Effect of Post-Curing Temperature Variation on Mechanical Properties of Adhesively Bonded Composite Laminates

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Abstract: The effect of post-curing temperature variation on the apparent interlaminar shear strength of adhesively bonded composite panels was studied experimentally. Three different cases were studied: a) co-curing of two uncured laminates with an adhesive film, b) co-curing of a cured laminate with an uncured laminate with an adhesive film, and c) co-bonding of two cured laminates with an adhesive film. Short beam shear (SBS) tests were performed according to ASTM D2344 to assess the mechanical properties of the cured laminates. The results of this study can be used for assessing the mechanical performance of soft-patch and hard-patch repair.

1. Introduction

The field repair of composite parts in aerospace industry is typically accomplished by adhesively bonding a soft patch (uncured prepreg) or a hard patch (cured prepreg) to the damaged area [1, 2]. The curing of the repair region takes place under the heat blanket rather than the oven or autoclave [3]. While the soft patches are easy to manufacture and exhibit excellent mold conformity, their mechanical properties are often inferior to the parent material. On the other hand, mechanical properties of the hard patches usually match those of the parent laminate; nevertheless, hard patch repairs are more expensive, may require a mold [2]. Due to the presence of the adjoining structures, frames, and the backside being exposed to ambient conditions, some of the heat generated by the heat blanket may be lost and result in cure temperature variation in both the cases of hard-patch and soft-patch repair. In this study, the effect of post-curing temperature variation on the interlaminar shear strength of adhesively bonded composite laminates was studied experimentally.

2. Experimentation

Cycom 5320 8HS is a toughened epoxy resin prepreg reinforced by 8 harness satin (8HS) carbon fiber and formulated for out-of-autoclave manufacturing. The Cytec-recommended cure cycle for this prepreg is isothermal cure at 250 F for one hour followed by freestanding post cure at 350 F for two hours. FM 300-2M film adhesive is a co-cure and secondary composite bonding adhesive. The Cytec-recommended cure cycle for FM 300-2M is isothermal cure at 250 F for either 30 minutes or 90 minutes. The above mentioned materials were used for this study. Figure 1 shows the temperature profiles used for curing the prepreg panels in an oven. In order to investigate the effect of degree of cure variation on the mechanical properties of the cured laminates, the post cure temperature was lowered from 350 F to 250 F.

A total of 17 panels were fabricated with 10 prepreg plies all in 0° direction. Panels 1 to 4 were cured without adhesive. Panels 5 to 10 were cured with the adhesive film placed in the middle of 10 plies. Panels 11 to 15 were also cured with the adhesive film placed in the middle of 10 plies. However, for these panels the bottom 5 plies were already cured using the cure cycle with post cure at 350 F and only the top 5 plies were co-cured with the adhesive film. These panels simulate the soft-patch repair. Finally, panels 16 and 17 were cured with the adhesive film placed in the middle of 10 plies. For these panels both the top and bottom 5 plies were already cured using the cure cycle with post cure at 350 F and only the top 5 plies were co-cured with the adhesive film. These panels simulate the hard-patch repair. Finally, panels 16 and 17 were cured with the adhesive film placed in the middle of 10 plies. For these panels both the top and bottom 5 plies were already cured using the cure cycle with post cure at 350 F. The adhesive film was used to co-bond the top and bottom plies (Figure 2). These panels simulate the hard-patch repair. Panels 1 to 15 were debulked for 8 hours and panels 16 and 17 were debulked for 30 minutes before being cured. A minimum of 26 inHg vacuum was applied throughout the debulking and curing process. The SBS tests were performed according to ASTM D2344.
Figure 2. Lay-up of the panels for this study.

