Experimental Study on Dry and Wet Bending Behavior of CF/GF Inter Laminated Hybrid Composites

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Abstract. Experimental study on the bending characteristics of dry and wet state (100°C boiled for 2 hours) in the same layering method, carbon (T700 unidirectional cloth)/glass (EWR800 multiaxial cloth) interlaminar hybrid composites with different mixing ratios. At the same time, the effects of 430LV vinyl resin and QC-350 epoxy resin on the bending properties of hybrid composites were compared and analyzed. The test results show that, In the same mixing ratio and the same test condition, QC-350 epoxy resin corresponding to the hybrid sample bending performance is better than 430LV vinyl resin; the wet bending strength and modulus of hybrid bending specimens are lower than those of dry bending specimens to varying degrees. The flexural strength and modulus of hybrid specimens increase with the increase of carbon fiber volume fraction. And as the volume of carbon fiber in the sample increases, the flexural strength and modulus of the hybrid sample increase to varying degrees. In addition, the results also show that the bending strength and modulus of hybrid bending specimens without post-curing treatment decrease in varying degrees at the same mixing ratio, whether in dry or wet state.

1. Introduction
At present, with the development of new materials, manufacturing technology and structural design level, composite materials are more and more widely used in ship structures. The application range gradually develops from light shell plate and other structures with less stress to masts, superstructures and even main hulls with medium or main load. Among them, the widely used fiber-reinforced composite materials mainly include carbon fiber Reinforced composites and glass fiber reinforced materials. Carbon fiber reinforced composite has relatively higher strength and modulus, and its disadvantages are low elongation and high brittleness, resulting in poor impact resistance of composite structure and high application cost; while glass fiber reinforced composite has relatively low strength, but good ductility and low cost [1-2]. Therefore, for the main load-bearing shell and plate parts with high requirements for the strength, rigidity and impact of the composite structure of the ship, the design scheme of the carbon / glass hybrid composite structure is naturally born. Through the reasonable design of the carbon / glass hybrid composite layer, the comprehensive advantages of mechanical properties and cost can be obtained [3-7].

For the composite structure of warship, because of the complexity of its service environment, such as seawater immersion, salt spray corrosion and other factors acting on the composite structure in different mechanisms [8], the mechanical properties of the composite structure are directly reduced,
among which the wet strength is an important index to characterize the hygroscopic aging characteristics of the composite [9], which is also a key index for the ship designer. Therefore, it is necessary to carry out the test and Research on the wet strength characteristics of hybrid composite materials. Because the bending test is easy to operate and widely used, it is an important index to reflect the comprehensive properties of composite materials [9]. At the same time, in order to facilitate the analysis of the wet strength characteristics, this paper intends to carry out the test and Research on the dry and wet bending characteristics of hybrid composite materials. At the same time, in order to optimize the bending characteristics of C / g hybrid composite shell, the influence of C / g hybrid ratio (0.90, 1.61, 1.76) on the dry and wet bending characteristics was also studied. In addition, for carbon fiber, its wettability with epoxy resin is better, but the cost of epoxy resin is higher, and its water absorption is poor; while glass fiber and vinyl resin have good wettability. Therefore, this paper also carries out the test and Research on the bending characteristics of the hybrid composite in dry state and wet state, and discusses the influence law, and makes optimization.

2. Sample preparation and test methods
Carbon / glass hybrid composite fiber reinforced material is mainly composed of T700 unidirectional cloth (manufacturer: Nanjing Haituo; Name: hitex-c300 unidirectional carbon fiber cloth) and ewr800 multi axial cloth (manufacturer: Changzhou Tianma; Name: ewr800 multi axial glass fiber, referred to as e800). The resin matrix is atatic-430LV vinyl resin (referred to as 430LV, Nanjing Jinling dsman) and QC-350 the physical and mechanical properties of epoxy resin (350 for short, manufacturer: huibai new material), fiber and resin are shown in Table 1.

| type  | Model     | Elongation at break /% | Nominal thickness/mm | Area density / (g/m²) | Water absorbency /% |
|-------|-----------|------------------------|----------------------|-----------------------|---------------------|
| fibre | T700      | 1.34                   | 0.31                 | 310                   | ---                 |
|       | EWR800    | 2.15                   | 0.78                 | 860                   | ---                 |
| resin | 350       | 4.4                    | ---                  | ---                   | 0.12                |
|       | 430LV     | 1.3                    | ---                  | ---                   | 0.08                |

