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Research on Lightweight Design of CFRP Engine Hood

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Abstract. Vehicle lightweight technology has become an important means to solve the fuel economy and environmental protection of vehicles. Carbon fiber reinforced polymer (CFRP) is the best lightweight material for body. The main objective of this paper is to apply CFRP to body panels (hood), the basic performances of CFRP hood were studied by finite element simulation and sample test, Exploring the feasibility of replacing CFRP parts with steel parts and testing its lightweight effect.

Key words: CFRP, Lightweight, Engine Hood.

1. Introduction

In recent years, with the rapid development of economy and the improvement of people's living standards, automobiles have become an indispensable part of daily life. With the increase of car ownership and the drastic consumption of energy, mankind is facing the situation of increasing lack of oil resources.

Vehicle quality can not only improve the performance of vehicles, but also meet the needs of energy saving and environmental protection. According to statistics from the World Association of Faulty Industries, for every 10% reduction in vehicle quality, fuel consumption can be reduced by 7%[1]. At present, steel parts on automobiles account for about 3/4 of the weight of the whole vehicle. If new lightweight materials, such as fiber composite materials, are used instead of the original steel parts, the weight of the whole vehicle can be reduced by about 300kg, fuel efficiency. Can increase 36%, emissions of harmful gases such as carbon dioxide can also be reduced by 17%[2].It not only reduces the use cost, but also is more green.

CFRP are the materials with the highest specific modulus and specific stiffness in currently used materials. At the same time it also has high temperature resistance. It has the characteristics of good weather resistance and strong designability, and it has become the most ideal lightweight material for automobile bodies[3].

2. Properties of CFRP

Carbon fiber is a kind of material with excellent mechanical properties. It not only has the inherent characteristics of carbon materials, but also has the softness and machinability of textile fibers. It is a new generation of reinforcing fibers. CFRP has incomparable specific strength and modulus with other materials, and its volume mass is 1.45-1.6 g/cm3, which is only 1/4-1/5 of ordinary carbon steel and 1/3 lighter than common aluminum alloy. The mechanical properties of CFRP are better than metal materials, its tensile strength is 3-4 times higher than steel, stiffness is 2-3 times higher than steel, greatly improving the anti-concave performance of parts.Under the same conditions, the section thickness and height of carbon fiber parts can be increased to meet the strength and stiffness requirements of the original steel structure[4-5].

3. Design of engine hood

3.1. Traditional hood structure

The hood has the advantages of heat insulation, sound insulation, light weight and rigidity. The traditional hood is made of low-carbon steel sheet metal. The hood is mainly composed of inner and outer plates, internal reinforcement plates, hinges and locking fasteners. The inner plate is 0.6 mm thick and the outer plate is 0.7 mm thick.The hood assembly is mainly composed of the inner and outer plates of the hood and the reinforcing plates by spot welding, gluing and binding. The hood assembly and the body are hinged together. Fig.1 shows the schematic diagram of the traditional hood structure.

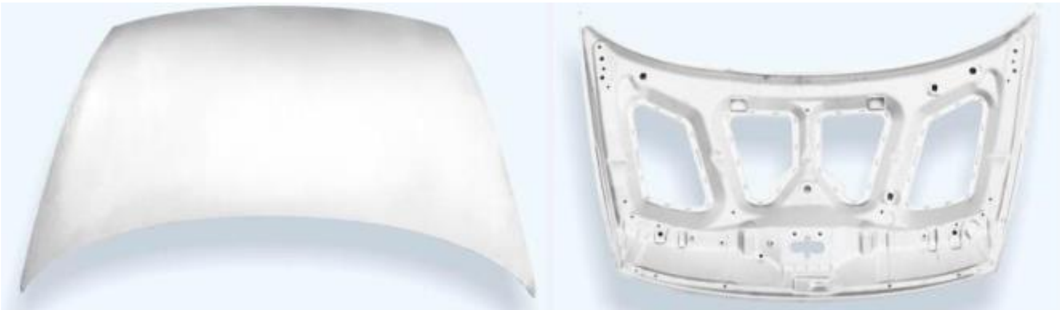

Fig.1 Traditional engine cover structure

3.2. Carbon fiber engine hood

CFRP is used for the inner and outer panels of the carbon fiber hood. According to the equal stiffness approximation theory, the design thickness of the inner panels is 2.1 mm, and the design thickness of the outer panels is 1.7 mm. Considering the technological problems of compound material forming, the structure and connection mode of each part should be simplified and adjusted accordingly. In terms of structure, the inner plate is removed from the gluing grooves, stiffeners and technological holes, and the edge is optimized, as shown in Figure 2.

