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SHORT COMMUNICATION

Nondestructive Testing Method for Finding out the Defects in a Composite Liner

C. Muralidhar and Sheri George
Defence Research & Development Laboratory, Hyderabad - 500 058.

ABSTRACT

A composite liner of carbon phenolic has been inspected by ultrasonic, X-ray radiography and X-ray computed tomography (CT) to find defects like delaminations, debonds, voids, foreign inclusions, etc. The geometry, detection of multiple defects and porosity of the liner make ultrasonic testing (pulse-echo and drycoupling) difficult for inspection. X-ray radiography being a non-contact technique finds multiple defects but compresses the structural information of 3-D volume into a 2-D image and interferes with overlying and underlying areas of the object. X-ray CT generates an image of a thin and cross-sectional slice of an object. The linear attenuation coefficients in terms of Hounsfield values have been measured, compared and correlated with CT images at the contrasts observed. 3-D images can be generated by stacking 2-D cross-sectional images of the slices. These 3-D images can be cut at any angle of choice for mapping the extent of delaminated/debonded areas. This type of information is difficult to obtain with conventional non-destructive testing techniques.

1. INTRODUCTION

The composite liner under study is a glass phenolic cylindrical liner of small diameter (approx. 30 mm) and having 7.5 mm thickness. These liners are relatively porous than their epoxy class of composite. The liner under study was difficult to be inspected by pulse-echo testing (PET) because the couplant seeps through porous structure, thereby causing contamination and inconsistent results. PET probes are difficult to sit properly on the small diameter of the liner and also difficult to detect multiple defects. Ultrasonic drycoupling technique eliminates the couplant contamination through its rubber-tipped probes. It gives attenuation values through transmission mode but it is difficult to interpret the defects. It also suffers from sizing the defects.

X-ray radiography is a non-contact technique which eliminates couplant contamination. The technique is able to detect delaminations, voids, foreign inclusions and porosity in the liner. It can detect even multiple defects and debond also if the liner is bonded to the aluminum casing. However, it compresses the structural information of 3-D volume into a 2-D image, the images interfere with underlying and overlying areas of the object and a single radiographic image does not provide sufficient information to localise a feature in 3-D.

X-ray CT generates an image of thin and cross sectional slice of an object. CT image represents point-by-point linear attenuation coefficients in the slice. The linear attenuation coefficients in terms of Hounsfield values(HU) have been measured, compared, and

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Figure 1. Tangential radiograph of glass phenolic cylindrical liner showing the delaminations and foreign inclusions.

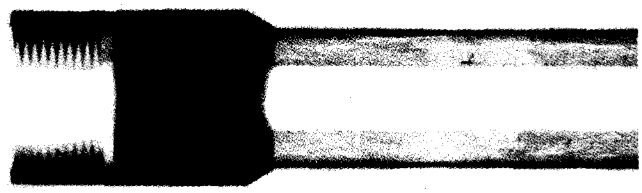

Figure 2. Tangential radiograph of liner and casing showing multiple delaminations and debonds.

correlated with CT images of the liner (with and without casing) at the contrasts observed. The density profile of the liner (at the location marked) clearly distinguishes interply density variations from debonds/ delaminations. 3-D images can be generated from the 2-D cross-sectional images of the slices. These 3-D images can be cut at any angle of choice for mapping the extent of delaminated/debonded areas. This type of referencing is not possible with conventional NDT techniques.

In earlier study[1], ultrasonic, radiography and thermography were used on a glass phenolic cylindrical liner to study the delamination. In another study,[2] the debond problem was studied using ultrasonic, radiography and CT on a glass phenolic liner bonded to an aluminum casing. In the present study, ultrasonic, radiography and CT have been used on the liner (with and without bonding) to find defects like delaminations, debonds, foreign inclusions and interply density variations, etc. The relative advantages and limitations of these techniques in assessing the above defects have been brought out.

2. EXPERIMENTAL PROCEDURE

The cylindrical composite liners under study were of high silica glass phenolic compound (thickness: 7.5 mm, outer diameter: 30 mm) with and without bonding, to aluminium casing (thickness: 2 mm). The liners were made by hand layup method and bonded to a aluminium casing with an epoxy adhesive. Ultrasonic drycoupling was done using Sonatest UFD-200. X-ray radiography was carried out using an equipment from Richseifert, Germany (320 kV, 13 mA max). The focal spot of 1.5 mm x 1.5 mm was used. The liners were inspected using a medical CT system (Zytec-2000i) from GE, USA. The linear attenuation coefficients in terms of HU values were measured, compared and correlated with the CT images at the contrasts observed. The voltage, current and time of exposure were 120 kV, 60 mA and 2.7s, respectively. A slice thickness of 1 mm was selected. In medical CT, the HU value for water and air is 0-1000, respectively and the values for the remaining materials are assigned accordingly.

