Influence of resin content on mechanical properties of composite laminates

K Yang¹², Y M Yue¹⁴, W P Zhao¹, Y Liang¹², L Mei¹² and J J Xue³

¹Shenyang Aerospace University, Shenyang 110136, Liaoning, China
²Liaoning General Aviation Academy, Shenyang 110136, Liaoning, China
³Liaoning Rui-xiang General Aircraft Manufacturing Co., LTD, Shenyang 110136, Liaoning, China

E-mail: ykangok@163.com

Abstract. The resin content has an important effect on the mechanical properties of composite laminates. In order to study the influence of different resin content on the mechanical properties of composite laminates, the mechanical properties of the standard samples of carbon fiber composite laminates with resin content of 30, 35, 40, 45, and 50% have been tested, and the fracture regions of the samples have been scanned by scanning electron microscope. The test results show that the tensile strength of the carbon fiber composite laminates increases first and then decreases with the change of resin content. When the resin content is 35%, the tensile strength reaches the maximum. Moreover, the elastic modulus decreases with resin content.

1. Introduction

Fiber reinforced resin matrix composites have the advantages of light weight, high specific strength and uniform stress distribution in the whole structure. They play an increasingly important role in the aerospace industry [1]. Carbon fibers are a kind of high-performance fibers mainly used as reinforcing phases of composites. The strength of composites depends largely on their reinforcement materials. Practice has proved that the resin content directly affects the tensile strength, modulus of elasticity, Poisson's ratio and other mechanical properties of composite laminates. Kawai et al [2] studied the effect of high temperature on the mechanical properties of T800H/epoxy resin-based unidirectional composite laminates. Rupnowski et al [3] studied the mechanical behavior of unidirectional T650/PMR-15 composite laminates at high temperature by finite element simulation. Ha et al [4] proposed a two-parameter power function fitting model to study the high temperature performance of resin matrix composite laminates and fitted the data at high temperature. Ming et al [5] studied the fatigue properties of AS-4/PEEK resin matrix composite orthogonal laminates and quasi-isotropic laminates at room temperature to 180°C. Yang et al [6] studied the deformation and stress distribution of composite thin-walled structure in the process of hot-pressing tank forming by means of finite element numerical simulation. Yang et al [7] used C-scan method to study and analyze the factors affecting the mechanical properties of composite single lap bonded joints. Song et al [8] studied the static mechanical properties of bismaleimide resin castable and carbon fiber reinforced resin matrix composites unidirectional laminates at different temperatures by means of experiments, discussed the influence of temperature on the mechanical behavior of materials, and finally analyzed the fracture morphology of materials. Hou et al [9] studied the characteristics of composite laminates fracture, and discussed the fracture morphology, fracture mode of fiber and matrix resin of fiber-reinforced resin matrix composites, as well as the
problems to be solved in fracture analysis. Shen et al [10] proposed an improved direct measurement method and an interactive M-integral inverse method to measure the traction-separation curve in the cohesion region of materials. In the finite element numerical model of the compact tensile fracture mechanics experiment, two methods were used to measure the traction-separation curve of the cohesion model. The method was verified by comparing with the finite element numerical solution and the interactive J-integral inverse method. In all the above studies, the influence of resin content on the mechanical properties of composite laminates has not been studied by means of scanning fracture surface with electron microscopy.

In this paper, the tensile properties of carbon fiber composite laminates with resin content of 30, 35, 40, 45, and 50% were tested. After testing, the fracture surfaces of the test pieces were scanned and analyzed. The results of testing and analysis can provide some reference for researchers to prepare related materials.

2. Testing materials and methods

2.1. Material and preparation of test pieces

The test piece was carbon fiber reinforced epoxy resin composite. T300 3K 40B/1000 was used as carbon fiber reinforced material. The matrix epoxy resin is prepared by LY 1564 SPT resin and XB 3487 curing agent according to weight ratio. For this type of carbon fiber and resin ratio, the supplier requires resin content of 30~50% as the best state, so this paper only studies and analyses composite laminates with resin content of 30, 35, 40, 45, and 50% respectively. The resin content mentioned in this paper was the weight ratio between resin and curing agent. According to the requirements of the vacuum bag hand paste forming process, the template was made, the vacuum assistant material was laid after the lay-up was completed, and then the curing process of epoxy resin (curing at room temperature 22h + 2h) was carried out. In addition, the fiber orientation was [0/90].

