The influence of pressure and thinner on the bonding properties of adhesives to metal and composite materials

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Abstract. In order to judge the influence of pressure and thinner on the bonding shear strength of composite material and metal, the experiment uses different proportions of thinner epoxy resin to impregnate 3K 240G carbon fiber cloth; Kevlar fiber is subjected to different curing pressures the 45 steel specimens bonded with cloth composite materials were cured at high temperature. Through the international standard ISO1747-1976 determination of the adhesive shear strength of vulcanized rubber and rigid metal plate-four-plate shear method, the shear strength of specimens under different proportions of thinner and different curing pressures is measured. The results show that the fiber cloth composite material with the same immersion time will not increase the shear strength of the specimen when a certain pressure is applied during the bonding and curing process with the metal. At the same time, the thinner in the adhesive of the immersion fiber cloth is 10% When, better shear strength can be obtained.

1. Introduction

With the development of science and technology, carbon fiber composite materials are more and more widely used in automobiles, aerospace and other industries [1]. However, when the carbon fiber cloth is untreated, the edges are too rough, which is not conducive to bonding and affects the bonding strength of the specimen, so it should be impregnated with an adhesive to improve the toughness of the carbon fiber cloth. However, due to the high viscosity of the epoxy resin used for impregnating carbon fiber cloth and poor permeability when impregnating carbon fiber cloth, a thinner can be added to its formulation to reduce the viscosity of epoxy resin and improve its fluidity and permeability [2]. Differences in the working temperature of the adhesive, the pressure during curing, and the curing time will cause the specimen to have different mechanical properties. Among them, the curing pressure during bonding is an important parameter of the mechanical properties of the specimen.

Domestic research scholar Yang Tao, a master of the Central Academy of Mechanical Sciences, was studying polyurethane-modified epoxy resin adhesives and pointed out that the addition of fillers such as thinners is to improve the mechanical properties of the cured adhesive, so there are limit values[3]; Sun Dongzhou and Sun Yu of the High Technology Research Institute, when studying the synthesis process of modified bisphenol S epoxy resin adhesive, found that after the addition of thinner exceeds 20%, small molecular compounds participate in the curing of The product reduces the strength of the adhesive. It is determined that the addition range of active thinner is 15%-20%[4]; Gan Chun from Hubei University conducted research on the preparation and performance of high-temperature UV-curable acrylic adhesives and found that if the amount of active thinner is too large, the curing shrinkage will increase, and if the amount is too small, the prepolymer will not be fully diluted. Will reduce the high temperature resistance and strength of the curing system [5]; Liu Zhen,
Luo Yong of Dianbang Technology measured the bonding strength of casein glue under different pressures, and the results showed that with the continuous increase of applied pressure, the adhesion strength gradually decreases \(^6\); When researching the process and bonding performance of the medium-temperature curing phenolic adhesive, Bai Tian and Xue Gang of the Heilongjiang Academy of Sciences concluded that the use of a pressure fixture on the test piece can slightly increase the shear strength as the curing pressure increases. When other conditions are suitable, the curing pressure should not be lower than 0.3Mpa, and the bonding test piece can obtain better bonding performance \(^7\); Wang Yunjia of Yanshan University was studying the bonding process of self-lubricating joint bearing pads, the adhesive used is Tie Ao Brand 204 glue, which requires a curing pressure of 0.1 ~ 0.2Mpa, the curing plan is loaded with a cone surface, and the feed of the cone axis is used to determine the pressure during the curing process of the adhesive, the results show that applying proper pressure can make the adhesive produce better plastic flow, thereby improving the bonding effect, but the pressure applied should not be too large, so as not to squeeze and overflow the adhesive and affect the bonding strength \(^8\). Combined with the research of other scholars, the paper dipped 3K 240G carbon fiber cloth into epoxy resin adhesive with different proportions of thinner, and then bonded it to the 45 steel specimen to study the mechanical properties of the specimen; Under the same thinner condition, the bonding performance of Kevlar cloth and 45 steel under different curing pressures.