3. RESULTS & DISCUSSION

Figure 1 is the tangential radiograph of the liner showing multiple delaminations and foreign inclusions. Figure 2 is the tangential radiograph of the casing with liner bonded showing multiple delaminations with debond. It is difficult to detect these defects either by PET or drycoupling technique. It is difficult to distinguish resin rich/resin-starved areas from delaminations/debonds in radiography because the contrast is not appreciable. Figure 3 shows the cross-sectional image of the liner. The variation in HU values observed in Fig. 3 is due to interply density variations. Figure 4 shows the density profile of the liner at the location marked. It is clear from Fig. 4 that HU values measured did not cross zero or negative within the liner, whereas HU values 0-1000 was observed in the hollow portion of the liner(air is present), which reveals that the contrasts observed are not due to air gaps but due to interply density variations within the liner.

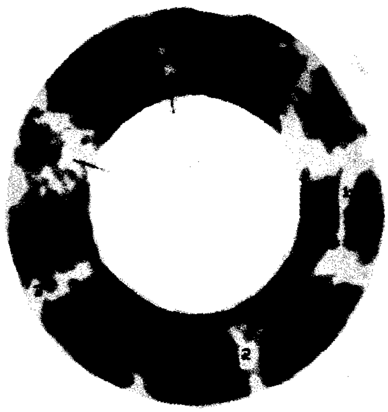

Figure 3. Cross-sectional image of the liner showing interply density variations.

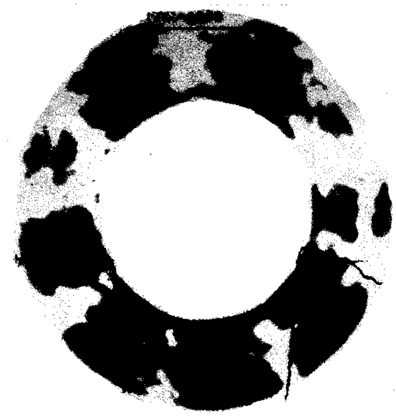

Figure 4. Density profile of the liner at the location marked

These contrasts may be misinterpreted as delaminations in radiography, whereas CT identifies and distinguishes them as interply density variations. This type of referencing is impossible with other NDT techniques. The interply density variations can be found only by CT because it can generate cross-sectional images of the object. Figure 5 shows the areas of debond between casing and liner, and delaminations within the liner. This demonstrates that CT could detect multiple defects. Figure 6 shows the images of planes cut from 3-D data of aluminum casing with liner indicating clearly the debond (shown left) and delamination (shown right).

4. CONCLUSIONS

Ultrasonic (PET, drycoupling) techniques were not able to detect various defects in glass phenolic liner (bonded and unbonded). Radiography could detect delaminations, debonds, and foreign inclusions. The contrasts are difficult to resolve and may require another NDT technique to support the data observed in radiography. CT revealed all the defects, including interply density variations. The measurement of HU at the contrasts could clearly distinguish delaminations/debonds. Further, the density profile could clearly demark the delaminations/debonds from interply density variations. This type of self-referencing is not possible with conventional NDT techniques. Thus, CT has emerged as a powerful non-destructive evaluation tool over conventional NDT techniques in assessing and analysing various defects and increasing the confidence level in the detection of defect.

Figure 5. Areas of debond between casing and liner, delaminations within liner.

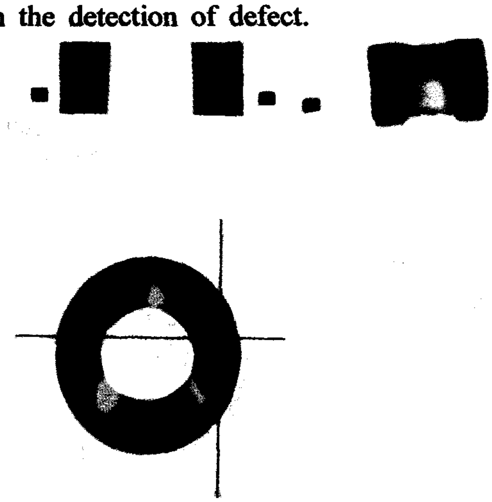

Figure 6. Images of planes cut from 3-D data showing debond (left) and delaminations (right).

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Contributors

Dr C Muralidhar obtained his PhD (Polymer/Ceramic Composites) from Indian Institute of Technology, New Delhi. He joined DRDO at the Defence Research & Development Laboratory (DRDL), Hyderabad, in 1988. He has been working in the field of nondestructive evaluation (NDE) of composite components since 11 years using various techniques, such as ultrasonic radiography and thermography. Presently, he is working in a team, which is developing industrial computed tomography (ICT) for NDE analysis of various composite components. He has published 18 research papers in national and international conferences. One of his papers was awarded as the best technical paper at a national conference (NDE-98), held at Thiruvanthapuram in 1998. He has been conferred with two *DRDO Awards* for his significant contribution in NDE of composites.

Mr Sheri George obtained his BE (Mechanical Engineering) from Govt College of Engineering, Thiruvanthapuram, in 1992. He did his Masters in Computer Integrated Manufacturing from PSG College of Technology, Coimbatore, in 1995. He joined DRDL as Senior Research Fellow in 1995. He is a member of the team which is working on the indigeneous development of industrial computed tomography. He has published four research papers in international and national conferences. One of his papers was awarded as the best technical paper at a national conference (NDE-98) at Thiruvanthapuram, in 1998.