In order to study the influence of carbon / glass hybrid ratio on the dry and wet bending characteristics of shell plates, the bending samples with hybrid ratio of 0.90, 1.61 and 1.76 were designed and manufactured respectively. The hybrid mode was interlaminar hybrid. The structure was similar to sandwich sandwich structure. T700 Carbon fiber cloth was laid at the top and bottom, ewr800 multi axial cloth was laid in the middle, and the thickness of corresponding samples was 12.8mm, 12.0mm and 11.4mm respectively. The hybrid bending sample is prepared by vacuum forming process. The structure of the sample is in accordance with GB /T1449-2005 test method for flexural properties of fiber reinforced plastics, length and width: 250mm * 30MM. The test structure type is shown in Figure 1.

![Figure 1. Structural Form of Bending Specimens](image)

Test scheme: static load three-point bending test at room temperature; test instrument: mts-5t universal testing machine; test speed: 2mm / min; span: 15h, H represents sample thickness; number of effective samples for each group of test is not less than 5; wet test refers to boiling at 100 °C for 2 hours.
3. Test results and analysis

The state of bending specimen before test is as shown in Figure 2, and the loading state of specimen is as shown in Figure 3.

![Figure 2. Pre-test State of Bending Specimens](image1)

![Figure 3. Test Loading State of Bending Specimens](image2)

| Table 2. Test results of inter laminar hybrid bending of 430LV vinyl resin (Post-curing treatment) |
|-----------------------------------------------|
| performance | state | Hybrid ratio (C:G)/ thickness (mm) |
| | | 0.90 | 1.28 | 1.61 | 1.20 | 1.76 | 11.4 |
| bending strength /MPa | Dry state | 402.5 | 467.8 | 489.23 |
| | Wet state | 395.6 | 450.9 | 479.69 |
| Strength retention /% | Dry state | 98.3 | 96.4 | 98.0 |
| | Wet state | 97.3 | 95.0 | 94.0 |
| Flexural modulus /GPa | Dry state | 40.26 | 42.80 | 44.23 |
| | Wet state | 39.53 | 42.0 | 43.57 |
| Modulus retention /% | Dry state | 98.1 | 96.1 | 98.5 |

| Table 3. Test results of interlaminar hybrid bending of QC-350 epoxy resin (Post-curing treatment) |
|-----------------------------------------------|
| performance | state | Hybrid ratio (C:G)/ thickness (mm) |
| | | 0.90 | 1.28 | 1.61 | 1.20 | 1.76 | 11.4 |
| bending strength /MPa | Dry state | 422 | 483 | 506 |
| | Wet state | 401 | 454 | 486 |
| Strength retention /% | Dry state | 98.3 | 95.0 | 94.0 |
| | Wet state | 97.3 | 95.0 | 94.0 |
| Flexural modulus /GPa | Dry state | 41.2 | 43.6 | 45.5 |
| | Wet state | 40.1 | 42.6 | 43.9 |
| Modulus retention /% | Dry state | 98.1 | 97.3 | 97.7 |

3.1. Effect of dry and wet state on bending properties of hybrid specimens

It can be seen from the test results in Table 2 that the bending strength and modulus of the above three kinds of C / g hybrid bending specimens, whether 430LV vinyl resin or QC-350 epoxy resin, decreased...
to a certain extent compared with the dry state test, but the bending strength and modulus still have a high retention rate, among which, taking 430LV vinyl resin hybrid bending specimen as an example, its bending strength retention rate of flexural strength is about 95% and that of flexural modulus is about 97%.

In terms of strength, during boiling process of wet samples, under the action of high temperature, water molecules can be immersed into the matrix at a faster rate, making the resin matrix swell and hydrolyze, resulting in plasticization of resin matrix, reducing the performance of the matrix, and then reducing the wet bending strength [9-10]; in terms of modulus reduction, because the bending modulus is mainly controlled by the fiber performance, whether it is carbon fiber or not it is glass fiber. Under the action of boiling water and heat, they do not absorb water basically, and the fiber performance is basically unchanged, but the performance of resin matrix is reduced, so that the bending modulus of composite materials is reduced, but the decrease is small.

