Research on low-speed collision performance of Collision resistance of different materials

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Abstract. In order to explore the impact of lightweight materials and structures on the performance of anti-collision beams, this paper selects aluminum alloy and carbon fiber as the research objects, and analyzes the difference in low-speed impact performance of open and closed anti-collision beams for these two materials. Based on the structure of carbon fiber materials, the mechanical properties of carbon fiber materials are analyzed. At the same time, a low-speed collision model is established using numerical simulation to study the maximum intrusion amount, intrusion acceleration and intrusion force changes with time during the collision of aluminum alloy and carbon fiber anti-collision beams, And finally use experiments to verify. The research results show that the impact of the open aluminum alloy anti-collision beam and carbon fiber anti-collision beam on the fluctuation range of the collision acceleration is less than that of the closed aluminum alloy anti-collision beam; at the same time, compared with the closed aluminum alloy anti-collision beam, the open aluminum alloy anti-collision beam and carbon fiber, the maximum intrusion of the anti-collision beam is reduced by 8.2% and 18.6%; the carbon fiber anti-collision beam has the greatest force during the collision, followed by the closed anti-collision beam and the open anti-collision beam. The test results are consistent with the numerical simulation, which further illustrates the rationality of the exploration results.

Keywords: lightweight, anti-collision beam, aluminum alloy, carbon fiber, numerical simulation.

1. Introduction
The anti-collision beam of a car is an important device for the passive safety of a car, which can effectively absorb and alleviate the external impact. When the vehicle collides, the collision energy is timely transferred to the energy absorbing device such as the energy absorbing box, and at the same time, the deformation of itself also absorbs part of the energy, and the relatively large impact force is reasonably transmitted to the rear of the car body and distributed to the entire body to reduce the collision Damage to vehicles and occupants [1-3].

Traditional anti-collision beams are mostly stamped from high-strength steel. The manufacturing process is complicated and heavy, and the production cost is high. With the global requirements for energy saving and emission reduction, the requirements for automobile lightweight have become more stringent. The high-strength steel anti-collision beam materials for automobiles can no longer meet the...
requirements for automobile lightweight [4-7]. Therefore, it is necessary to find new materials to replace high-strength steel to meet the requirements of automobile lightweight and realize energy saving and emission reduction. As two commonly used lightweight materials, aluminum alloy and carbon fiber composite materials have been gradually applied to the actual production of anti-collision beams. In China, Xu Zhongming and others conducted optimization research on aluminum alloy anti-collision beam structure and determined the optimal cross-sectional structure. Chen Zeyao et al. carried out a lightweight analysis on the front anti-collision beam of a car based on the response surface method. Yang Xujing and other foreign scholars SIMON P et al. systematically compared the impact performance of dual-phase steel anti-collision beams and aluminum alloy anti-collision beams. However, at this stage, there is no systematic comparative study on the collision performance between the anti-collision beams of these two materials, and the selection of the two materials lacks theoretical guidance [4-9].

In this paper, two materials of aluminum alloy and carbon fiber anti-collision beams are selected as the research objects, and the maximum intrusion amount, intrusion speed, and intrusion force are used as indicators to analyze the difference in low-speed impact performance of open and closed anti-collision beams. Analysis and verification.

2. Research object and mechanical analysis

This article takes the front anti-collision beam of a certain car as the research object. Figures 1(a) and 1(b) are aluminum alloy anti-collision beams with different structures, and Figure 1(c) is a carbon fiber anti-collision beam. The energy absorbing boxes are all 6005-T4 aluminum alloy, and the dimensions are exactly the same. The material selected for the two aluminum alloy anti-collision beams is 5083 aluminum alloy, and the carbon fiber anti-collision beam is composed of 12 layers. Both the aluminum alloy anti-collision beam and the carbon fiber anti-collision beam are 3mm thick.

