Development of lightweight high-performance carbon fiber child safety seat

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Abstract

With the gradual implementation of ECE R129,the performance of child safety seats has been put forward higher requirements. At the same time, the problem of excessive weight of child safety seats affects the convenience of their use. In order to solve this problem, a lightweight carbon fiber seat for children was developed. The structure and crashwort hiness of the seat were studied. The total weight of the seat was 6.86 kg, which was 30% less than that of the conventional seat for children. The CFRP child seat has excellent crash safety performance. The maximum head displacement of the frontal crash is 418.4 mm, which is much lower than the prescribed value. The chest and head acceleration also meet the requirements of the law. At the same time, it can meet the requirements of the latest ECE R129 for side impact protection. The research shows that it is feasible to apply CFRP to the design of children's seat, which can greatly improve the performance of children's seat while reducing weight.

Keywords

Child safety seat, carbon fiber, simulation analysis, lightweight.

1. Introduction

Child safety seats are protective device designed to improve the safety of child passengers. As children's safety issues become more and more concerned by society, the use of child safety seats is becoming more and more extensive[1,2] .In 2011,China also promulgated the National Standard for Motor Vehicle Child Crew Constraint System[3],which further standardized the design and use of child safety seats. In recent years, with the gradual implementation of the ECE R129 regulations, new requirements have been put forward for the side collision protection capability of child safety seats[4].A lot of researches on the structure and performance of child safety seats have been carried out at home and abroad[5-8],which has greatly improved the safety of child safety seats. However, most of the child safety seats on the market today use plastic in combination with a metal skeleton to increase their strength, which leads to an increase in the weight of the child safety seat. It is extremely inconvenient to use and even causes misuse.

Carbon fiber is a new fiber material with high strength and high modulus. It has outstanding mechanical properties and anisotropic characteristics. At present, carbon fiber reinforced epoxy resin matrix composite (CFRP) is the most widely used. Its tensile strength is 7-9 times that of steel, its density is less than 1/4 of steel, and its modulus of elasticity is higher than that of steel. Its specific strength and specific modulus are the highest among existing structural materials[9].In recent years, carbon fiber has become more and more widely used in the field of automotive lightweight[10-12].

Based on this, in order to solve the problem of overweight of children's safety seat, this paper developed a lightweight carbon fiber child safety seat, studied its structure and collision performance, and improved the overall performance of the child safety seat.

2. Carbon fiber child safety seat design goals and modeling design

2.1 Design goals

Group: Group I, suitable for children aged 9~18kg;

Target weight: no more than 7kg (the weight of the child safety seat in this group is generally more than 10kg);

Main materials: carbon fiber + plastic parts + foaming + fabric + metal, etc., the machine components should use carbon fiber as much as possible, and only if the process or structure is not allowed can other materials be used;

Structural function: it needs to be assembled with the body by ISO-FIX. It needs a 5-point Y-belt structure and the angle of the seat back can be adjusted.

CAE analysis: formability, joint performance, structure and safety analysis, optimization, and benchmarking of carbon fiber parts;

Test: The vehicle road test and trolley test meet the requirements of GB27887\ECE R44\ECE R129.

2.2 Modeling design

Based on the general requirements of GB27887\ECE R44\ECE R129 and other regulations on the structural dimensions of child safety seats, combined with the structural functions proposed by the design goals, with the design methods such as ergonomics and visual design, taking into account the forming characteristics of carbon fiber composite materials., the design shown in Fig. 1 is determined.

Fig. 1 Carbon fiber child safety seat modeling design

The overall design is smooth, which is beneficial to the formation of carbon fiber composite materials, and it reserves the space for the realization of some structural functions such as tilt adjustment and headrest height adjustment.

3. Carbon fiber child safety seat structure design

3.1 Process selection

At present, the carbon fiber forming process includes vacuum infusion forming, compression molding, RTM forming, wet molding, autoclave forming, etc., taking into account cost, surface quality, product performance, etc., the carbon fiber child safety seat process selection is vacuum infusion. reasons are as following:

(1) The fiber volume content is equivalent to the general liquid molding process (about 50%);

(2) It can meet the requirements of single-sided smooth and appearance quality (single-sided mold);

(3) FRP molds can be selected to reduce the cost of the mold;

(4) It can meet the process requirements for sample manufacturing;

(5) Only the oven is required for heating, which can reduce the manufacturing process cost;

(6) The process is mature, the product rejection rate is low, and the molding process risk can be reduced.

