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An overview of methods to detect composite/substrate bonding

Donald McNicol
Main methods

- Ultrasonic
- Radiography
- Acoustic Impedance
- Microwave
Ultrasonic

- Readily available
- Data can be reported
- Wide range of techniques
- Can be automated
- Data can be recorded
- Minimal environmental/safety impact
- Difficult materials
- Difficult to interpret
- Needs reflector
- Needs couplant
Radiography

- Provides clear image
- Provides record
- Well understood and accepted
- Significant environmental/safety impact
- Disruptive to work area
- Significant training and regulatory requirement
- Difficult to detect small density changes
Acoustic impedance

- Bondmaster readily available
- Track record
- Provides good point data
- Minimum environmental/safety impact
- Needs physical disbond to operate
- Data difficult to record
- Requires couplant
- Very difficult to automate for area coverage
1. Introduction
2. Theory overview
3. Application
4. Pros and cons
5. Summary
Microwave inspection of non metallic materials

Materials
- Thermoplastics
- Fiberglass piping and patches
- Reinforced and non-reinforced rubber
- Concrete
- Ceramic
- Any other bulk dielectric/composite
Detectable defects

- Delaminations
- Disbonds
- Foreign Material Inclusions
- Voids
- Changes in thickness
- Moisture or liquid contamination
- Mechanical damage
- Physical changes due to chemical attack
Principle of operation
Material test pieces are bathed in Microwave Energy of a constant frequency. (Low GHz)

Different dielectric constants reflect varying levels of μW energy to a detector.

The energy level is sampled across the test piece and plotted to create an image.
Principle of operation

Detector output is in Volts
Data presentation

- Detector voltage A, B and C (A-B) at an X,Y position
- Amplitude in Gray scale or Color
- Data plot can be manipulated in quasi 3D
Deployment
At left is a reinforced rubber expansion joint in cooling water service in a US nuclear power plant. The joint is 138 inches in diameter, and approximately 8 inches long (thick). This joint, along with 11 other joints in identical service, was inspected using a fully automated scanner under computer control. Evisive Scan® images of several of these joints can be seen on the following slides.
The 2 scan images above represent the results from the inspection of the large reinforced rubber expansion joints shown on the previous page. Of the 12 joints inspected, 11 of them appeared essentially identical to the top image. Note the interlaced indications at approximately ±30 degrees from the vertical. These represent reinforcing fabric strips used in the manufacturing process. The vertical linear indication at X=17.5 is a surface blemish. The lower image represents a scan of the only joint with internal delamination damage. Note how the reinforcing fabric pattern is almost completely obscured by the damage.
Example – Fiberglass pipe coupon

Fiberglass Pipe Coupon

Two Four Inch Pieces of FRP Pipe Connected Via Glued Coupling

Scan Results
(Shown rolled out into flat plane for ease of viewing)
Example – Fiberglass “Clockspring” reinforcement

Fiberglass Reinforced O.D. Pipe Patch
Example – Fiberglass “Clockspring” reinforcement

Flaw Areas
Poor Substrate Adhesion

Ch B - Evasive NDT file - 10-11-2005 15:05:23
C:\Test\Scans\clock5
Example – “AquaWrap” reinforcement

Reinforcement applied over 4 rectangular air bags (approx 0.005 air gap) First (0.5” x 0.5”) applied to surface at 0 degree, second (1” x 1”) at 90 degrees, third (1” x 1”) obliquely at 180 degrees between layers 2 and 3 and fourth (1” x 1”) obliquely at 270 degrees between layers 6 and 7 of 8.
Example – “AquaWrap” reinforcement

0.5” Disbond at surface

1” Disbond between layers 2 and 3

1” Disbond at surface

1” Disbond between layers 6 and 7
Example – GRP to GRP
Example – GRP to GRP
Example – GRP to GRP
Microwave – application status

Current usage

• Body armour
• Ceramic heat shields
• HDPE gas distribution piping
• Earthmover tyre rock detection
• Rubber expansion joints in nuclear power stations
• HDPE water pipe in nuclear power stations
• Composite laminate sheet manufacture
• GRP water /chemical piping

Proven application

• Subsea pipe and manifold insulation
• Clockspring type re-enforcement
• Piping insulation field joints
• Wind turbine blades
• Marine sonar domes
• Marine “stealth” material bonding
• Aircraft composites
• CUI
• HDPE electro-fusion welds
• GRP and HDPE pipe internal erosion/degredation
Microwave - pros and cons