(a) Closed aluminum alloy anti-collision beam (b) Opening aluminum alloy anti-collision beam

(c) Opening carbon fiber anti-collision beam

Figure 1 Schematic diagram of three anti-collision beams

3. Establishment of finite element model

3.1. Material mechanical parameters

In the finite element model, the mechanical properties of 5083 aluminum alloy are obtained through tensile experiments. The equipment used is a WDW-series electronic universal testing machine with a tensile rate of 5mm/min. The mechanical properties are shown in Table 1. The mechanical parameters of carbon fiber obtained by traditional mechanical methods are shown in Table 2.
Table 1 Mechanical properties of 5083 aluminium alloy

| Parameter | Value |
|-----------|-------|
| $\rho$/g•cm$^{-3}$ | 2.79 |
| $E$/GPa | 68.9 |
| $u$/MPa | 0.31 |
| $\sigma_s$/MPa | 158.3 |
| $\sigma_b$/MPa | 321.5 |

Table 2 Mechanical parameters of carbon fiber materials tested

| Parameter | Value |
|-----------|-------|
| Density $\rho$/Kg•mm$^{-3}$ | 1.52e-6 |
| Longitudinal tensile strength $X_t$/GPa | 2.2 |
| Longitudinal compression strength $X_c$/GPa | 1.47 |
| Transverse Young's modulus $E_a$/GPa | 127 |
| Transverse tensile strength $Y_t$/GPa | 0.0489 |
| Longitudinal Young's modulus $E_b$/GPa | 8.41 |
| Longitudinal compressive strength $Y_c$/GPa | 0.199 |
| In-plane shear modulus $G_a$/GPa | 4.21 |
| Transverse compressive strength $Y_c$/GPa | 0.154 |
| Principal Poisson's ratio PR$\alpha$ | 0.309 |
| Poisson's ratio PR$\beta$ | 0.02049 |

3.2. Establishment of finite element model

In this paper, the finite element software ABAQUS is used to analyze the low-speed collision of the anti-collision beam. The finite element model is shown in Figure 2. Based on the national standard counterweight test vehicle, the front end is equipped with a bumper. The vehicle moves at a speed of 15km/h and collides with a 40% offset rigid barrier. The end plane of the energy absorbing box at the rear end of the anti-collision beam is bound to the trolley, and the trolley and barriers are set as rigid bodies.

Figure 2 Finite element model

4. Analysis of simulation results

4.1. Analysis of collision acceleration

Figure 3 shows the relationship between the acceleration curve of the trolley movement direction and time during the collision process. All the curves have 6 obvious wave crests. This change mode is related to the collapse mode of the energy-absorbing box and the deformation mode of the anti-collision beam. Corresponding. It can be seen from the figure that for the open-type carbon fiber anti-collision beam, the energy absorption box is crushed to absorb energy at 0-28ms. This is because the stiffness of carbon fiber is greater than that of aluminum alloy. When the anti-collision beam is hit The energy is transferred to the energy absorbing boxes on the left and right sides. In the process of initial velocity yielding of the energy absorbing box structure, the reaction force of the collision support gradually increases, and the first acceleration peak appears. After that, the energy absorbing box was crushed at the first level, the reaction force was reduced, and the acceleration was reduced. When the first-level crushing space of the energy absorbing box is insufficient, as the material hardens and the deformation resistance of the subsequent structure increases, the supporting reaction force increases,
and the acceleration increases again. When the supporting reaction force increases to a certain level, the subsequent structure will collapse in second order, and the supporting reaction force begins to decrease and the acceleration decreases. In the process of alternate stacking and deformation of energy absorbing boxes, the collision energy is gradually absorbed. When the time is 29ms, after the energy absorbing box has been completely crushed, the energy has not been completely absorbed. At this time, the carbon fiber, which is relatively difficult to deform at the front end, is required to absorb energy. Therefore, the acceleration curve appears a sudden drop process, and the appearance of the wave peak is related to the carbon fiber. The design is related to the size of the four planes.