3.2 Material selection

The carbon fiber child seat reinforcement is selected from T300 grade fiber wire, mainly because:

(1) The child seat back plate and seat on the market are all plastic structures, and the load is not large. The T300 grade carbon fiber wire can fully meet the strength requirements;

(2) T300 grade carbon fiber wire's modulus is 230GPa,which can meet the child seat's stiffness requirements;

(3) The cost of other high-strength or high-modulus filaments is significantly higher than that of T300 grade fiber wire;

(4) T300 grade carbon fiber wire is the main level for civilian use, it has sufficient supply and convenient procurement.

3.3 CAS surface design

Refer to the relevant standards, the design of the seat's CAS surface is as shown in Fig. 2:

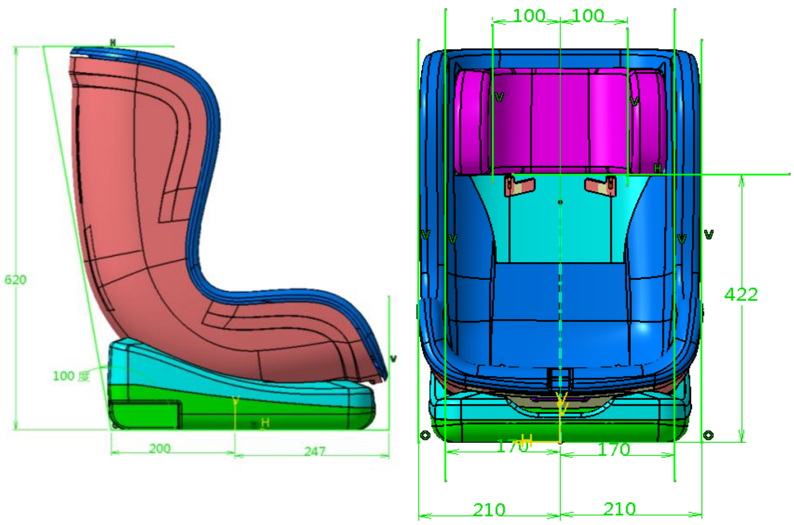


Fig. 2 Carbon fiber child safety seat CAS surface design

3.4 Mechanism design

According to the structural function requirements, the institutions that need to be designed mainly include: inclination adjustment mechanism, headrest height adjustment mechanism, and ISO-FIX connection mechanism.

3.5 Connection design

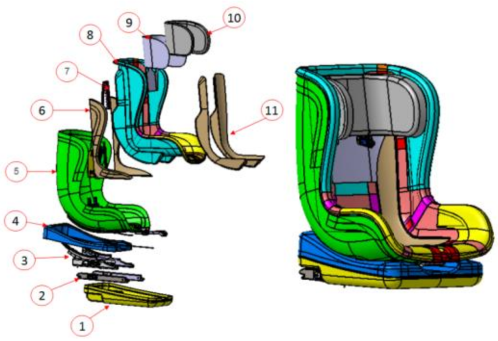
The connection between the carbon fiber and the carbon fiber parts is adhesive connection, and the lower part of the seat base adopts a stepped section to ensure the surface difference of the outer surface. The joint between the inner and outer layers of the seat body is designed for gluing, and a foam sandwich structure is used to fill the gap. The adhesive thickness is designed to be 0.5 mm.

The connection between carbon fiber, metal and plastic parts is mainly adhesive connection, and the riveting is used for matching. The thickness of the bonding is designed to be 0.5mm,and it is necessary to design the bonding tool.

3.6 Carbon fiber pavement analysis

From the analysis of the pavement, the fiber deformation is mainly concentrated at the corners and the ribs. In order to make the fibers adhere well to the mold, the fiber cloth is divided into a plurality of pieces, and a lap joint is provided in the transition region. In the end, it can be achieved without large-area fiber deformation, and can be manually repaired in actual operation.

The designed carbon fiber child safety seat refinement model is shown in Fig. 3. The total weight of the child safety seat is 6.86kg.