3. Results

Average values of SBS strength along with the respective standard deviation is shown in Table 1. It indicates that the SBS strength for the panels post cured without adhesive at temperatures ranging from 300 F to 350 F (panels 1 to 3) does not vary significantly. However, for post-cure temperatures below 300F, the SBS strength reduces gradually with reducing the post cure temperature (panels 3 to 5). This is in contrast with other results suggesting a gradual decrease in the mechanical properties with decreasing the post cure temperature. The observed difference in the SBS trend could be attributed to the difference in the layup. While the laminates in this study were all laid up in 0 direction, the laminates in the previous study were placed in quasi-isotropic [90/45]_s order. The observed dependence of the SBS strength trend on the stacking sequence calls for attention in establishing any correlation between the state of cure and mechanical properties for the composite materials. It is also notable that the panels cured with adhesive (panels 6 to 15) show a significant decrease in the SBS strength as compared to the panels cured without adhesive. However, the SBS strength trend for both sets of panels is almost identical. Also, panels simulating a soft patch (11 to 15) had a higher SBS than their matching panels co-cured with adhesive (panels 6 to 10). This could be attributed to the fact the bottom plies for the soft patch panels were fully cured. Finally the panels simulating a hard patch (panels 16 and 17) had the highest SBS strength amongst all panels cured with adhesive. This could be explained knowing that the both top and bottom plies for these panels are fully cured and also the adhesive is almost fully cured resulting in the minimal adverse effect of adhesive on the mechanical properties of the laminate.

Table 1. Average SBS strength for studied panels.

<table>
<thead>
<tr>
<th>Panel Number</th>
<th>Panel Code</th>
<th>SBS Strength (ksi)</th>
<th>Stdev (ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>350 F W/O</td>
<td>12.46</td>
<td>0.289</td>
</tr>
<tr>
<td>2</td>
<td>330 F W/O</td>
<td>12.29</td>
<td>0.197</td>
</tr>
<tr>
<td>3</td>
<td>300 F W/O</td>
<td>12.27</td>
<td>0.098</td>
</tr>
<tr>
<td>4</td>
<td>270 F W/O</td>
<td>11.02</td>
<td>0.175</td>
</tr>
<tr>
<td>5</td>
<td>250 F W/O</td>
<td>10.10</td>
<td>0.239</td>
</tr>
<tr>
<td>6</td>
<td>350 F W</td>
<td>11.24</td>
<td>0.226</td>
</tr>
<tr>
<td>7</td>
<td>330 F W</td>
<td>10.78</td>
<td>0.387</td>
</tr>
<tr>
<td>8</td>
<td>300 F W</td>
<td>10.79</td>
<td>0.315</td>
</tr>
<tr>
<td>9</td>
<td>270 F W</td>
<td>9.76</td>
<td>0.067</td>
</tr>
<tr>
<td>10</td>
<td>250 F W</td>
<td>8.62</td>
<td>0.096</td>
</tr>
<tr>
<td>11</td>
<td>350 F SP</td>
<td>11.29</td>
<td>0.150</td>
</tr>
<tr>
<td>12</td>
<td>330 F SP</td>
<td>11.34</td>
<td>0.307</td>
</tr>
<tr>
<td>13</td>
<td>300 F SP</td>
<td>10.83</td>
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</tr>
<tr>
<td>14</td>
<td>270 F SP</td>
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<td>0.205</td>
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<tr>
<td>15</td>
<td>250 F SP</td>
<td>9.80</td>
<td>0.226</td>
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<tr>
<td>16</td>
<td>350 F HP</td>
<td>12.54</td>
<td>0.217</td>
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<tr>
<td>17</td>
<td>250 F HP</td>
<td>12.50</td>
<td>0.240</td>
</tr>
</tbody>
</table>

4. Conclusion

From this study it was observed that the laminates simulating a hard patch repair (case c) were least affected by post-cure temperature variation suggesting that the co-bonding could also take place at temperatures below 250 F. The laminates simulating a soft patch repair (case b) exhibited better mechanical properties than those co-cured using two uncured laminates with an adhesive film (case a). This was attributed to the fact the bottom plies for the soft patch panels were fully cured. A general decrease in the mechanical properties were observed by introducing an adhesive film in the midplane of the uncured laminates (case a vs. laminates cured with no adhesive).

5. References