![Curve of X-direction acceleration with time in three structures](image)

**Figure.** 3 Curve of X-direction acceleration with time in three structures

For the open aluminum alloy anti-collision beam at 0-30ms, the energy-absorbing box is first crushed to absorb energy, and multiple crests and valleys appear. Because the material of the anti-collision beam and the energy-absorbing box is the same, the energy-absorbing box is compressed during the deformation process. During the collapse process, the front end of the anti-collision beam is also deformed simultaneously, but the deformation energy absorption is less than the energy absorption box. When the energy absorption box is completely crushed, the front end continues to deform due to the folding method and energy absorption of the plane deformation parallel to the direction of movement. There are similarities in box deformation, so peaks and valleys also appear. For the closed anti-collision beam of pure aluminum alloy, the same as the first two open types, the energy absorbing box first absorbs energy and then is completely crushed. After the energy absorbing box is completely crushed, there will still be multiple peaks and valleys. But at this time, the amplitude of the wave crests and troughs is obviously larger than the first two types of anti-collision beams. This is because two ribs with guiding functions are added to the closed anti-collision beam, which has a greater impact on acceleration changes. Based on the above analysis, it can be seen that the impact of the open aluminum alloy anti-collision beam and the carbon fiber anti-collision beam on acceleration fluctuation is less than that of the closed aluminum alloy anti-collision beam, and the cushioning effect is better than that of the also closed aluminum alloy anti-collision beam.

### 4.2. Maximum intrusion of anti-collision beam

During a collision, it is generally desirable to reduce the amount of intrusion while reducing the peak acceleration, so as to achieve the maximum protection effect for the occupants. In this paper, the maximum intrusion amount $w$ is represented by the four points of the contact position of the anti-collision beam and the barrier and the focus position of the ridge line.

$$
 w = \frac{\sum_{i=1}^{4} \sqrt{x_i^2 + y_i^2 + z_i^2}}{4}
$$

(1)
Where \( w \) is the maximum intrusion, \( i \) is the single point taken, and \( x, y, \) and \( z \) are the coordinate values. Among them, the values of \( x, y, \) and \( z \) are measured at the coordinate positions marked in Figure 4.

![Coordinate system diagram](image1)

![Schematic diagram of invasion method](image2)

**Figure 4** Intrusion Analysis Chart

![Graph showing correspondence between intrusion and three structures](image3)

**Figure 5** Correspondence between intrusion and three structures

Figure 5 shows the correspondence between the three types of anti-collision beams and the maximum intrusion. It can be seen from the figure that the carbon fiber anti-collision beam has the smallest intrusion, which is 101.1mm. This is because the stiffness of carbon fiber materials is higher than that of aluminum alloy materials, so the intrusion is the least amount. The intrusion of the two aluminum alloy anti-collision beams is greater than that of carbon fiber, and the opening anti-collision beam has the largest intrusion. Compared with the open anti-collision beam, the intrusion of the closed aluminum alloy anti-collision beam and carbon fiber anti-collision beam is reduced by 8.2% and 18.6% respectively. This is because the closed anti-collision beam has a similar force in the four planes parallel to the direction of motion during the collision, which can all play a role in hindering deformation, while the two outermost planes of the open anti-collision beam have weaker hindrance than the closed anti-collision beam. Hit the beam, so the deformation is greatest.

4.3. **Maximum invasive force analysis**

Figure 6 shows the force change curve along the direction of the car movement during the collision. From the figure, it can be seen that from time 0 to 20ms, the collision force fluctuates severely with a large amplitude. The force fluctuation phenomenon from 21ms to 30ms still exists, and the force value
The range increases. This is because at the beginning of the collision, the buffering force during the energy absorption process of the energy absorbing box structure is smaller than that of the anti-collision beam, which causes the force to start to fluctuate less. When the energy absorbing box is completely deformed, the anti-collision beam begins to deform and therefore fluctuates. The value starts to increase. During the collision, the force $F$ has 6 peaks, and the magnitudes are different. The cause of the fluctuation phenomenon is related to the material and structure. Because acceleration and force have a corresponding relationship, the force fluctuation phenomenon has a corresponding relationship with the change of the acceleration curve. Among them, the carbon fiber anti-collision beam has the greatest force, followed by the closed anti-collision beam and the open anti-collision beam.

