

# Study on the Mechanical Properties of Composite Materials for Polar Lifeboats

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**Abstract:** Although the fiber / glass fiber interlaminar hybrid laminated composite can meet the heating requirements of the polar lifeboat cabin door and the air in the ice prone area, it can not ensure the strength of the lifeboat to meet the requirements when it is applied to the lifeboat shell and hatch area. Therefore, this paper carries out the relevant mechanical tests on the carbon fiber composite specimen, compares the strength of the FRP material with that of the traditional lifeboat, and carries out the strength analysis of the polar lifeboat with carbon fiber material in the hoisting state by using ABAQUS finite element software. The results show that the strength of the polar lifeboat with this kind of composite material meets the requirements.

**Keywords:** Polar lifeboat, Carbon fiber composite, Mechanical properties.

## 1. Introduction

Lifeboat is a special equipment for rescuing drowning people or evacuating crew when the ship is in distress. Polar cold climate may lead to the weakening of the stability of lifeboats, freezing of pipelines, failure of navigation equipment and threats to the lives of passengers. As a kind of high-performance reinforcing material, carbon fiber has many excellent properties, such as low density, low resistance, high strength and high modulus, high temperature resistance, conductivity and heat conduction[1-2]. The composite material made of the composite and resin has the advantages of light weight, high strength and strong designability. The main structural material of lifeboat is glass fiber reinforced unsaturated polyester resin composite material[3]. Therefore, it is of great practical significance to study a kind of reinforcement material which can be used as lifeboat body to ensure the normal life-saving ability of polar lifeboat in polar cold climate.

According to the recommendations of lifeboat manufacturers and relevant literature, and the material parameters required for simulation analysis can be obtained through test, the tensile test of carbon fiber / glass fiber interlaminar hybrid laminated composite is carried out. Three kinds of specimens are made according to the type I specimen of GB / t1447-2005. The tensile properties of the samples are tested, and the stress-strain curve of the material is obtained by processing the data. The strength of the three samples and

FRP materials was compared, and whether the three materials met the strength requirements of lifeboat was analyzed[4]. In addition, during the whole process of lowering the suspended lifeboat equipped with polar ships from the boat frame to the water, the most dangerous state of the lifeboat is in the suspended state, especially when the lifeboat is fully loaded, it is subject to the upward pulling force of three hooks in the bow and tail of the hull due to its own gravity. The stress concentration and large stress will occur in the boat near the hook. In order to analyze the strength of the lifeboat in the suspended state, ABAQUS software is used to simulate and calculate the strength of the lifeboat with and without carbon fiber, and make a comparative analysis. Finally, the economy of the polar lifeboat with carbon fiber is analyzed.

## 2. Strength Test of Composite Sample

### 2.1. Test principle

For tensile test, the specimens need to be tested according to the test method of fiber reinforced composites, and the tensile load is applied at the same speed along the axial direction of the specimen until the specimen is broken. In the process of the test, it is necessary to measure and record the tensile load and the elongation length of the specimen before calculating the tensile stress, tensile strain, tensile modulus and drawing the stress-strain curve. The specimen is made according to the type I specimen of GB / t1447-2005. The specific type is shown in Figure 1, and the specific size is shown in Table 1.