①base lower plate, ②ISO-FIX, ③seat flip structure, ④base upper plate, ⑤seat outer plate, ⑥side buffer foams, ⑦headrest lifting mechanism, ⑧seat inner plate, ⑨headrest outer plate, ⑩headrest foam, ⑪filled foams

Fig. 3 Carbon fiber child safety seat refinement model

4. Carbon fiber child safety seat CAE simulation analysis

The carbon fiber child safety seat CAE simulation analysis process is shown in Fig. 4:

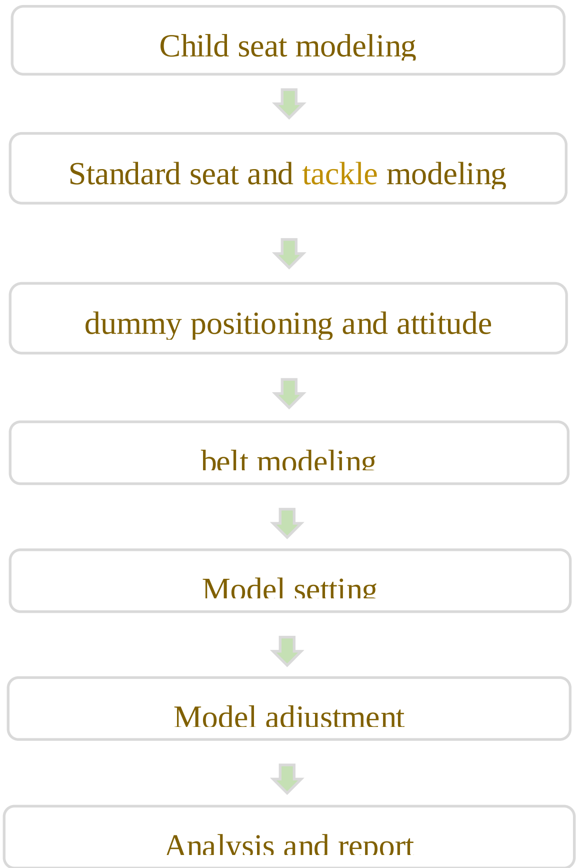


Fig. 4 Carbon fiber child safety seat CAE simulation analysis process

4.1 Finite Element Modeling

The carbon fiber child safety seat CAE simulation finite element modeling includes steps such as child safety seat modeling, standard seat and tackle modeling, dummy positioning, attitude adjustment, and seat belt modeling[13-16].

The experimental tackle seat coordinate system is used as the reference coordinate system, and other systems are matched with it. The Z axis is the front direction, the X axis is the lateral direction, and the Y axis is the height direction. At the same time, choose a unified unit system.

As shown in Fig. 5,the carbon fiber child safety seat CAE simulation finite element model is established. The number of nodes is 141,000 and the number of units is 156,000.

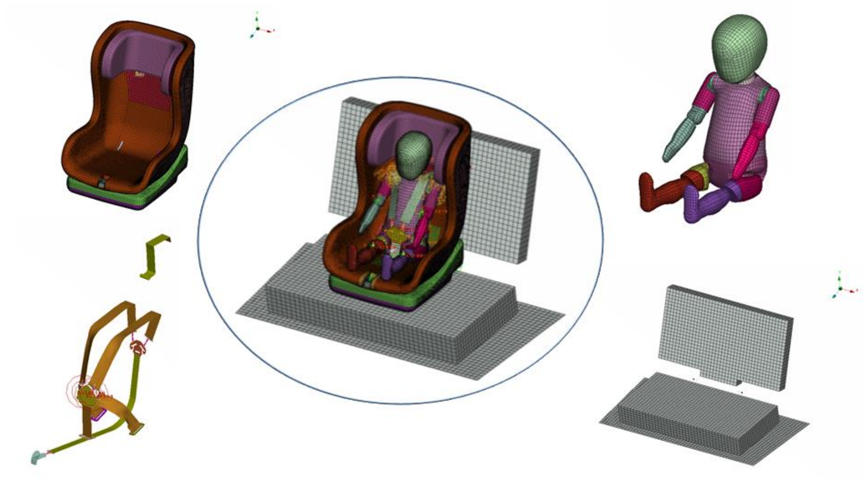
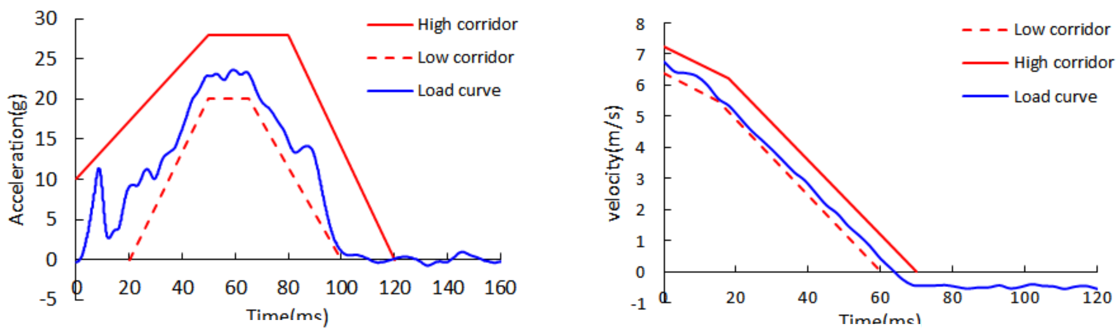


