Abstract

Composites are the materials which have proven their superiority over other conventional materials for applications in aerospace, defence and other advanced application areas. However, along with multiple advantages associated with composites, one major area for concern associated with composites is the presence of defects. These defects may significantly degrade the properties of composites leading to the catastrophic failure of the component. Composites may have process induced defects like delamination, resin starved and the resin rich zones etc. Sometimes it becomes very difficult to distinguish between resin rich and resin starved zones by NDT inspection, and sometimes these defects may even go undetected. With the objective of assessing the efficiency of Thermography and Pulse Echo Ultrasonic NDT (PET) techniques for distinguishing between resin rich and resin starved zones, a 5mm thick carbon-epoxy laminate was fabricated with multiple types of defects embedded in it. A novel fabrication technique was adopted to create clear air defects and defects to simulate the presence of resin rich, resin starved and foreign object inclusions. Detailed Thermography and PET tests were carried out and it was found that for clear air defects, the Thermography and PET are equally good; whereas, the Thermography has advantage over PET in detecting resin rich zones. Conversely, the PET has advantage over Thermography in detecting resin starved zones. Findings from this study need to be further probed for other materials and defect configurations to derive final conclusions for distinguishing between resin rich and resin starved zones.

Keywords: Composites, Delamination, PET, Resin Rich, Resin Starved, Thermography

1. Introduction

Composite materials are increasingly used in aerospace, naval, automotive and many other industries due to their high specific strength and stiffness properties. Due to inherent complexities of composite structure manufacturing, various types of defects such as voids, inclusions, delaminations, disbonds, resin rich resin starved zones etc. may be present in the final product. Proper assessment of these defects is essential for effective utilization of these products. There are several NDT techniques like radiography, ultrasonic testing, shearography, infrared thermography etc for detecting defects in composite. Although traditional techniques such as ultrasonics, easily reveal the presence of flawed areas, however, they are time consuming; Whereas, Infrared thermography is a faster and non-contact technique, which does not require any coupling agent.

Infrared thermography is being applied for variety of applications ranging from detection of delaminations and disbonds in layered structures, assessing hidden corrosion in metallic components, detection of local wall thinning in metallic tubes, cracks in ceramics and metals, voids, impact damages and inclusions in composite materials, investigation of adhesion integrity of kissing bond region in plastic welded joints etc. [1-3]. It provides faster, safe, non-contact and nondestructive tool for evaluation of sub-surface defects in materials. Active Infrared (IR) thermography NDT is well known technique for assessment of sub-surface defects in composite structures [4-5]. This technique does not affect the material or structure’s
future usefulness and at the same time provides an excellent balance between quality control and cost-effectiveness. In active infrared thermography, the object is heated briefly by a heat source and an IR camera monitors the transient temperature behavior of the surface. The presence of sub-surface defects in the test material disturbs the heat flow inside the test specimen, and this disturbance caused by the defect gets manifested on the surface as a hot or cold spot as seen by the IR camera.

The two types of defects which occur in composites are resin starved (Voids, Delamination) and the resin rich defects. In current study an attempt has been made to compare the applicability of Ultrasonic and Thermography techniques in detecting the resin rich and resin starved zones in composites. Effect of the ultrasonic probe diameter on defect detectibility too has been studied.

2. Experimentation

2.1 Fabrication of composite laminates with implanted defects

The material used in the current studies was Carbon-epoxy. One laminate of dimensions 300x300x5mm was fabricated by using carbon-epoxy UD prepreg. Depth of all the defects was 2.5mm from one of the side. All the defects had same thickness. Prepreg layers were laid in 0-90° pattern. Various types of defects were implanted in the laminate. Defect details are given in Table 1 and Figure 1.

Table 1: Details of implanted defects

<table>
<thead>
<tr>
<th>Defect No.</th>
<th>Defect type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Glass balloons</td>
</tr>
<tr>
<td>2</td>
<td>Blank groove</td>
</tr>
</tbody>
</table>

![Figure 1: Details of implanted defects](image-url)
<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Foam Pieces</td>
</tr>
<tr>
<td>4, 5, 6</td>
<td>Same as 1, 2, 3</td>
</tr>
<tr>
<td>7</td>
<td>Liquid epoxy resin (later cured during curing of laminate)</td>
</tr>
<tr>
<td>8</td>
<td>Carbon fiber tow</td>
</tr>
<tr>
<td>9</td>
<td>Carbon fiber tow</td>
</tr>
<tr>
<td>10, 11</td>
<td>Same as 7 &amp; 8</td>
</tr>
<tr>
<td>12, 13</td>
<td>Same as 9</td>
</tr>
<tr>
<td>14</td>
<td>Cured epoxy resin pieces</td>
</tr>
<tr>
<td>15</td>
<td>Metal piece</td>
</tr>
<tr>
<td>16</td>
<td>Blank groove covered with high temp. polyethylene sheet</td>
</tr>
</tbody>
</table>

### 2.2 Experimental details

NDT experiments were carried out by using Thermography and Pulse Echo Ultrasonic Technique (PET). Experimental details are given as follows:

#### 2.2.1 Thermography

Thermography experiments were conducted by using Flash Thermography setup. The flash time was 5ms and the heating power was 9.6KJ. Frame capture rate was 50Hz. The raw data collected from thermography experiments was curve fitted by using TSR technique [6]. Data processing was carried out by using 1st derivative and 2nd derivative techniques. The processed images were analyzed and the thermogram at the time instance with maximum defect detectibility and clarity was used for interpretations and drawing conclusion.