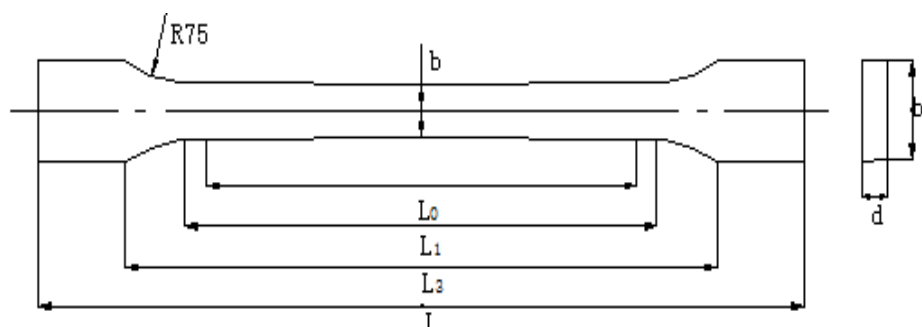


Figure 1. Type I test piece type

**Table 1.** Type I specimen size standard

Symbol /mm	Name	Type I
L	Total length (minimum)	180
L <sub>0</sub>	Gauge	50±0.5
L <sub>1</sub>	Intermediate parallel length	55±0.5
L <sub>3</sub>	Distance between fixtures	115±5
b	End reinforcement length (minimum)	10±0.2
b <sub>1</sub>	Tip width	20±0.5
d	Thickness	2~10

The tensile strength, tensile strain, and tensile modulus formulas required for the data processing of the tensile test are as follows:

$$\sigma = \frac{F}{b \cdot d} \quad (1)$$

where:

$\sigma$ —Tensile stress (tensile strength), unit: MPa;

F—Elastic load, unit: N;

b—Sample width, unit: mm;

d—Sample thickness, unit: mm.

$$\varepsilon = \frac{\Delta L}{L_0} \quad (2)$$

where:  $\Delta L$ —The deformation increment of the gauge length  $L_0$  corresponding to the elastic load increment  $\Delta F$ , unit:

mm.

$$E = \frac{L_0 \cdot \Delta F}{b \cdot d \cdot \Delta L} \quad (3)$$

Where:

E—Elastic Modulus, unit: MPa;

$\Delta F$ —Elastic load increment, unit: N.

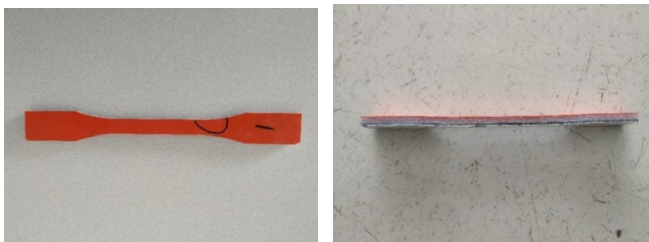
## 2.2. Test

Three kinds of test pieces A1, B1 and C1 were prepared according to the standard I type. The test piece was mounted on a mechanical testing machine, and the tensile force was applied by applying a load at a loading speed of 2 mm/min. And the elongation length of the test piece. The obtained test pieces are shown in Fig. 2, the specific dimensions are shown in Table 2, and the test pieces are placed as shown in Fig. 3.

**Table 2.** Three test piece sizes

Specimen type	SpecimenA1	SpecimenB1	SpecimenC1
Specimen structure	CJ+Z+G+Z+G+G+C+Z+BJ	CJ+Z+G+Z+G+C+G+C+Z+BJ	CJ+Z+G+Z+C+G+C+G+C+Z+BJ
L/mm		180	
L <sub>0</sub> /mm		50	
L <sub>1</sub> /mm		55	
L <sub>3</sub> /mm		115	
b/mm	10.12	10.16	10.16
b <sub>1</sub> /mm		20	
d/mm	6.36	6.47	6.97

Where: CJ is a white gel coat, Z is a glass fiber mat 300 g/m<sup>2</sup>, G is a glass fiber 600 g/m<sup>2</sup>, C is a 3 k carbon fiber 200 g/m<sup>2</sup>, and BJ is a white gel coat.

**Figure 2.** Test piece production**Figure 3.** Tensile properties test

## 2.3. Result analysis

The tensile properties of the samples were compared with those of standard FRP materials. The performance parameters are shown in Table 3.