3.2. Influence of hybrid ratio on bending properties of specimens

It can be seen from table 2 that the bending strength and modulus increase in varying degrees with the increase of carbon fiber volume content in the sample, whether in the dry state or in the wet state. The results show that the bending strength and modulus of 430LV resin matrix hybrid dry samples are 16.2% and 21.6% higher than those of 0.9, respectively, and 6.3% and 9.9% higher than those of 1.61 and 1.76, respectively. The modulus has a significant effect, the higher the volume content, the greater the bending strength and modulus; in addition, the bending strength and modulus of the interlaminar hybrid composite are mainly determined by the material properties of the outer layer of the hybrid composite. Because the outer layer of the hybrid sample is carbon fiber dimension, this also increases the contribution of carbon fiber content to the improvement of the bending strength and modulus of the hybrid sample contribution rate.

In addition, the failure modes of bending specimens with different hybrid ratios are basically the same under the same resin matrix. It is mainly manifested in: in the initial damage stage, the indenter contacts with the upper carbon fiber. With the increasing load, the stress concentration in the contact area is relatively serious. The fiber and resin in the contact area of the bending sample and the indenter first appear crushing failure, and the carbon fiber produces brittle fracture; then, with the further increase of the load, the hybrid sample produces brittle sound, because of the glass fiber fracture elongation. The interface layer of CF / BF hybrid fiber composite is affected by two kinds of fibers. The interface layer plays an important role in stress transfer and crack propagation between fiber and matrix. Therefore, when the load increases, the shear stress of resin matrix exceeds the shear strength of bulk. As a result, the bonding interface between carbon fiber and glass fiber appears delamination failure, and the interface crack propagates rapidly to both sides, resulting in the bending failure of hybrid samples. However, for wet samples, on the one hand, due to water absorption, the matrix is plasticized, the performance of the matrix is reduced, and the bonding strength between fibers is further weakened; on the other hand, the resin will expand after moisture absorption, and the obvious difference in this kind of wet expansion will inevitably make the fiber subject to axial tensile stress, the matrix subject to compressive stress, and at the same time, shear occurs at the fiber / matrix interface. Due to the wet stress, the bonding interface between the carbon fiber and the glass fiber decreased and the interlayer cracking occurred.

3.3. The effect of resin type on the bending properties of hybrid specimens

It can be seen from table 2 and figure 5-figure 6 that with the increasing volume content of CFRP, the bending strength and modulus of the hybrid samples corresponding to the two resins are increasing, and under the same hybrid ratio, whether in the dry state or in the wet state, because the performance of QC-350 epoxy resin is better than 430LV vinyl ester resin, the bending strength and modulus of the hybrid samples corresponding to QC-350 epoxy resin matrix are higher than 430LV ethylene Ester resin. For bending strength, the increasing trend of bending strength is basically the same under different mixing ratio of two resin corresponding hybrid samples; but for bending modulus, the increasing trend of bending modulus of two resin corresponding hybrid samples is the same under the same mixing ratio in dry state test, but in wet state test, the increasing trend of bending modulus of 430LV resin corresponding
bending samples is 0.9 ~ 1.61. The growth rate of the bending modulus of 430LV resin is slightly higher than that of QC-350 resin when the mixing ratio is in the range of 1.61-1.76, which shows that the effect of the performance degradation caused by the plasticization of the two resins on the bending modulus is basically the same when the carbon fiber content is slightly lower, but with the increase of the carbon fiber content, the performance degradation caused by the plasticization of the resin on the bending modulus is basically the same. The quantity has a more significant impact, among which the degradation rate of 430LV vinyl resin is slightly lower than QC-350, which makes the modulus of the corresponding bending sample of 430LV vinyl resin slightly higher than QC-350. However, it is proved that the water absorption rate of 430LV vinyl resin is slightly lower than that of QC-350 epoxy resin according to the water absorption rate of the resin in Table 1.

Figure 5. Variation of Bending Strength of Dry and Wet Specimens at Different Hybrid Ratios

Figure 6. Variation of Bending modulus of Dry and Wet Specimens at Different Hybrid Ratios

3.4. Effect of post curing treatment on bending properties

The test data in Table 2 are obtained by conducting bending test after the curing treatment of hybrid bending samples. The so-called post curing treatment refers to putting the cut bending samples into constant temperature oven for baking, with baking time of 24h and baking temperature of 60 °C. In order to study the effect of post curing process on the properties of hybrid bending specimens, 430LV resin matrix was used as molding resin in this experiment. In this test, without post curing treatment, the cut hybrid bending specimen is placed at room temperature (25 °C) for 24 hours.