Fig.2 Package structure finite element mesh

3.3. Lightweight effect of carbon fiber engine hood

Carbon fiber hood has been simplified in material, structure and process. It can reduce mass by 8.45kg and weight loss ratio by 45.53%, as shown in Table 1.

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Tab.1 Weight reduction effect comparison

Materials	Density (Kg/m3)	Thickness of inner and outer plates(mm)	Engine hood assembly quality(Kg)
mild steel	7850	0.6/0.7	18.56
carbon fibre	1600	2.1/1.7	10.11

4. Structural performance analysis of carbon fiber engine hood

The simplified 3D model of CFRP hood is established by UG software, and is imported into Abaqus software to mesh. Then, the first-order constraint mode, the stiffness of rear corners, the stiffness of middle and rear parts and the stiffness of side and middle parts of the hood are analyzed by CAE.

4.1. Order constrained modal analysis

Constraints: Restrict all degrees of freedom at the hinge and body mounting points, release the rotational freedom of the hinge shaft; Restrict translational freedom at the lock; Restrict all degrees of freedom at the buffer block position. The first 6 order modes are extracted and the output frequency range is 0~100 Hz.

From the Abaqus software, the 1 stage mode of the hood assembly is 47.51 Hz, as shown in Figure 3.

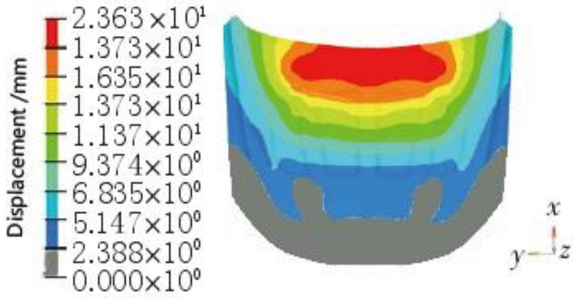

Fig.3 Order modal analysis of carbon fiber engine hood displacement cloud picture

4.2. Stiffness analysis of back corner

Constraints: Restrict all degrees of freedom (1, 2, 3, 4, 5, 6) of the hinge and body mounting points, release the rotational freedom of the hinge shaft; Restrict the z-direction freedom of the buffer block and lock position. Load conditions: apply Z to the 100 N load at the corner of the outer panel, perpendicular to the surface of the paper.

According to Abaqus software, the rear corner stiffness Z displacement of the hood assembly is 0.713mm, as shown in Figure 4.

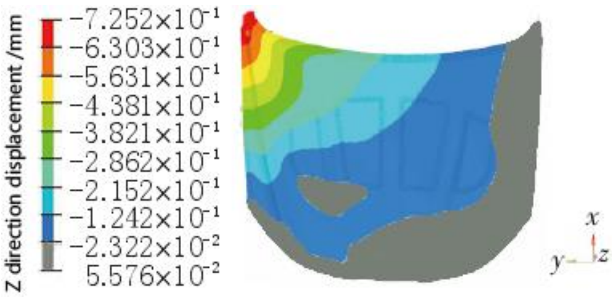

Fig.4 Displacement analysis of carbon fiber engine hood rear corner

4.3. Mid rear stiffness analysis
Constraints: Restrict all degrees of freedom of hinge and body mounting point, release the rotational freedom of hinge shaft; Restrict the translational freedom of lock; Restrict the Z-direction translational freedom of buffer block.

Load Conditions: Four elements of the inner and outer plates at the midpoint of the back end are connected by a multi-point constraint (MPC) and applied with a load of 100 N in Z direction perpendicular to the paper face out.

From Abaqus software, the middle and rear stiffness Z-direction displacement of the hood assembly is 0.966mm, as shown in Figure 5.

