Study on Buckling Behavior of Glass Fiber Sandwich Structure

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Abstract. A range of glass fiber sandwich structures were manufactured utilizing VARI technology and hydrothermal accelerate aging tests were carried out for them at four temperatures (25℃, 40℃, 55℃, 75℃) with three durations (10 days, 20 days, 30 days). Subsequent buckling tests on these structures recognized the principal failure mode as overall buckling, additionally, interface debonding and foam shearing were observed, moreover, the maximum load value is negatively related to the above two hydrothermal parameters and decreased by 19.53% and 17.27% respectively after 30-day aging and the exposure at 75℃. Furthermore, SEM images of the structures’ surface suggest that as temperature and time increase, the resin dissolution are escalated contributing to more distinct undermining of buckling capacity.

Keywords. Glass fiber sandwich structure, hydrothermal aging, buckling property, property degradation.

1. Introduction
The characteristics including high strength/stiffness-weight ratio, energy absorption and soundproof function [1-3] in sandwich-structured composites lead to their common application in engineering components. Glass fiber sandwich structure is composed of core foam with two face sheets of glass fibre-reinforced laminates, which is known as a new type of material. It is mainly preferable for aerospace and marine field [4] because of its good mechanical property, uncomplicated preparation technology, thermal insulation and very low water absorption characteristics [5-6]. But notably, in recent articles, it is reported that the hydrothermal environment have a relatively great influence on the mechanical property of fiber reinforced composites. Yan wa [7] pointed out that there is a 12% decline in the bending strength for T800 carbon fiber laminates after hydrothermal exposure, similarly, by means of in situ on-Line monitoring systems, Yaozhang Han [8] observed that the bending strength of glass fiber with high temperature treatment decreases by 18%. Moreover, in a project [9] involving accelerate aging tests, composites are exposed at 180℃ with duration of 4 days, 8 days, 16 days and 32 days respectively before low-speed crash test, it is noted that the load bearing capacity degrades greatly with the extent of aging time. On the other hand, Chao Shuang [10] reported a more significant decline in the shearing strength of T700/TDE-85 composites after hydrothermal aging, which is up to 33%. Nevertheless, the existing research has tended to focus on composite panels rather than sandwich structures, meanwhile, most of aging tests incline to set a small number of temperature variables because of the costs so that there exists a certain limitation of reflecting the temperature’s effect. Therefore, in this work, the glass fiber reinforced sandwich structures prepared by VARI technology are considered to investigate the influence of temperature and time on failure mode and capacity subjected to buckling test following hydrothermal aging test.
2. Experiment Procedure

2.1. Sandwich Structures Preparation
The glass fiber sandwich structure in this paper is made of woven glass fibers, core polyurethane foam and vinylester resin matrix, the preparation process: first of all, lay out the fibers and foam as depicted in figure 1(a), then wrap these material layers with vacuum bag and seal the gaps between the bag and mould with tapes for an airtight space. Next is using pump machine to draw the air out of the space. After checking the airtightness, transport the mixture of resin and hardener (MEKP) into the wrapped space through tubes, finally, keep the vacuum pressure until the appearance of impregnation, then leave them to cure at room temperature, on-site preparation process is shown in figure 1(b).

![Figure 1. VARI technology.](image)

(a) Layers layout  
(b) On-site preparation process

2.2. Buckling Test Preparation
According to ASTM D5229/D5229M, hydrothermal tests are carried out for the structures at 25 ℃, 40 ℃, 55 ℃, 70 ℃ respectively with 10 days, 20 days and 30days, the tested structures can be divided into 12 categories by these parameters. Followed by the hydrothermal exposure duration, bucking test were conducted with 5 mm/min loading speed on machine css-44100, as shown in figure 2. Referring to ASTM C364/C364M, specimen geometry: length l= 150 mm, width w= 60 mm, height h= 16 mm, and the buckling strength is determined by:

$$\sigma = \frac{P_{\text{max}}}{2 \times h \times t_f s}$$  \hspace{1cm} (1)

where, $\sigma$ (MPa), $P_{\text{max}}$ (N), $h$ (mm), $t_f$ (mm) stand for buckling strength, maximum bearalbe load value, height and fiber panel thickness of single side consecutively.

