MECHANICAL CHARACTER OF ASYMMETRIC CFRP/Al LAMINATES

First A. Zhao Junqing*, Second B. Liu Wenbo†

*Affiliation of Zhao Junqing
School of Astronautics, Harbin Institute of Technology Harbin 150001, China
zhaojunqing@hit.edu.cn

†Affiliation of Liu Wenbo
School of Materials Science and Engineering, Harbin Institute of Technology, Harbin 150001, China
liuwenbo@hit.edu.cn

Key words: CFRA (carbon fiber reinforced aluminum laminates), tensile, adhesive interface, finite element, three point bending, shear stress.

Summary: The mechanical properties of the carbon fiber reinforced aluminum laminates and its interface are investigated. To study the mechanical character of CFRP/Al laminates, tensile and three point bend experiment of CFRP/Al laminates were conducted. Also, finite element analysis of the strains and interfacial shear stress in the laminates are performed. The strains obtained from simulation agree with those by the tensile experiment, and the interfacial shear stress between the carbon fiber laminates and aluminum sheet displays a nonlinear distribution. Analysis illustrate there are no failure of the adhesive interface between CFRP and the Aluminum sheet. Mechanic analysis and test of three points bending showed shear damage of CFRP emerged in CFRP/Al laminates.

1 INTRODUCTION

Carbon fiber has excellent performances, such as high specific strength and specific modulus, light-weighted, and corrosion-resistant1,2. In modern aerospace and astronomical engineering, composite pressure containers often utilize carbon fiber due to its superb mechanical properties3-5. Compared to traditional metallic pressure vessels, composites vessels have high strength and are light-weighted, making them the future materials for pressure vessels6,7. Despite these superior characters, composite vessels are much weaker in air impermeability than metal ones. This weakness leads to leakage of liquids and gases8,9 if not taken good care of. To ensure the safety, an metallic liner can be used to enhance the air impermeability so as to prevent the possible leakage3,9,10. Aluminum becomes a satisfactory choice for this purpose due to its low density and high ductility. Based on the issues of both safety and economy, composite pressure vessels with a liner will satisfy the need of cyclic use in service11. The disaster damage is pressure vessel blasting. The leakage and week carrying capacity is the reason leading explosion. Due to CFRP main role is bearing, three point bending test was also conducted in the investigation.

Because quite different on elastic moduli of Aluminum and carbon fiber, it is observed that under hydraulic pressure, the metallic liner will buckle and wrinkles present. These wrinkles
appear since the deformation in carbon fiber composite and aluminum liner are not compatible. Such phenomena will affect greatly the cycling performance and so a research on the mechanical performance and deformation of the carbon fiber reinforced aluminum laminates is necessary.

The incompatible deformation originates from the fact that the elastic limit of the carbon fiber composite is 1.7%, while for the aluminum alloy it is only 0.18% and converts 0.3% after experiencing pretension. When loaded, they two together give an expansion of 1%. Then during the unloading, carbon fiber composite is still in elastic range, but plastic deformation formed during the loading in the aluminum alloy cannot be recovered. Also, it is clear that while unloading, aluminum alloy is in compression. Since the aluminum liner is quite thin, wrinkles are very likely to appear at places on the interface of weak bonding, leading to the incompatibility of the deformation.

2 EXPERIMENT

2.1 Specimens Perparation

The unidirectional 0° composite laminates are wound on a digital twister from carbon fiber T700 with an epoxy matrix. An aluminum alloy sheet is then bonded to the composite using TDE-85/MPD adhesive, and then cured according to curing system. Neglecting the curing residual stress, the made shape and size of the laminate is shown in Fig. 1. The specimen is 15 mm wide, 200mm long, and the aluminum sheet, carbon fiber composite and the adhesive are 1.8 mm, 2.2 mm and 0.2mm in thickness respectively.

![Figure 1: Sizes of the carbon fiber/aluminum laminate specimen.](image)

2.2 Tensile Experiment

Tensile repeat laminate tested by machine. The measured strain of the carbon fiber composite and aluminum alloy are depicted in Fig.2 and Fig3. we know the laminate initial strain is zero as the loading and the laminate residual strain surpass 0.21% after the first unloading. After first repeat, the laminate strain formed a closed loop between 0.21% and 1% basically. Experiment result shows that as the number of repeat increases, the residual strain increases. The results given in this paper takes the average from five specimens.

2.3 Three Point Bending Experiment

The specimens is loaded till damage occurs, and at that time aluminum alloy was in plastic status and born compression stress, owing to the elastic modulus of CFRP laminates is much larger than aluminum sheet, together with the size of the specimens, hence the neutral axis position should in CFRP laminates. Above the neutral axis aluminum sheet and part CFRP laminates sustains compression stress, below the neutral axis the other part CFRP laminates bears tensile stress. Shear damage emerged in CFRP instead of the interface between CFRP laminates and Aluminum sheet.
3 SIMULATION AND ANALYSIS

3.1 Simulation model and results

A 2D finite element model of the CFRP aluminum laminates is setup using Ansys. The 4-node PLANE42 element is used. The model has 600 elements and 707 nodes in total. The mechanical properties of the three kinds of materials are measured and listed in Tables 1 and 2. Different meshing scales are used in different materials, since they have different thicknesses. The laminate is simulated by applying loading-unloading process cyclically. The simulation results are showed in Fig. 2~ Fig. 4.

