Experimental Study on Mechanical Properties of Fiber Composite Material Adhesion to Metal

Qinghua Li*, Yuxin Jiao, Yan Zhang, Ranran Tian and Yu Zeng

College of Machinery and Vehicle Engineering, Changchun University, Changchun 130022, China
Email: *liqh@ccu.edu.cn; ^jiaoyx1025@163.com; 839770593@qq.com; 
@naidoudou@126.com; 1090279757@qq.com

Abstract. The fiber composites were impregnated at different times and bonded to metal materials; the mechanical properties of the bonded composites were measured. In this article, two kinds of materials, the carbon fiber fabric and the Kevlar fiber fabric, were compounded with epoxy resin E51 to form the fiber fabric composite material. The composite material was bonded to the surface of 45 steel by modified epoxy resin adhesive. The bond strength of composites were measured by the tensile method of determination of the bond strength between vulcanized rubber and metal, the shear strength of composites were measured by Four-plate shear method of determination of the bond strength of vulcanized rubber and rigid metal sheets by the international standard ISO 1747-1976, to obtain the maximum bond strength and shear strength of the composite material, and the corresponding optimum immersion time of the carbon fiber fabric.

Keywords. Fiber composites, adhesive strength, shear strength, steel.

1. Introduction

The carbon fiber is a new kind of high modulus and high strength fiber material with more than 95% carbon content [1]. Carbon fibers can be classified into T300, T700 and T800 according to their performance grades. The higher the grade, the higher the strength [2]. According to the specifications of carbon fibers, they can be divided into 1K, 3K, 12K, etc. 1K represents that one bunch of carbon fibers contains 1000 filaments. The larger the K value, the heavier the gram number, the lower the price, and the higher the strength [3]. At present, carbon fibers have been widely used in aerospace, national defense, vehicles and other fields [4]. Kevlar fabric, a new type of fiber material, has the advantages of low density, high strength, good toughness and high temperature resistance. Its composite armor with steel and aluminium has been widely used in tanks, body armor, aircraft carriers, etc. [5].

Duan Guochen, Zhao Jingli et al. studied the tensile properties and shear properties of composites with C-1107 and A1002 carbon fibers and FRP. It was pointed out that the tensile strength of C-1107 carbon fiber is better, and the shear strength of A1002 carbon fiber is slightly higher [6]; Chen Weihong studied the use of inorganic glue to bond carbon fiber fabric to reinforce the positive section of the concrete beam that is undergoing the maximum load prestress. The flexural performance test of 8 concrete beams with ultimate load prestress and 6 prestressed concrete continuous beams subjected to ultimate load were reinforced with a layer of carbon fiber fabric bonded with inorganic glue. According to the test results, he proposed a calculation method of the bending bearing capacity considering the influence of the ultimate load on the concrete beam, and established the stiffness...
calculation formula [7]; Wang et al. analyzed the carbon fiber reinforced concrete beams to find out the mechanical properties of the carbon fiber and the distribution of shear stress in the structural adhesive. According to the test results, the distribution of the bond shear stress of the carbon fiber reinforced beam is basically the same as that calculated by the completely combined section in most of the sections; However, in the section near the end of the carbon fiber, the bond shear stress suddenly increases and reaches the maximum at the end [8]; Li et al. have studied the technology of Kevlar fiber Composite Pipeline Strong Repair, summarized and analyzed the technology, pointed out that the technology has the advantages of simple use, can permanently repair the corrosion defects, cracks and mechanical damage inside and outside the pipeline, and can complete the pipeline maintenance without affecting the normal transportation of the pipeline [9]; Chen, Gao et al. glass fiber, carbon fiber or Kevlar fiber are respectively combined with epoxy resin. Using this composite material to study a magnetic resonance superconducting magnet tie rod, through the test: it is found that the tensile strength of the tie rod is greater than or equal to 500 MPa in the range of 4-50K from low temperature to room temperature and 50-300K, and the heat leakage is minimum, which improves the stability of the magnetic resonance imaging system, meets the important requirements for hanging cryogenic vessels or cold shields in the magnetic resonance imaging system, and prolongs the service life [10]. This article focuses on the T300’s 1K 120G carbon fiber cloth, 3K 240G carbon fiber cloth and Kevlar fiber cloth. The modified epoxy resin is bonded with 45 steel to study the adhesive strength and shear strength after bonding.

2. Test Materials and Preparation
The materials and instruments used in this experiment are shown in Table 1.

| Name                      | Manufacturer                                                      |
|----------------------------|-------------------------------------------------------------------|
| 1K 120G, 3K 240G Carbon Fiber Fabric | Akrilik Kimya Sanayii Co.                                          |
| Kevlar Fabric              | Japanese Teijin Luchen New Material Technology Co., Ltd.          |
| Epoxy Resin E51            | Hangzhou Wuhuigang Adhesive Co., Ltd.                             |
| Phenolic Resin             | Henan Hengyuan New Material Co., Ltd.                             |
| Toughening Agent           | Dongguan Xinsheng Plastics Firm                                   |
| Curing Agent               | Sinopharm Chemical Reagent Co., Ltd.                              |
| Bake Oven                  | China Wujiang Asia Pacific Oven Manufacturing Factory             |
| Performance Test Stretcher machine | Jiangsu Mingzhu Instrument Co., Ltd.                              |

According to the selected materials, the following treatments are made:
Fiber Fabric dipping: Cut 1K 120G, 3K 240G carbon fiber fabric and kevlar fabric into required length, heat and mix E51 epoxy resin and diluent in proportion of 10:1 until colloidal melts [11], and evenly spread the finished epoxy resin on different kinds of fibre fabric. The impregnation time is 1 to 7 hours, and the impregnated fibers were subsequently dried at a drying temperature of 230°.
Configuration of modified epoxy resin adhesives: epoxy resin E51, phenolic resin, toughening agent and curing agent are allocated according to the ratio of 100:40:15:4 [12].
Remove impurities from the surface of the test piece: Use acetone reagent to remove impurities on the surface of the test piece to facilitate uniform coverage of the adhesive.
Adhesiving: The impregnated fiber cloth is pasted on the surface of the uniformly coated test piece, and the film is formed into a film at a normal temperature, and then dried, and the drying temperature is 180° [13].