### 2. Test materials and preparation

The materials and equipment used in this test are shown in Table 1.

| Name                        | Manufacturer                               |
|-----------------------------|--------------------------------------------|
| 3K 240G carbon fiber cloth  | Turkey Aksa Company                         |
| Kevlar cloth                | Teijin Luchen New Material Technology Co., Ltd. |
| Epoxy resin E51             | Hangzhou Wuhuigang Adhesive Co., Ltd.       |
| JH-5748 active thinner      | Hangzhou Wuhuigang Adhesive Co., Ltd.       |
| Oven                        | China Wujiang Asia-Pacific Oven Factory     |
| Performance test tensile machine | Jiangsu Mingzhu Instrument Co., Ltd.    |

Pretreatment and steps of test materials:

1. Pre-impregnation of fiber cloth: 3K 240G carbon fiber cloth and Kevlar fiber cloth are impregnated, and epoxy resin with a thinner ratio of 5%, 10%, and 15% is used for impregnation. The impregnation time is 2 to 4 hour. After the immersion is completed, put it in the oven for high-temperature drying at 230°C;

2. Configure modified epoxy resin adhesive: Configure epoxy resin E51, phenolic resin, toughening agent, and curing agent according to the ratio of 100:40:15:4 \(^9\);

3. Pretreatment of the surface of the test piece: Wipe the surface of the newly processed test piece with acetone reagent to remove surface oil, dust, etc., to improve its mechanical properties during bonding;

4. Adhesive curing: Evenly spread the modified epoxy resin on the surface of the test piece, and then bond it with 3K 240G carbon fiber material. On this basis, the specimen was cured at a high temperature, the curing temperature was 150°C, and the curing time was 2 hours;

5. Curing pressure pretreatment: The best ratio of thinner is obtained from the above test. Based on the results of this experiment, a curing pressure test is carried out. Because the best mechanical properties of 3K 240G carbon fiber cloth are not different from Kevlar fiber cloth, it is large, and thicker fiber cloth is needed in the working process of automobile synchronizer. Therefore, the experiment uses Kevlar fiber cloth composite material impregnated for 2 hours to bond with 45 steel for curing pressure test;
6 Pressure bonding: Evenly spread the modified epoxy resin on the surface of the test piece, and then bond it with the Kevlar composite. After the bonding is completed, different pressures such as $0\text{MPa}$, $0.25\text{MPa}$, $0.5\text{MPa}$, $0.75\text{MPa}$, etc. are applied to the test piece, and high temperature curing is performed under this pressure.

3. Test and result analysis

Install the processed test piece on the performance tensile testing machine, as shown in Figure 1, conduct a test to determine the mechanical properties of the 3K 240G carbon fiber cloth composite material and metal bonding under different proportions of thinner, and obtain the best thinner ratio. The experiment adopts the international standard ISO1747-1976 to determine the adhesive shear strength of vulcanized rubber and rigid metal plate—four-plate shear method for testing [10].

According to the load obtained by the tensile testing machine, the shear strength of the specimen can be obtained by the calculation formula (1) of the four-plate method.

$$\sigma_{sh} = \frac{P}{S}$$

In the formula: $\sigma_{sh}$—the shear strength of composite and metal bonding (MPa); $P$—Maximum force value of specimen failure (MN); $S$—Sample bonding area $[10]$ ($m^2$).

3.1. The four-plate shear method measures the shear strength of specimens under different proportions of thinners

The tensile load of the specimen was measured by fixing the specimen on the performance test stretcher in batches. Figure 2 shows the variation curve of the tensile load of the specimen under different thinners with different proportions and with unchanged curing pressure.

It can be seen from the figure that when the proportion of thinner is 5%, the maximum load of 3K 240G carbon fiber cloth is $15.659 \times 10^3 MN$ after 2-hour immersion. When the proportion of thinner is 10%, the maximum load of 3K 240G carbon fiber cloth is $35.26 \times 10^3 MN$ after 4-hour immersion, and the tensile load of the specimen is relatively good. When the proportion of thinner is 15%, the fluidity of epoxy resin mixed with thinner is too strong, which is not conducive to bonding, so it is not considered.
From the load obtained from the experiment, the shear strength of the specimen is obtained by calculating formula (1), as shown in Figure 3. Figure 3 shows the change curve of the shear strength of the specimen under different proportions of thinner and different immersion time when the curing pressure is constant. It can be seen from the figure that when the proportion of thinner is 5%, the maximum shear strength of 3K 240G carbon fiber cloth is $38.24\, \text{MPa}$; the proportion of thinner is 10%, and the carbon fiber cloth of 3K 240G is immersed for 4 hours. The maximum shear strength it can bear is $54.89\, \text{MPa}$. It can be seen from the figure that the calculated shear strength of the specimen is consistent with the tensile load measured in the test. Although the peak value of the shear strength is different under different proportions of thinner, the proportion of thinner is 10%. At this time, the metal specimens bonded by carbon fiber cloth composite materials can obtain better shear strength.