#### 2.2.2 PET ultrasonic

PET Ultrasonic experiments were carried out with 2.5MHz probe. The probe diameter was 10mm and the coupling agent used was water soluble gel.

### 3. Results and Discussion

Data obtained from Thermography and Ultrasonic NDT was analyzed and for clear analysis the defects have been segregated in four groups. These are:

1. Defects with defect echo and no back-wall echo by PET
2. Defects with both defect echo and back-wall echo by PET
3. Defects detectible by Thermography but not by PET
4. Defects detectible by none of the technique

These four groups of defects are discussed in following sections.
3.1 Defects with defect echo and no back-wall echo by PET

Under this category the defects were detectible by both the techniques. These defects are shown in Figure 2. The processed thermogram is given in Figure 3. The detectible defects include defect no. 1, which constituted air balloons. Air balloons consist of finite volume, due to which during cure the prepreg layers do not compress and result in finite volume defect. Similarly defect No. 3, 5 & 15 constituted finite volume inserts resulting in either clear air defects or low diffusivity insert. Defect no. 2 didn’t constitute any insert but was a blank groove. During cure the prepreg layers might have slightly compressed resulting in distorted and smaller sized defect. Defect no. 16 and 19 constituted empty grooves but were covered with thin polyethylene sheet. Due to this sheet, neither the resin filled the groove nor the prepreg layers got compressed. This has resulted in clear air defect with well defined shape.

From these observations it is inferred that the defects which were detectible by both the techniques constituted clear air gap or the insert with low thermal diffusivity. Thermography and PET ultrasonic were found equally good for detecting these types of defects; however, thermography has added advantage over PET that it gives information about the defect size too, which is very important information for Non-destructive inspection of composites.

![Figure 2: Defects detectible both by Thermography and PET techniques](image-url)
Figure 3: Processed thermogram

Figure 4: Defects with defect echo and back-wall echo by PET
3.3 Defects detectible by Thermography only

Defects which are detectible by only Thermography are shown in Figure 5. Defects under this category include defect No. 10, 14 & 17, which are filled with resin. These defects simulate resin rich zones in composites. These defects have been clearly detected by Thermography but not detectible by PET. No detection of these defects by PET implies that there is no air entrapment in these defects.

Defect no. 9 (Carbon fibre tow) has been detected by Thermography but not by PET. Incidentally, it has been seen in previous section that the defect no. 8, which is also a carbon fiber tow defect and of much larger size than the similar defect 9 has not been detected by Thermography. This shows that the defect no. 9 has definitely got some air entrapment due to which it is detectible by thermography. However, even with air entrapment it is not detectible by PET. This could be due to the smaller size of the defect in comparison to the Ultrasonic probe diameter. Similarly, there could be some air entrapment at defect 18 too, due to which it is detectible by thermography but not by PET.

From these observations it is inferred that the defects which are detectible by thermography but not by PET are either resin rich defects or are the defects with air entrapment and of smaller size than the UT probe diameter.

Figure 5: Defects detectible by Thermography only
3.4 Defects detectible by none of the technique

Defect no 9 & 11 are having carbon fiber tow embedded in it and have not been detected by any of the methods. It could be due to the reason that these defects are much smaller in size and the PET has difficulty in detecting the defects smaller than the probe diameter. Moreover, thermography has difficulties in detecting resin starved defects. These defects are shown in Figure 6.

Defect no. 5 too has not been detected by any of the method. This could be due to the reason that the pepreg layers have been compressed during curing resulting in disappearance of the defect. Due to which none of the technique could identify this defect.

![Figure 6: Defects detectible by none of the techniques](image)

4. Conclusion

A carbon-epoxy laminate with artificially implanted defects was fabricated. A variety of defects were implanted in the laminate to assess the feasibility of defect detection by thermography and PET NDT techniques. It was observed that certain defects were detectible by both the techniques and some went undetected by either of the technique. There were certain defects detectible by only one of the technique. It has been found that for clear air defects both the techniques are equally good. PET has been found advantageous over Thermography in detecting resin starved zones; whereas, Thermography has an edge over PET in detecting resin rich zones. For the defects detectible by none of the techniques it is expected that the prepreg layers have compressed during cure resulting in disappearance of the defect. However, for finding the exact reason why few defects went undetected, it is planned to carry out the CT scan on the laminate. This will help in visualizing the internal
structure of the laminate layer-by-layer and act as a tool in corroborating the findings from Thermography and PET techniques.

References


