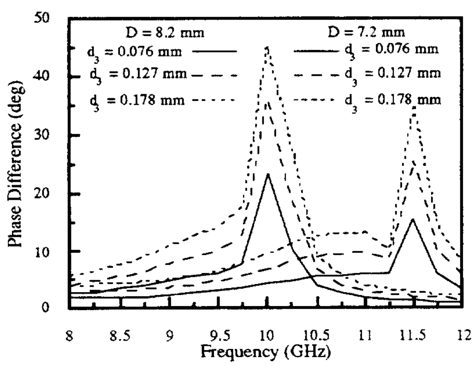

Fig. 2: Phase difference vs. frequency for two overall thicknesses of $D = d_2 + d_3 + d_4$, and three disbond values, d_3.

It is clear that depending on the overall thickness, D, there is a frequency range with the best sensitivity (11.5 GHz for D = 7.2 mm, and 10 GHz for 8.2 mm). It is also obvious that outside these frequency ranges the detection sensitivity is worse or even negligible. For a fixed frequency of operation the sensor may be calibrated to give information about the disbond thickness. In a similar fashion the significance of the airgap value (d_1) and the composite geometry (conductor backed and terminated by air) as well as the relative depth of disbond will be discussed. Extensive measurements to support the theoretical calculations are also presented in application to disbond layers as thin as a few microns at X-band frequencies.

References

[1] Bakhtiari, S., S. Ganchev, N. Qaddoumi and R. Zoughi, "Microwave Non-Contact Examination of Disbond and Thickness Variation in Stratified Composite Media," *IEEE Transactions on Microwave Theory and Techniques*, vol. 42, no. 3, March 1994.

[2] Bakhtiari, S., S. Ganchev and R. Zoughi, "Microwave Frequency Optimization for Accurate Thickness or Dielectric Property Monitoring of Conductor Backed Composites." *Materials Evaluation*, vol. 51, no. 6, pp. 740-743, June 1993.

[3] Zoughi, R. and S. Bakhtiari, "Microwave Nondestructive Detection and Evaluation of Disbonding and Delamination in Layered-Dielectric-Slabs," *IEEE Transactions on Instrumentation and Measurement*, vol. 39, no. 6, pp. 1059-1063, December 1990.