### 3.2. The four-plate shear method measures the shear strength of specimens under different curing pressures

Through the above experiment and analysis, the Kevlar fiber cloth impregnated with epoxy resin mixed with 10% thinner is selected, and the fiber cloth composite material is bonded with the 45 steel with modified epoxy resin adhesive. Under the different pressure by using performance test tensile machine, measured specimen tensile load along with the change of curing pressure curve, as shown in figure 4. When the pressure is $0\, \text{MPa}$, the maximum load is $15.122 \times 10^3\, \text{MN}$. When the pressure is $0.75\, \text{MPa}$, the minimum load is $6.074 \times 10^3\, \text{MN}$, that is, the tensile load of the specimen decreases gradually with the increase of the pressure.
Figure 5. The curve of the shear strength of the specimen with the pressure

From the load obtained from the experiment, the curve of the shear strength of the specimen with the curing pressure is obtained by the calculation formula (1), as shown in Figure 5. It can be seen from the figure that when the applied pressure is 0MPa, the maximum shear strength is 23.54MPa; when the applied pressure is 0.7MPa, the minimum shear strength is 9.46MPa. It can be seen from the figure that the load of the test specimen is consistent with the calculated shear strength change law. The shear strength of the specimen does not increase with the increase of curing pressure, but gradually decreases and gradually decreases after 0.5MPa, Tend to be flat.

4. Conclusion

Through experimental analysis, it is obtained that the fiber cloth composite material with the same immersion time applies a certain pressure during the bonding and curing process with the metal, which will not enhance the shear strength of the specimen. At the same time, the proportion of the thinner in the adhesive impregnated fiber cloth is at 10%, a better shear strength can be obtained, which improves the mechanical properties of the specimen, and lays a foundation for further research on the bonding process of composite materials and metals.

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References

[1] Hongwei He, Jianlong Wang, Kaixi Li. Mixed resin and carbon fibres surface treatment for preparation of carbon fibres composites with good interfacial bonding strength[J]. Materials & Design, 10.1016/j.matdes.2010.05.031.
[2] Xu Botao. Development and application of high temperature resistant structural adhesives for automobiles [D]. Northwestern Polytechnical University, 2004.
[3] Yang Tao. Research on polyurethane modified epoxy resin adhesive [D]. Central Academy of Mechanical Sciences, 2017.
[4] Sun Dongzhou, Sun Yu, Zhang Zhi, Kong Xianzhi, Lu Hu, Li Yue, Yu Guoliang, Zhang Liying. Synthesis process of modified bisphenol S epoxy resin adhesive[J]. Chemistry and Adhesion, 2016, 38(04):255-259.
[5] Gan Chun. Preparation and performance study of high temperature UV-curable acrylic adhesive [D]. Hubei University, 2017.
[6] Liu Zhen, Luo Yong. Study on the influence of pressure and drying time on the bond strength of casein glue[J]. Guangdong Chemical Industry, 2018, 45(06): 53+107.
[7] Tian Tian, Xue Gang, Sun Mingming, Li Jianhui, Song Caiyu, Zhang Bin. Study on curing process and bonding properties of moderate temperature curing phenolic adhesives[J]. Chemistry and Adhesion, 2019, 41(04): 275-278+292.
[8] Wang Yunjia. Research on the bonding technology of self-lubricating joint bearing gasket and its tooling design [D]. Yanshan University, 2015.
[9] Zhang Yulong. 300 cases of practical adhesive formulation and production [M]. China Textile Publishing House, 978-7-5064-4824-6.
[10] National Bureau of Technical Supervision; Determination of the adhesive shear strength of vulcanized rubber and metal four-plate method [S]; GB/T12830-91.