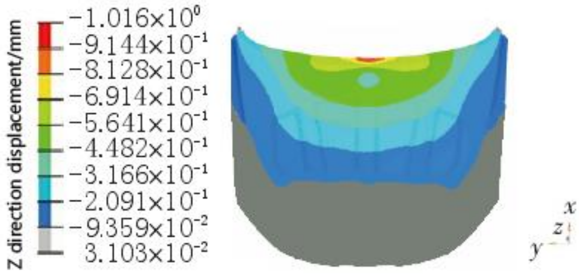

Fig.5 Displacement cloud chart for stiffness analysis of rear part

4.4. Stiffness analysis of side center
Constraints: Restrict all degrees of freedom of the hinge and body mounting point, release the rotational freedom of the hinge shaft; Restrict the z-direction freedom of the lock.

Load Conditions: On the right side of the hood corresponding to the midpoint of the connecting line between the lock and the hinge mounting point, the inner and outer panels are connected by MPC with five units each, and a negative y-180 N load is applied, parallel to the paper face to the left.

According to Abaqus software, the stiffness y displacement in the middle of the side of the hood assembly is 0.351 mm, as shown in Figure 6.

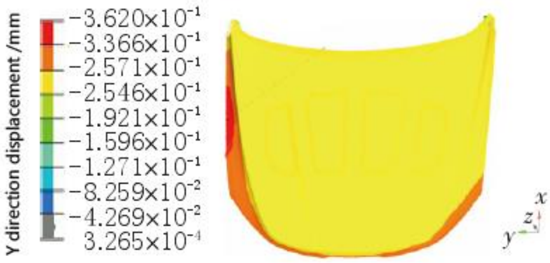

Fig.6 Displacement cloud chart of lateral central stiffness analysis

4.5. Performance analysis and comparison
The above method is used to analyze and compare the performance of the steel structure hood, as shown in Table 2.

Tab.2 Performance analysis and comparison

working condition	target value	carbon fibre	Steel structure
1 order constraint modes/HZ	⩾25	47.51	31.66
Corner stiffness (N/mm)	⩾50	140.23	101.23
Mid rear stiffness(N/mm)	⩾60	108.35	96.56
Lateral central stiffness(N/mm)	⩾120	496.85	410.86

As can be seen from Table 2, the first restraint mode, the stiffness at the rear corner, the stiffness at the middle and rear parts and the stiffness at the middle of the side all meet the target values, and are slightly higher than the steel structure hood.It shows that there is a problem of excessive design in the structure of carbon fiber hood, which can be further optimized to make the structure design more reasonable and the weight reduction effect more obvious on the premise of meeting the performance requirements.

5. Structural optimization

There is a problem of over-design for the carbon fiber hood structure. First, it can be optimized by thinning the thickness. The inner plate is optimized for a design thickness of 1.7 mm, and the outer plate is optimized for a design thickness of 1.2 mm. The optimized performance analysis results are shown in Table 3.

Tab.3 Performance analysis and comparison

working condition	target value	carbon fibre	Steel structure
1 order constraint modes/HZ	⩾25	32.34	31.66
Corner stiffness (N/mm)	⩾50	110.56	101.23
Mid rear stiffness(N/mm)	⩾60	98.45	96.56
Lateral central stiffness(N/mm)	⩾120	420.73	410.86

It can be seen from Table 3 that after dimension optimization, the 1st-order constrained mode, the rear corner point stiffness, the mid-rear portion stiffness and the middle-side stiffness of the carbon fiber hood all meet the target value, but the rear corner point stiffness, the mid-rear stiffness and the side The stiffness of the middle and the middle is slightly lower than that of the steel hood. Whether the size optimization scheme is feasible or not needs to be verified by bench or road test.

6. Conclusion

In this paper, the hood of a car is taken as the research object. CFRP is used to replace the traditional steel material. The first-order constrained mode, torsional stiffness, mid-rear stiffness and side-to-side stiffness are analyzed by CAE software. It shows that the performance indexes of CFRP can meet the target value and are superior to steel, which proves the feasibility of replacing with carbon fiber material and achieves the goal of weight loss of 45.53%. At the same time, for the problem of over-design, the reference direction of size optimization is proposed.

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