- Inspect previously uninspectable materials
- Locate and characterise defects that lead to mid to long term failure
- Automated
- Data recorded
- Fast
- System use restricted to qualified operators
- Recognised by some regulatory bodies
- Broad range of applications

- Inspect previously uninspectable materials!
- Starting to be accepted
- Restricted surface temperature range
- Topside, dry use only
- Extensive training
- Extensive experience

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### Table 2: NDE selection and acceptance criteria for defects that could potentially occur during operation (Update of Table 5 from ISO 14692 Pt. 4, additions shaded in light blue)

<table>
<thead>
<tr>
<th>Operational defects</th>
<th>Cause(s)</th>
<th>Consequence(s)</th>
<th>Recommended NDE method(s)</th>
<th>Other potential NDE methods</th>
<th>Criteria</th>
<th>Corrective action</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flange cracks, leaks</td>
<td>Bolts over- or under-torqued, GRP against raised face flanges.</td>
<td>Joint not sealed, leakage, Reduced life</td>
<td>Visual inspection</td>
<td>Ultrasonics, Radiography</td>
<td>No leakage permitted</td>
<td>Replace flange (major defect), Grind and fill minor cracks with resin.</td>
<td>Radiography unlikely to be successful unless well aligned.</td>
</tr>
<tr>
<td>System failure, e.g. burst pipe</td>
<td>Design conditions, loads, temperatures exceeded. Operational procedures inadequate (e.g. water hammer due to valve opening).</td>
<td>System failure</td>
<td>Visual inspection</td>
<td>Monitoring by acoustic emission or leak detection methods</td>
<td>No failure permitted</td>
<td>Replace pipe or system</td>
<td>NDE not likely to be applicable</td>
</tr>
<tr>
<td>Ageing</td>
<td>Long-term materials degradation</td>
<td>Weepage</td>
<td>Ultrasonics</td>
<td>Ultrasonics, microwave, shearography, acousto-ultrasonics or transient thermography to detect delamination damage associated with ageing or impact.</td>
<td>More than 20 % reduction in original axial modulus</td>
<td>Accept, but monitoring required</td>
<td>Delamination may occur in the latter stages of ageing leading to weepage. Main initial damage mechanism is matrix cracking. Linear scanning UT methods (B-scan, C-scan) more likely to pick up delaminations. Phased array or rapid scanning wheel probes may be considered, given greater speed and quality of visual indication. If GRP quality and surface finish sufficient to allow higher frequencies (1-2.5 MHz).</td>
</tr>
<tr>
<td>Operational defects</td>
<td>Cause(s)</td>
<td>Consequence(s)</td>
<td>Recommended NDE method(s) ISO 14692</td>
<td>Other potential NDE methods</td>
<td>Criteria</td>
<td>Corrective action</td>
<td>Comments</td>
</tr>
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</tr>
<tr>
<td>Ageing (Continued)</td>
<td></td>
<td></td>
<td>Destructive testing and characterisation of condition or NDE using ultrasonic velocity to measure matrix cracking non-destructively</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Impact damage</td>
<td>Impact e.g. from dropped scaffolding, tools</td>
<td>Weepage</td>
<td>Ultrasonics, Visual inspection</td>
<td>Transient thermography, ultrasonics, microwave, shearography or acousto-ultrasonics to detect delamination damage associated with impact</td>
<td>In accordance with Table A.1 Visual inspection</td>
<td>Replace (major defect), Temporary repair (minor detect)</td>
<td>Visual inspection would be normal practice. Thermography can have a good sensitivity to the characteristic features of impact damage (conical damage area, multi-layer delamination). Ultrasonic A-scan or phased array can detect existing damage dependent on surface finish and thickness. Shearography potentially good but expensive.</td>
</tr>
<tr>
<td>Earthing cable damage</td>
<td>Some cables susceptible to corrosion in marine atmosphere</td>
<td>Earthing reduced or eliminated</td>
<td>Visual inspection, Mega-ohm meter</td>
<td>None</td>
<td>None permitted</td>
<td>Replace cables</td>
<td>ISO unlikely to be applicable</td>
</tr>
</tbody>
</table>
Microwave can detect and characterise irregularities that cannot be detected by other NDE techniques.

• Inspection speed and cost is comparable with Ultrasonic methods
• No hazardous emissions
• No environmental impact
• Major regulatory body approval in process