**Table 3.** Tensile properties of composites

Specimen type	Carbon fiber layer	Maximum load F/KN	Tensile Strength $\sigma_t$ /MPa	Tensile modulus $E_t$ /GPa
Specimen A1	One layer	8.849	137.480	10.653
Specimen B1	Two layers	10.855	165.140	12.853
Specimen C1	Three layers	12.862	181.627	12.656

According to the current manufacturer's specifications, the tensile strength of FRP material should not be lower than 135MPa, and the tensile modulus should not be lower than 10GPa. It can be seen from the table that the tensile strength and tensile modulus of the three laminated composites prepared in this paper satisfy the material requirements, which lays a foundation for its practical application on large lifeboats; The increase of the maximum tensile load of the

composite material and the tensile strength are also increasing. The main reason is that the tensile strength of the carbon fiber is stronger than that of the glass fiber. During the stretching process, the carbon fiber acts to strengthen the FRP composite[5].

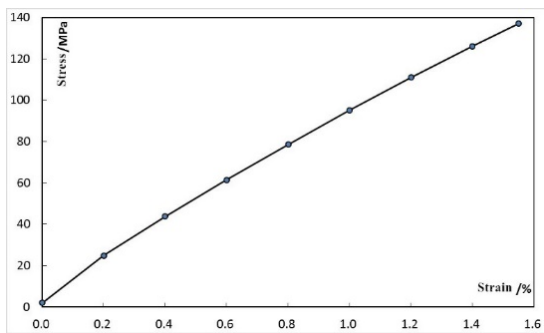


Figure 4. Test piece A1 stress-strain curve

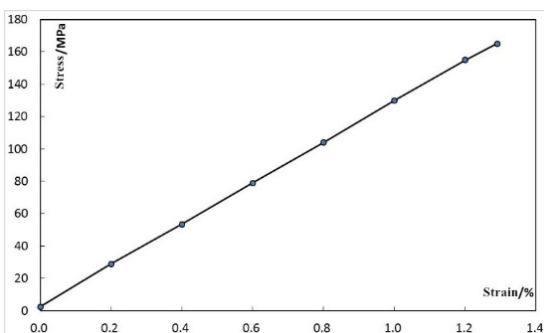


Figure 5. Test piece B1 stress-strain curve

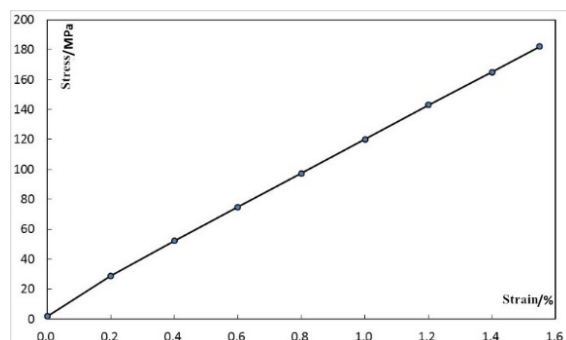


Figure 6. Test piece C1 stress-strain curve

Fig. 4, 5 and 6 are stress and strain curves of carbon fiber/glass fiber interlaminar hybrid laminated composites under tensile load. It can be seen from the figure that the three structural composites have similar deformation relationship. At the beginning of tension, the stress of the three composites increases linearly with the increase of deformation. When the composites are finally broken, the stress suddenly decreases to 0.



Figure 7. Fracture morphology of composite materials

Fig 7 is a fracture profile of the composite after tensile failure. In the composite of three structures, the carbon fiber breaks at the fracture, but the glass fiber breaks unevenly, first debonding, and then broken, indicating that the carbon fiber/glass fiber interlaminar hybrid composite is stretched, carbon fiber pull The modulus of elongation is large, the strain at break is small, and the tensile force is increased, so that the carbon fiber layer is first broken. At this time, the glass fiber layer is subjected to all tensile forces and finally pulled off.

### 3. Strength Analysis of Polar Lifeboat in Lifting State

The finite element software ABAQUS is used to analyze the stress and strain of the suspended lifeboat in the process of lowering at a constant speed. The stress and strain changes before and after the deployment of carbon fiber materials are compared, which provides the basis for the safe application of carbon fiber / glass fiber interlaminar hybrid composite.