3. Test and Result Analysis
In order to measure the mechanical properties of fiber reinforced composites after bonding with metals
and find the optimum impregnation time corresponding to the maximum value of bonding strength and shear strength of the bonded composites. In this article, the determination of the bond strength between vulcanized rubber and metal [14] and the international standard ISO1747-1976 vulcanized rubber and rigid metal plate bonding shear strength - four-plate shear method to test [15].

The adhesive strength of three kinds of composite fibers was tested by the tensile method of measuring the bond strength between vulcanized rubber and metal.

The processed test pieces were fixed in batches on the performance test stretching machine. As shown in figure 1, the performance tensile test was carried out to obtain the performance test data of each specimen. The experimental results show that the specimens have good tensile properties in 5 hours of impregnation. 1K 120G carbon fiber fabric produces the maximum load, 47.39×10^{-3} MN; 3K 240G carbon fiber fabric produces the maximum load, 47.79×10^{-3} MN; Kevlar fabric produces the maximum load, 45.06×10^{-3} MN as shown in figure 2.

![Figure 1](image1.png)

**Figure 1.** Fixed the test piece on the performance test machine.

![Figure 2](image2.png)

**Figure 2.** The scatter plot of the tensile load of the composites varying with impregnation time.

The adhesive strength of each specimen was calculated by equation (1) of the tensile method for the determination of the bonding strength between vulcanized rubber and metal, as shown in figure 3.

\[
\sigma = \frac{P}{S}
\]  

(1)

In the formula: \(\sigma\)—Adhesive Strength of Composite Material to Metal (MPa); \(P\)—Maximum Failure Load of Sample (MN); \(S\)—Adhesion area of specimen [14] (m²).

Analysis of experimental calculation data (figure 3) shows that the Adhesive strength of composites does not increase with the increase of soaking time. At the time of the immersion time of 5 hours, the maximum adhesive strength of 1K 120G carbon fiber fabric is 257.72MPa; the maximum adhesive strength of 3K 240G carbon fiber fabric is 259.87MPa; kevlar fabric produces maximum
adhesive strength of 245.02 MPa.

![Image of line diagram](image1.png)

**Figure 3.** The line diagram of adhesive strength of composites as a function of immersion time.

Testing shear strength of three kinds of composite fibers by four-plate shear method.

Fixed the processed specimens in batches on the performance test machine. As shown in figure 4, the performance tensile test was carried out to obtain the performance test data of the specimens. The experimental results show that (as shown in figure 5): 1K 120G carbon fiber fabric has good tensile performance in 5 hours of impregnation time, and the maximum load is $37.34 \times 10^{-3}$ MN; 3K 240G carbon fiber fabric has good tensile properties in 4 hours of impregnation, and the maximum load is $35.26 \times 10^{-3}$ MN. Kevlar fabric has good tensile properties in 4 hours of impregnation, and the maximum load is $32.66 \times 10^{-3}$ MN.

![Image of tensile test machine](image2.png)

**Figure 4.** Fixed the specimen on the transmission belt tensile test machine.

![Image of scatter plot](image3.png)

**Figure 5.** The scatter plot of the tensile load of the composites varying with impregnation time.
Through the calculation formula of the four-plate method (2), the shear force of each specimen is calculated as shown in figure 5.

\[
\sigma_{sh} = \frac{P}{S}
\]

(2)

In the formula: \(\sigma_{sh}\) — Shear Strength of Composites and Metals (MPa); \(P\) — Maximum Failure Load of Sample (MN); \(S\) — Adhesion area of specimen [15] (m²).

Analyze experimental calculation data (figure 6) shows that the shear force of composites varies in a fluctuating manner. The maximum shear strength of the 1K 120G carbon fiber fabric at the time of the immersion time of 5 hours was 58.13 MPa; the 3K 240G carbon fiber fabric is impregnated. The maximum shear strength was 50.89 MPa at the time of 4 hours; the Kevlar fabric produced a maximum shear strength of 50.84 MPa at the time of the immersion time of 4 hours.

![Figure 6. The line diagram of shear strength of composites as a function of immersion time.](image)

4. Conclusion

Through the above two experimental methods, it is concluded that in the case of immersion time is 1 to 7 hours, the 1K 120G carbon fiber fabric produces the maximum adhesive strength at the time of immersion time of 5 hours, which is 257.72 MPa, and the maximum shear strength is 58.13 MPa; the maximum adhesive strength of 3K 240G carbon fiber fabric is 259.87 MPa, at the time of immersion for 5 hours, and the maximum shear strength is 50.89 MPa; at the time of impregnation for 4 hours; Kevlar fabric produces maximum adhesive strength at the time of immersion for 245.02 MPa hours, maximum shear strength at the time of immersion for 4 hours, and maximum shear strength at the time of immersion for 50.84 MPa. The maximum adhesive strength and shear strength of the composite material obtained from the experiment at the optimum impregnation time will lay a foundation for the author to continue to study the wear resistance of the fiber composite synchronous ring.

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