Fig. 5 Carbon fiber child safety seat CAE simulation finite element modeling

4.2 Loading and analysis

In the case of a frontal collision, the impact acceleration specified by the regulations is applied to the model, which is equivalent to a maximum speed of 50-52 km/h; in the case of a side collision, the speed curve as shown in the figure is applied to the side door. Fig. 6 shows the acceleration waveform in the case of a frontal collision and the velocity waveform in the case of a side collision in the ECE R129 trolley test :



a) b)

Fig. 6 Regulatory waveform

a) frontal collision acceleration waveform and regulatory channel; b) side collision speed waveform and regulatory channel

The main assessment indicators include: head acceleration (3ms), head HPC (15ms), chest acceleration (3ms) and the force of the seat.

4.3 Simulation analysis results

The simulation analysis includes multiple collision conditions. This paper selects the most severe misoperations(without the use of the upper belt) in the frontal collision and the side collision simulation results to analysis.

(1) Q3 dummy is upright and collided frontally(misoperation)

Fig. 7 shows the head joint acceleration, chest joint acceleration and head displacement curve of the dummy when the Q3 dummy is upright and collided frontally(misoperation). Table 1 shows the comparison between the simulated value and the regulatory value. It can be seen that all indicators of the dummy meet the regulatory requirements.