#### 3.1. Establishment of finite element model

Due to the complexity of the internal structure of the lifeboat, in order to facilitate the modeling, the 7.5m lifeboat is simplified as follows: under full load, the weight of each part of the lifeboat is evenly distributed on the inner deck, and the total weight of the lifeboat is about 9.9t. The three-dimensional deformable shell model of lifeboat without and without carbon fiber composite material is established [6]. The density of glass fiber composite is 1700kg / m<sup>3</sup>, the elastic modulus is 10GPa, Poisson's ratio is 0.3, the density of carbon fiber / glass fiber composite is 1515 kg / m<sup>3</sup>, the elastic modulus is 10.653 GPA, Poisson's ratio is 0.3; the full load lifeboat only bears its own gravity during the lifting process, and the defined gravity load is 9.8 The results show that the boundary conditions at the three hook positions are fully constrained, as shown in Figure 5.8; the mesh size of lifeboat without and without carbon fiber is 0.1, and the four node curved thin shell or thick shell element is adopted, in which the total number of nodes of lifeboat without carbon fiber is 11193, and the total number of elements is 11493; the total number of nodes of lifeboat with carbon fiber is 11133 and the total number of elements is 11393.

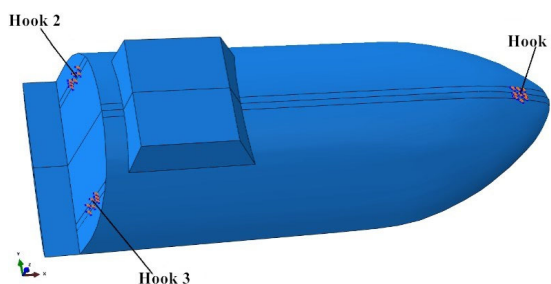


Figure 8. Boundary conditions

#### 3.2. Result analysis

It can be seen from Figure 9 that the stress of lifeboat without CFRP is mainly concentrated around the hook, and the stress in other areas is very small. Among them, it can be seen from figure a that the maximum stress at unit 97 near the bow hook of the lifeboat is 60.96mpa, and the direction is along the normal direction; from figure B, the maximum stress at Unit No. 7849 near the tail hook is 14.22mpa, and the direction is outward along the normal direction.

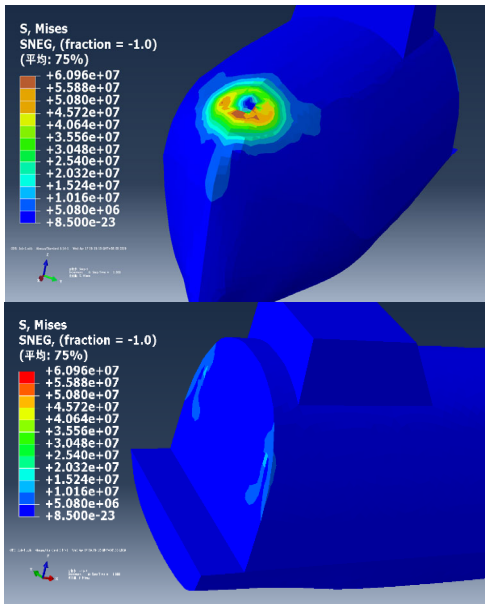


Figure 9. Lifeboat stress cloud diagram without carbon fiber composite

The red grid area in Figure 10 is the layout area of carbon fiber composites. It can be seen that the distribution of carbon fiber stress is consistent with that of carbon fiber composite material. It can be seen from figure C that the maximum stress at unit 1645 near the bow hook of the lifeboat is 76.97mpa, and the direction is along the normal direction; from figure D, the maximum stress at unit 10555 near the tail hook is 15.08mpa, and the direction is outward along the normal direction.