![Figure 6 Variations in the intrusive forces of the three structures](image)

5. Test analysis

Through the above finite element analysis, it can be obtained that the carbon fiber anti-collision beam has a similar effect to that of the closed aluminum alloy during the collision, and it can also further realize the lightweight of the car. In order to verify this result, this test adopts the national standard collision special trolley with a mass of 1000Kg. Install the carbon fiber anti-collision beam at the front end of the trolley, the trolley hits the rigid offset barrier at a speed of 15Km/h, and the collision position of the trolley and the offset barrier is shown in Figure 7.

![Figure 7 Schematic diagram of collision contact](image)
The change of the carbon fiber anti-collision beam after the test is shown in Figure 8. From the figure, it can be seen that the aluminum alloy energy absorbing box has been completely crushed at the end that collided with the offset barrier, and the carbon fiber anti-collision beam has also been deformed and deformed. Tearing between layers. Figure 9 shows the comparison curve of the test and simulation acceleration after collision. It can be seen from the figure that the change curve of the test and simulation is basically the same. The maximum difference in acceleration value is 4.5%. Within the allowable range of error, the experimental value can be considered to be the same. The simulation values match, and the carbon fiber anti-collision beam has a similar effect to the aluminum alloy anti-collision beam.

![Figure 8 Schematic diagram of carbon fiber anti-collision beam after test](image)

![Figure 9 Test and simulation acceleration comparison curve](image)

After the test, SpinArm-Apex portable three-coordinate measuring equipment was used to analyze the intrusion amount of the contact position of the carbon fiber anti-collision beam before and after the collision. Figure 10(a) is the three-coordinate equipment for measuring points. The points selected in Figure 11(b) are the criteria for judging the amount of intrusion. Table 3 uses the evaluation formula in 3.2 to analyze the measurement points, and obtains the maximum intrusion value of the simulation and test after the impact of the carbon fiber anti-collision beam. It can be seen from the table that the difference between the simulation result and the maximum intrusion amount obtained from the experimental result is only 3.4mm. Within the allowable range of error, the simulation result is relatively accurate and conforms to the actual situation.
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6. Conclusions
The main conclusions of this article are as follows:

Based on the anisotropic characteristics of composite materials, the relationship expression between the elastic constants of composite materials is obtained through theoretical analysis.

Through analysis of the acceleration, maximum intrusion and intrusion force during the collision of the anti-collision beam, the results show that the acceleration fluctuation amplitude of the closed aluminum alloy anti-collision beam is larger than that of the open aluminum alloy anti-collision beam and carbon fiber anti-collision beam; The maximum intrusion of the open aluminum alloy anti-collision beam is 123mm followed by the closed aluminum alloy anti-collision beam and the carbon fiber anti-collision beam; the peak force of the closed aluminum alloy in a collision is the largest, followed by the carbon fiber anti-collision beam and the open aluminum Alloy anti-collision beam.

The comparison of experimental research and simulation results shows that the maximum intrusion of carbon fiber anti-collision beams differs by 1% from the simulation results, and the intrusion is the smallest among the three types of anti-collision beams; the acceleration fluctuations in the test have the same trend as the numerical simulation, with the largest difference The part is 0.4g, within the allowable error range, the test effectively verifies the accuracy of the simulation.

In summary, the carbon fiber structure is preferentially selected among the three types of anti-collision beams because of its light weight, which is conducive to the realization of lightweight cars.

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