This test is mainly conducted for two kinds of hybrid bending samples with the hybrid ratio of 1.61 and 1.76 without post curing treatment. The test scheme and instruments and equipment are consistent with the bending test after post curing treatment. The test results are shown in Table 4.
Table 4. Test results of interlaminar hybrid bending of 430LV vinyl resin (uncured)

| Performance          | State   | Hybrid ratio (C:G) | Thickness (mm) |
|----------------------|---------|-------------------|----------------|
|                      |         | 1.61              | 12.0           | 17.6          | 11.4 |
| Bending strength /MPa| Dry state| 220.5             | 319.4          |               |
|                      | Wet state| 312.2             | 442.2          |               |
| Strength retention % |         | 142               | 139            |               |
| Flexural modulus /GPa| Dry state| 35.00             | 37.1           |               |
|                      | Wet state| 40.2              | 39.7           |               |
| Modulus retention %  |         | 112.9             | 107            |               |

Obviously, it can be seen from table 4 that, compared with the hybrid bending test results after post curing treatment, under the same hybrid ratio, the bending strength and bending modulus are reduced to different degrees in both dry and wet test states. When the hybrid ratio was 1.61, the bending strength and modulus decreased by 52.9% and 18.2% respectively. When the hybrid ratio was 1.76, the bending strength and modulus decreased by 34.7% and 16.1% respectively. In the dry state test, the decrease of bending strength is larger, and the decrease of bending strength is more than 30%. This is because the hybrid sample has not been post cured, or the resin matrix formed by the hybrid sample has not been fully cured, which leads to the decrease of the adhesion of the resin at the hybrid sample interface, especially the area where the carbon fiber and glass fiber interface are bonded. In addition, the resin has not been post cured After curing treatment, the shear strength of the resin itself was reduced, which could not meet the requirements of the coordinated deformation between the fiber fabrics in the test process, resulting in the failure state of the hybrid bending sample: under the action of small load, the interlaminar damage of the sample occurred in advance, and the damage crack extended rapidly to both ends, and the initial area mainly occurred at the joint of carbon fiber and glass fiber, such as Figure 7. As for the bending modulus, it also has a certain impact on the bending modulus of hybrid samples due to the performance degradation of molding resin without post curing treatment, but the bending modulus mainly depends on the fiber fabric, so the impact of bending modulus on the bending strength is relatively small.

![Figure 7. Failure state of bending specimen (uncured)](image)

It can also be seen from table 3 that when the hybrid ratio is 1.61, the wet bending strength and modulus decrease by 30.8% and 4.3% respectively, and when the hybrid ratio is 1.76, the wet bending strength and modulus decrease by 7.8% and 8.9% respectively. That is to say, the bending strength and modulus of the wet bending specimen are not decreased but increased compared with the dry bending specimen without post curing treatment. When the hybrid ratio is 1.61, the wet bending strength and modulus are increased by 42% and 12.9%, respectively. When the hybrid ratio is 1.76, the wet bending strength and modulus are decreased by 39% and 7.0%, respectively. This is because the molding resin is equivalent to the post curing treatment in the process of high temperature boiling at 100 °C, which greatly improves the performance of the resin. Although the high temperature boiling will also cause the performance of the plasticized resin to decrease, in general, the effect of the post curing treatment on the bending performance of the hybrid sample is greater than that of the water absorption plasticization, which also leads to the mixing under the two mixing ratios Compared with the dry
bending strength and modulus, the wet bending strength and modulus of the hybrid specimens are improved to some extent.

4. Conclusion

Through the above research work, the following conclusions are drawn.

(1) Compared with the dry state test, the bending strength and modulus of the cured C / g hybrid bending specimens, whether 430LV vinyl resin or QC-350 epoxy resin, decreased to some extent, but the bending strength and modulus still had high retention.

(2) For the C / g hybrid bending specimen after post curing treatment, whether 430LV vinyl resin or QC-350 epoxy resin is used as molding resin, the C / g hybrid ratio is in a certain range, with the increase of carbon fiber volume content, the bending strength and modulus are increased in varying degrees, and the final failure mode of the hybrid specimen is basically the same.

(3) The bending strength and modulus of QC-350 epoxy resin are higher than 430LV vinyl ester resin at the same hybrid ratio, whether in dry or wet state.

(4) Compared with the results of post curing hybrid bending test, the bending strength and bending modulus of the hybrid bending specimens without post curing are reduced to different degrees in the same hybrid ratio, whether in the dry state or in the wet state. However, compared with the dry bending specimen, the bending strength and bending modulus of the wet bending specimen will not be reduced, but will be improved, because the resin is equivalent to post curing treatment in the process of boiling at 100°C.

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