2.2. Tensile testing

![Figure 1. The tensile testing machine of Instron 8801.](image)

Manufacturing of test samples and tensile test was carried out with reference to ASTM D3039/D3039M-08 (Standard test method for tensile properties of polymer matrix composite materials). The model of the testing machine was Instron 8801 (figure 1), and the longitudinal tensile loading rate was 2mm/min. The elastic modulus was measured by an extensometer with a scale of 50 mm and a model of Instron 2620-601. After the mechanical properties were tested, the fracture morphology of the specimen was
observed by scanning electron microscopy (SU3500) after enlarging the appropriate multiple, and the fracture characteristics were obtained. Resin content testing equipment is muffle furnace and analytical balance. Finally, the relevant data were processed according to the above criteria.

3. Results and discussion

3.1. Mechanical properties analysis

In tension test, five test specimens for each resin content. In order to reduce the error of test data, each test piece with different resin content was tested (showed tables 1-5), and the average value of effective test results was obtained. Figures 2 and 3 depict curves of tensile strength and elastic modulus versus resin content, respectively. From these curves, it can be seen that the tensile strength of carbon fiber composite laminates increases first and then decreases with the change of resin content. When the resin content is 35%, the tensile strength value reaches the maximum, and the elastic modulus value decreases with the increase of resin content.

| Table 1. Test results on tensile properties for a 30% resin content. |
| No. | Thickness (mm) | Width (mm) | Tensile strength (MPa) | Elastic modulus (×10^3 MPa) |
|-----|----------------|------------|------------------------|----------------------------|
| 1   | 2.12           | 15.07      | 621.62                 | 57.42                      |
| 2   | 2.07           | 15.12      | 736.39                 | 61.74                      |
| 3   | 2.02           | 15.13      | 724.67                 | 59.16                      |
| 4   | 2.07           | 15.09      | 668.85                 | 57.39                      |
| 5   | 2.07           | 15.1       | 717.78                 | 58.83                      |
| Average | 2.07         | 15.10      | 693.86                 | 58.91                      |

| Table 2. Test results on tensile properties for a 35% resin content. |
| No. | Thickness (mm) | Width (mm) | Tensile strength (MPa) | Elastic modulus (×10^3 MPa) |
|-----|----------------|------------|------------------------|----------------------------|
| 1   | 2.32           | 15.14      | 663.29                 | 53.03                      |
| 2   | 2.32           | 15.1       | 706.02                 | 55.59                      |
| 3   | 2.33           | 15.13      | 682.87                 | 53.9                       |
| 4   | 2.23           | 15.15      | 745.62                 | 54.84                      |
| 5   | 2.17           | 15.08      | 682.7                  | 55.93                      |
| Average | 2.28         | 15.13      | 700.63                 | 54.27                      |

| Table 3. Test results on tensile properties for a 40% resin content. |
| No. | Thickness (mm) | Width (mm) | Tensile strength (MPa) | Elastic modulus (×10^3 MPa) |
|-----|----------------|------------|------------------------|----------------------------|
| 1   | 2.51           | 15.01      | 616.38                 | 51.43                      |
| 2   | 2.49           | 15.07      | 637.37                 | 50.83                      |
| 3   | 2.45           | 15.07      | 611.71                 | 51.86                      |
| 4   | 2.51           | 15.05      | 608.54                 | 49.38                      |
| 5   | 2.50           | 15.06      | 617.50                 | 49.88                      |
| Average | 2.49         | 15.05      | 618.50                 | 50.88                      |
Table 4. Test results on tensile properties for a 45% resin content.

| No. | Thickness (mm) | Width (mm) | Tensile strength (MPa) | Elastic modulus (×10^3 MPa) |
|-----|----------------|------------|------------------------|----------------------------|
| 1   | 2.72           | 15.13      | 608.9                  | 48.84                      |
| 2   | 2.67           | 15.11      | 635.56                 | 48.26                      |
| 3   | 2.87           | 15.16      | 517.75                 | 45.07                      |
| 4   | 2.7            | 15.1       | 582.46                 | 48.77                      |
| 5   | 2.66           | 15.12      | 672.71                 | 49.51                      |
| Average | 2.73     | 15.13      | 601.24                 | 47.82                      |

Table 5. Test results on tensile properties for a 50% resin content.

| No. | Thickness (mm) | Width (mm) | Tensile strength (MPa) | Elastic modulus (×10^3 MPa) |
|-----|----------------|------------|------------------------|----------------------------|
| 1   | 3.07           | 15.09      | 459.24                 | 42.33                      |
| 2   | 2.92           | 15.07      | 549.68                 | 44.73                      |
| 3   | 2.94           | 15.06      | 558.59                 | 43.73                      |
| 4   | 2.86           | 14.96      | 601.65                 | 44.53                      |
| 5   | 2.97           | 15.05      | 540.95                 | 43.21                      |
| Average | 2.95     | 15.05      | 542.02                 | 43.71                      |

Figure 2. The change of tensile strength with the resin content.