![Figure 2. Test devices.](image)

(a) Universal testing machine  
(b) Buckled specimen
3. Results and Discussion

3.1. Damage Morphology

The failure modes in structures subjected to buckling loads are presented in figure 3. It can be observed that the behaviour of structures with different hydrothermal parameters follow the same pattern: during the loading process, initial deformation on the structures exhibited as axial compression, then as the load increased, the middle part begin to bend laterally and overall buckling can be observed in all cases. When the displacement continues to grow, the overall buckling deformation proceeds accompanied by interface debonding and foam shearing phenomena, as shown in figure 4. From the figure, more details about local damages can be observed, looking more closely at interface debonding damages, most of them happened on the the end and inside the buckling arc with no exception, as shown in figures 4 (a-b), a few occurred in the middle of the structures (figure 4(c)). As for the shearing damages, they are mainly concentrated on the end as well and the cracks develop progressively from the outside to the inside, as shown in figure 4(d). Therefore, based on the above observations, the failure mode can be concluded that a process begin as overall buckling, then with the load increasing, some cracks occur at the interface leading to the progressive debonding damage, meanwhile, the core foam is broken due to the shearing force.

| Temperature | NA  | 10d | 20d | 30d |
|-------------|-----|-----|-----|-----|
| 25°C        | ![Image](image1) | ![Image](image2) | ![Image](image3) | ![Image](image4) |
| 40°C        | ![Image](image5) | ![Image](image6) | ![Image](image7) | ![Image](image8) |
| 55°C        | ![Image](image9) | ![Image](image10) | ![Image](image11) | ![Image](image12) |
| 70°C        | ![Image](image13) | ![Image](image14) | ![Image](image15) | ![Image](image16) |

**Figure 3.** Failure Mode.
3.2. Experiment Curves

Figure 5 presents buckling load-displacement curves of the structures with different hydrothermal conditions. It can be detected that the trend of these curves show consistence and mainly experience three stages: in the first stage, the load increases linearly and slowly, then it remains the linear upward trend and reaching the capacity of the structures with a sharp increase in the slope, ultimately, with the continuous increase of the displacement, the load begins to decline until complete failure. Based on peak values in table 1, it can be known that, under the exposure period of 10 days, 20 days and 30 days respectively, the limit loads drop by an average of 7.30%, 13.14% and 19.53% sequentially; over the temperature rang from 25 ℃ to 70 ℃, the limit loads decrease by 9.73%, 11.82%, 14.45% and 17.27% correspondingly. According the data, it can be clearly reflected that hydrothermal exposure environments not only have adverse effects on the capacity of the structures, but also the degree of the effects is in direct proportional (constant of variation is close to 1) with the hydrothermal parameters (see figures 6-7).
Table 1. Maximum load value (KN).

| Duration / Temperature | 25°C | 40°C | 55°C | 70°C |
|------------------------|------|------|------|------|
| 10 days                | 6.51 | 6.41 | 6.29 | 6.19 |
| 20 days                | 6.20 | 6.05 | 5.88 | 5.67 |
| 30 days                | 5.84 | 5.66 | 5.41 | 5.14 |

*a* Under the natural aging, the value is 6.85 KN.

3.3. SEM Images

For further investigate the mechanism of hydrothermal effect, Scanning Electron Microscope (SEM) is adopted to evaluate tested structures, as shown in figure 8. The comparison between these two images can suggest that there is a significant growth in the level of resin dissolution as the temperature and time increase. Serving as adhesion as well as a protection for fiber part, the dissolution is certainly associated with the decline in bonding strength mentioned in section 3.1, meanwhile, direct exposure of fibers due to the reduction of resin hinders the buckling capacity considering that the mechanical properties are mainly determined by the strength of fiber laminates. Overall, the negative effect of hydrothermal exposure on the buckling behaviors is caused by resin dissolution in nature, and as temperature and time rise, the dissolution are escalated cause more distinct drop in buckling strength.

![Figure 6. Strength-time curve.](image)

![Figure 7. Residual capacity curve.](image)

(a) Before aging test  
(b) After aging test

4. Conclusion

(1) The failure mode for the structures under the buckling load begins as overall buckling, then as the load increases, the development of cracks on the interface leading to debonding damage, meanwhile, the core foam is broken due to the shearing force.
(2) The buckling strength of the structures is negatively related to the temperature and time, and compared with the structures without aging, the maximum load after 30-day aging and exposed at 75°C decrease by 19.53% and 17.27% respectively.

(3) The negative effect of hydrothermal exposure on the buckling behaviors is naturally caused by resin dissolution, meanwhile, as temperature and time increase, the dissolution are escalated contributing to more distinct undermining of buckling capacity.

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