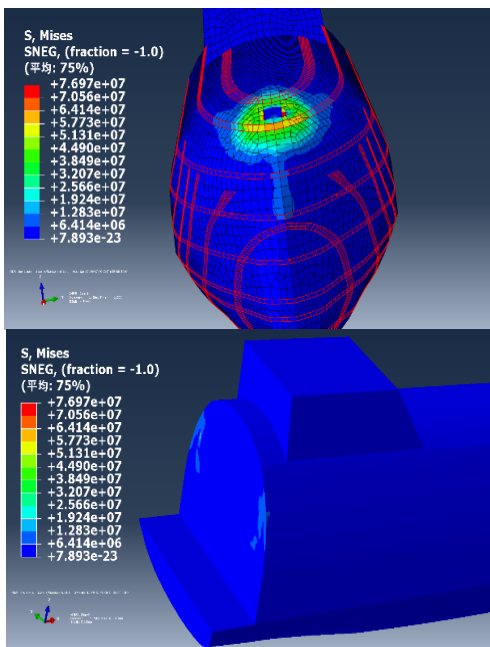


Figure 10. Lifeboat stress cloud with carbon fiber composite

By comparing and analyzing the stress distribution of lifeboat before and after CFRP placement, it can be found that the stress distribution of lifeboat has changed after CFRP placement, the maximum stress of lifeboat hull increases, and the maximum stress change at bow position is 16.01mpa. The main reason is that the difference between the material properties of carbon fiber composites and that of glass fiber

composites leads to the stress concentration, but the maximum stress is less than the tensile strength of glass fiber composites and carbon fiber composites. Therefore, although the stress of the lifeboat increases after the carbon fiber composite is arranged, it still meets the tensile strength requirements of the hull material [7].

It can be seen from Figure 11 that the deformation of lifeboat without CFRP is mainly concentrated near the hook, and the deformation in other areas is very small. Among them, it can be seen from figure e that the maximum strain at unit 351 near the bow hook of the lifeboat is 0.0061; from figure F, the maximum strain at unit 10555 near the hook at the tail is 0.0014.

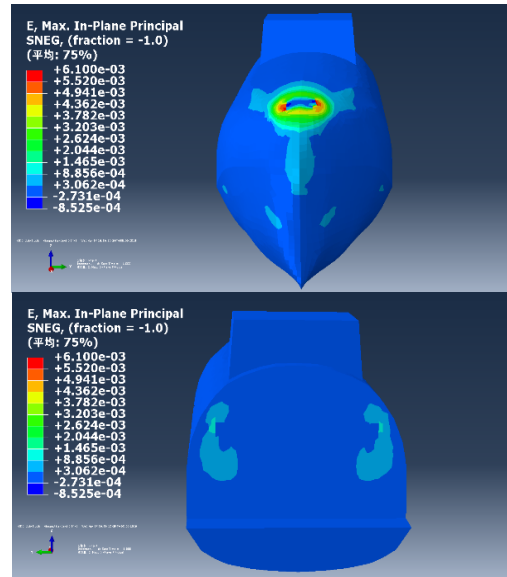


Figure 11. Lifeboat strain cloud diagram without carbon fiber composite

It can be seen from Figure 12 that the deformation distribution of the lifeboat with CFRP is basically the same as that of the lifeboat without CFRP. It can be seen from figure g that the maximum strain at Unit No. 351 near the bow hook of the lifeboat is 0.0057; from figure h, the maximum strain at unit 10555 near the hook at the tail is 0.0015.

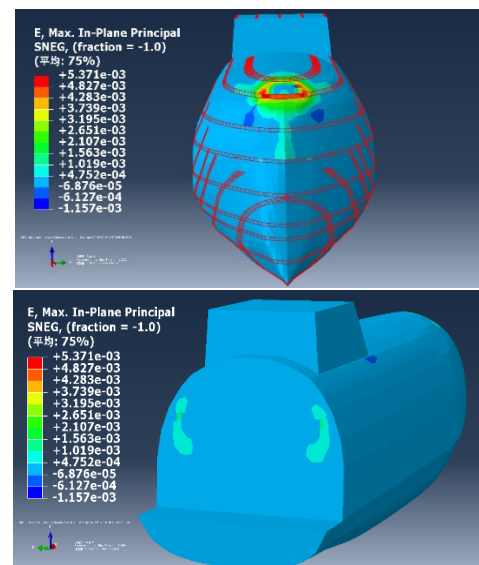


Figure 12. Lifeboat strain cloud map with carbon fiber composite material  
By comparing and analyzing the deformation of the