<table>
<thead>
<tr>
<th>Material</th>
<th>Elastic Modulus /GPa</th>
<th>Poisson’s Ratio</th>
<th>Yielding strength /MPa</th>
<th>Ultimate strength /MPa</th>
<th>Shear modulus /MPa</th>
<th>ductility /%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum alloy 5A03</td>
<td>70</td>
<td>0.3</td>
<td>108</td>
<td>218</td>
<td>—</td>
<td>23</td>
</tr>
<tr>
<td>TDE-85/MPD</td>
<td>3.9</td>
<td>0.3</td>
<td>72.8</td>
<td>20</td>
<td>2.5</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Mechanical properties of the aluminum alloy liner and the interface glue.

<table>
<thead>
<tr>
<th>$E_x$/GPa</th>
<th>$E_y$/GPa</th>
<th>$E_z$/GPa</th>
<th>$V_{xy}$</th>
<th>$V_{yz}$</th>
<th>$V_{xz}$</th>
<th>$G_{xy}$/GPa</th>
<th>$G_{yz}$/GPa</th>
<th>$G_{xz}$/GPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>138</td>
<td>9.98</td>
<td>9.98</td>
<td>0.3</td>
<td>0.28</td>
<td>0.28</td>
<td>4.79</td>
<td>5.86</td>
<td>5.86</td>
</tr>
</tbody>
</table>

Table 2: Mechanical properties of the T700 Carbon Fiber/Epoxy composites

Figure 2: Strain comparison of experiment and simulation.
3.2 Simulation and experiments result analysis

Fig. 2a shows that measured maximum strain of the carbon fiber composite obtained from experiment is smaller than simulation. Fig.2b illustrates the measured maximum strain of the aluminum alloy obtained from experiment is consistent with simulation. From the Fig. 2 and Fig. 3, the measured initial strain of carbon fiber composite and aluminum alloy is positive. As above statement, the maximum strain of carbon fiber composite of the experiment is smaller than simulation, while the maximum strain of aluminum alloy is close to simulation. Also the residual strains of carbon fiber composite and aluminum alloy at unloading end by both approaches increase as repeats times increases, and they agree well.

At the first repeat, Fig.2a and Fig.3a reveal residual strain of carbon fiber composite is 0.087% by strain gauge. Fig.2b and Fig.3b illustrate residual strain of aluminum alloy is up to 0.26% by strain gauge owing to aluminum alloy has been gotten into plastic status. The residual strain of laminates by extensometer is 0.21% that between carbon fiber composite and aluminum alloy. Due to the elastic limit of the aluminum alloy is 0.18% and becomes 0.3% after pre-tensile treatment, if only testing aluminum alloy, the residual strain perhaps maintain at 0.7%~0.8%.

From Fig.4, depicts the results only on a range of 20-50 mm to the center. Within 20-30 mm range, the interfacial shear stress is almost zero. It increases gradually between 30-40 mm but still very small, and rising rapidly between 40-50 mm range, the maximum interfacial shear stress occurs at the first unloading end. The shear stress decreases gradually
as repeat number increase during unloading. The difference of interfacial shear stress between the first/fifth repeats, and fifth/tenth repeats, are relatively large compared to that between the tenth/thirteenth repeats. The interfacial shear stress reads 3.42MPa for its maximum by Fig.4. However, experimental measurement reveals 20MPa of the TDE-85/MPD adhesive shear strength. So the interface between the composite and the aluminum alloy will not rupture due to shear.

Three Point Bending Experiment show that aluminum alloy was in plastic status and born compression stress and CFRP suffer tensile stress. In the neutral axis there is the maximum shear stress occurring in CFRP by relative formula, and its value larger than the epoxy resin shear strength, thus shear damage emerged in CFRP. Meanwhile the specimen displayed the shear damage in CFRP.

4 CONCLUSIONS

As there are wrinkles occurring in pressure vessel when it experience curing or water pressure testing, the interface shearing and peeling strength between carbon fiber composite and aluminum alloy should be considered. Due to the thermal residual stress and residual stress as manufacturing and experiment respectively, the wrinkles will appear in pressure vessels in view of the above factors. In this paper, the interface shearing strength can fully meet the tensile repeat experiment of the CFRP aluminum laminates. However the peeling strength experiment of the interface of the laminates is more difficult to do. Similar experiment should be done of the CFRP aluminum laminates with defects as weak and no bonding, perhaps two-way stretch experiment should be more corresponding pressure vessel working conditions. So as to improve the state of the appearance of wrinkles in the pressure vessel, there are a lot of things needs to be done. Since the vessel bear bending during services, and three point bending illustrated shear damage of CFRP laminates. In order to avoid catastrophe damage, the CFRP character should improved.

REFERENCES

[8] P. Mertiny, A. Gold, Quantification of leakage damage in high-pressure fibre-reinforced