Figure 3. The change of elastic modulus with the resin content.

When the resin content reaches 35%, the composite obtains better comprehensive mechanical properties. This is because when the number of fibers is small, the stress of the composite is relatively small, and because of the addition of fibers, the original continuous matrix is cut off, and a certain number of days of defects are formed in the resin, which is not conducive to the increase of elastic modulus. When the number of fibers increase to a certain extent and they distribute evenly in the resin matrix, the fibers can bear the stress well. Due to the interfacial bonding between the fibers and the matrix, the deformation of the fibers is limited by the matrix, and the fibers also prevent the deformation of the matrix, so that the composites can be well strengthened. However, when the content of fibers is too high, some fibers cannot be fully infiltrated by resin, thus forming many weakly bonded interfaces in the material. When the material is stressed, these interfaces are easy to desorb and pull out, stress transfer failure and performance degradation.

3.2. Fracture scanning morphology

After testing the tensile properties of carbon fiber composite (CFRP) laminates, the fracture specimens
Figures 4(a)-4(e) show the fracture morphology of CFRP laminates with different resin content after tensile fracture. From the graph, it can be seen that due to the different resin content, the carbon fiber layer had different gaps. When the resin content is 35%, the arrangement of carbon fiber layer at the fracture surface is orderly and the matrix resin is evenly distributed after curing; when the resin content is less than 35%, the distribution of matrix resin is not uniform, and the lack of resin between the carbon fiber layer and the layer at the fracture surface is prone to occur, resulting in a certain angle in the transverse arrangement of the carbon fiber layer after curing; when the resin content is less than 35%, the matrix resin distribution is not uniform. When the content of resin is more than 35%, the excess resin accumulates between the carbon fiber layer and the layer after curing, which also results in a large deviation angle in the transverse direction of the carbon fiber layer after curing, which leads to the inconsistency between the direction of the stress and the fiber axis during the tensile process, and directly affects the tensile strength value. The elastic modulus is the ratio of the tensile strength to the
deformation of the specimen. Because the resin content changes the stress direction of the carbon fiber, the deformation of the specimen in the axial direction also changes, so that the elastic modulus changes with the resin content.

Moreover, carbon fiber reinforced epoxy resin composites were made up of resin matrix to bond the reinforced fibers into a whole and bear external loads together. Therefore, enough resin must be infiltrated into the carbon fiber cloth and bonded and solidified into a whole. If the resin content was low in the process of composite forming, the local resin content will be lower than the limit, so that the fibers cannot be fully infiltrated by the resin and be well bonded together, resulting in the degradation of composite properties. Conversely, if the resin content was too high in the process of composite forming, it will cause local resin content.

4. Conclusions
In theory, the higher the fiber content in the composites, the lower the resin content and the higher the strength of the composites. Therefore, the fiber content should be increased as much as possible in the process. Experiments show that this is not the case in fact. If the resin content is too low, it will lead to the phenomenon of poor glue in the composites, make the fibers bond fast and reduce the properties of the composites. If the content of resin is too high, it will cause the damage of the resin body in the composite material and will also cause the decrease of the properties of the composite material. Therefore, the resin content of carbon fiber reinforced composites should be controlled optimally.

In this paper, the fracture areas of standard carbon fiber composite laminates with different resin content (resin content 30%, 35%, 40%, 45%, 50%) were scanned by electron microscopy, and the tensile test results and fracture morphology were compared and analyzed, the results show that:

- The tensile strength of CFRP laminates increases first and then decreases with the change of resin content. When the resin content is 35%, the tensile strength reaches the maximum value;
- The modulus of elasticity decreases with the increase of resin content;
- When the resin content is 35%, the infiltration effect of carbon fibers is better, the combination with resin reaches a more appropriate state, and the mechanical properties are the best;
- When the resin content is 35%, the deviation angle of the carbon fiber layer is smaller after curing, and the direction of force is in good agreement with the fiber axis.

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