lifeboat before and after the placement of carbon fiber composites, it can be found that the maximum deformation of the lifeboat hull decreases after the placement of carbon fiber composite materials, and the maximum strain change at the bow position is 0.0004. The main reason is that the carbon fiber is added into the lifeboat, which makes the structural strength of the lifeboat larger, improves the resistance to deformation of the lifeboat, and thus reduces the deformation of the lifeboat. Therefore, the strength of the lifeboat still meets the design requirements and can be used safely.

#### 4. Economic Analysis

The traditional polar lifeboat interior space heating and cabin door heating, using the heat tracing belt. In this paper, the specimen a with the largest thermal efficiency, that is, the carbon fiber cloth / glass fiber cloth interlaminar hybrid gluing composite structure with only one layer of 3K carbon fiber cloth is applied to the freezing area of the hull and cabin door of polar lifeboat, which has better economy than the traditional heat tracing belt [8].

There are 147 pieces of carbon fiber cloth laid on the lifeboat, which needs about 6 square meters of carbon fiber cloth, and the mixing ratio of carbon fiber cloth and resin is 1:1, so the price of carbon fiber cloth composite material only accounts for about 15% of the price of heat tracing belt; Secondly, the special installation structure should be designed for the heat tracing belt in the lifeboat and cabin door area, while the carbon fiber cloth can be directly laid in the specified area when the hull is manufactured; Carbon fiber as a heating body has high electric conversion rate, higher thermal efficiency than the heat tracing belt, and the scattered heat sources are conducive to the uniform temperature distribution in the boat, and there is no need to arrange auxiliary blast equipment. In conclusion, laying carbon fiber cloth on the lifeboat for heating the space and cabin door of the lifeboat not only reduces the process, but also saves the material, power and labor costs.

#### 5. Conclusion

In the tensile process, the carbon fiber plays a role in

strengthening the glass fiber reinforced plastic composite. When the number of carbon fiber layers increases, the tensile strength of the composite material increases continuously. The tensile strength and tensile modulus of the sample are greater than those of the lifeboat glass fiber composite material. Finally, the carbon fiber layer is broken first, then the glass fiber layer is subjected to all the tensile forces, and finally is broken. When the carbon fiber composite material is arranged on the lifeboat, the stress on the hull increases, but it still meets the tensile strength requirements of the hull material, and the deformation caused by the force is also reduced. Therefore, the strength of the lifeboat still meets the design requirements.

#### References

- [1] China Classification Society. Guidelines for polar ships. 2016.
- [2] Chung D D L. Comparison of submicron-diameter carbon filaments and conventional carbon fibers as fillers in composite materials[J]. Carbon, 2001, (39): 1119-1125.
- [3] Li Shuangna. Study on formulation and properties of glass fiber / unsaturated polyester resin composites [J]. Harbin Institute of technology, 2012:4-5.
- [4] Duan Guochen, Zhao Jingli, Zhao Weichao. Mechanical properties of E51 epoxy resin based carbon fiber composites [J]. Research Report and monograph, 2018, 31 (2): 42-43.
- [5] Kasen M B. Cryogenic properties of filamentary—reinforced composites: an update[J].Cryogenics, 1981,21(6):323-340.
- [6] Kasen M B. Mechanical performance of graphite-and aramid-reinforced composites at cryogenic temperatures[J]. Adv Cryog Eng Mater, 1982,28: 165-177.
- [7] Yang Jianzhong, Xiong Guangjing, et al. Experimental study on flexural behavior of concrete beams strengthened with high strength glass fiber / carbon fiber hybrid composites [J]. Acta civil engineering, 2004, 37 (7): 18-34.
- [8] Wang zuihan. Study on properties of glass fiber cloth and carbon fiber cloth reinforced phenolic epoxy resin composites [J]. Wuhan University of engineering, 2015: 47-62.