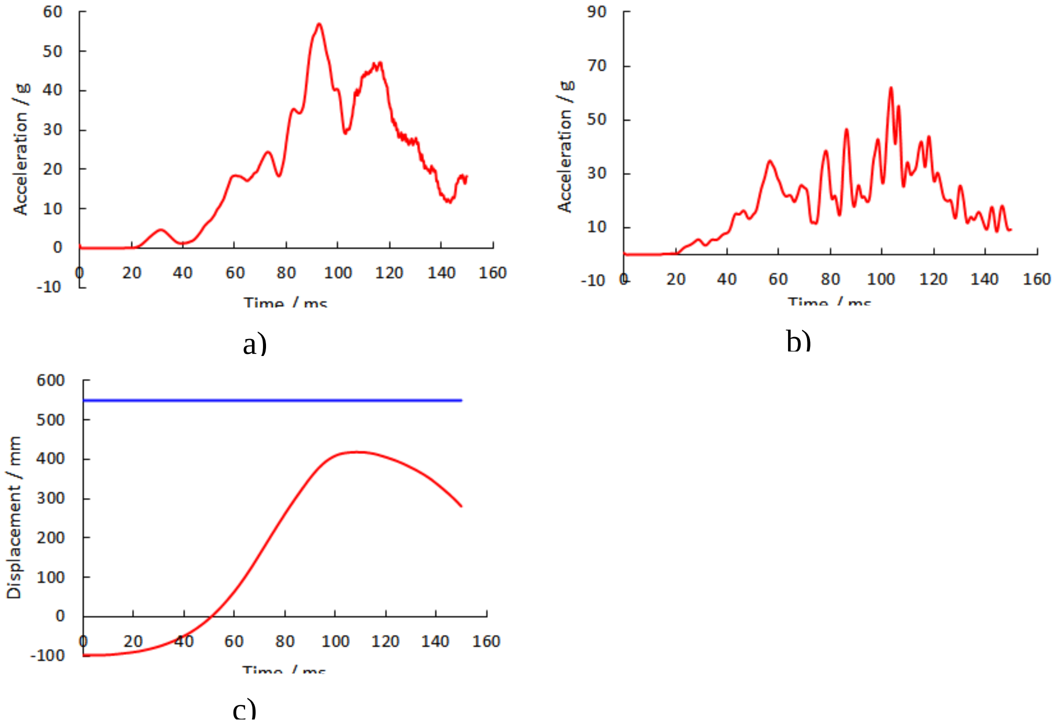


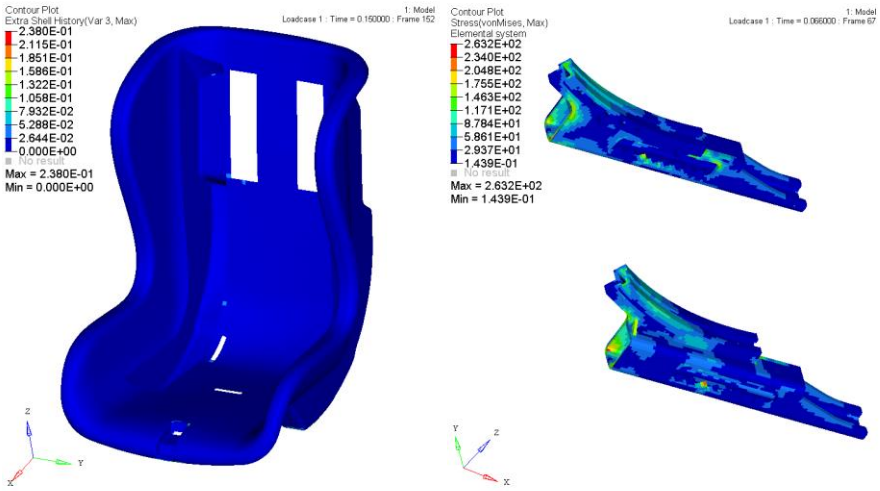
Fig. 7 Q3 dummy upright frontal collision(misoperation) simulation analysis curve

a)dummy head joint acceleration;b)dummy chest joint acceleration;c)Horizontal displacement of the dummy head

Table 1 Q3 dummy upright frontal collision(misoperation) simulation analysis results

	Horizontal displacement of the head/mm	Head (3ms) joint acceleration/g	HPC(15)	Chest (3ms) joint acceleration/g
Regulatory value	550	80	800	55
Simulation value	418.4	54.6	231.1	43.4

The structure of the carbon fiber child safety seat is analyzed, and the seat inner plate and slide rails with the most force are selected for research. the maximum damage factor cloud map of the seat inner plate and the maximum Von Mises stress cloud diagram of the slide rail mechanism are shown in Fig .8.It can be seen from the figure that the maximum damage factor of carbon fiber inner plate is 0.24,the computational safety factor is 4.2,and no damage occurs; the maximum equivalent stress of the slide mechanism is 216Mpa,the maximum equivalent plastic strain is 1.9%.small parts are plastically deformed but the mechanism doesn’t damaged.



a) b)

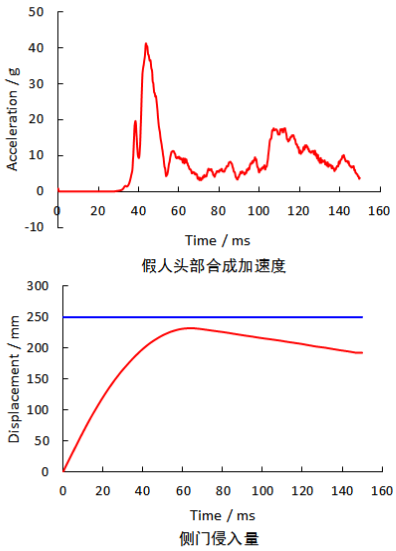
Fig. 8 Q3 dummy upright frontal collision(misoperation)seat force situation

a)the maximum damage factor cloud map of the seat inner plate; b)the maximum Von Mises stress cloud diagram of the slide rail mechanism

(2) Q3 dummy upright side collision

Fig. 9 shows the head joint acceleration and the head displacement curve of the dummy when the Q3 dummy is side-collided. Table 2 shows the comparison between the simulated value and the regulatory value. It can be seen that all indicators of the dummy meet the regulatory requirements.

The structure of the carbon fiber child safety seat is analyzed. the seat plate and slide rails with the most force are selected for research. The maximum damage factor cloud map of the seat inner plate and the maximum Von Mises stress cloud diagram of the slide rail mechanism are shown in Fig .10.It can be seen from the figure that the maximum damage factor of the carbon fiber inner plate is 1,and the unit is deleted, single or multiple layers of damage occur locally. For the side collision analysis, the seat is partially damaged and energy is absorbed due to direct contact between the door and the child seat so that children can be better protected. The maximum equivalent stress of the slide rail mechanism is 215Mpa,and the maximum equivalent plastic strain is 1.3%.small parts are plastically deformed but the mechanism doesn’t damaged.



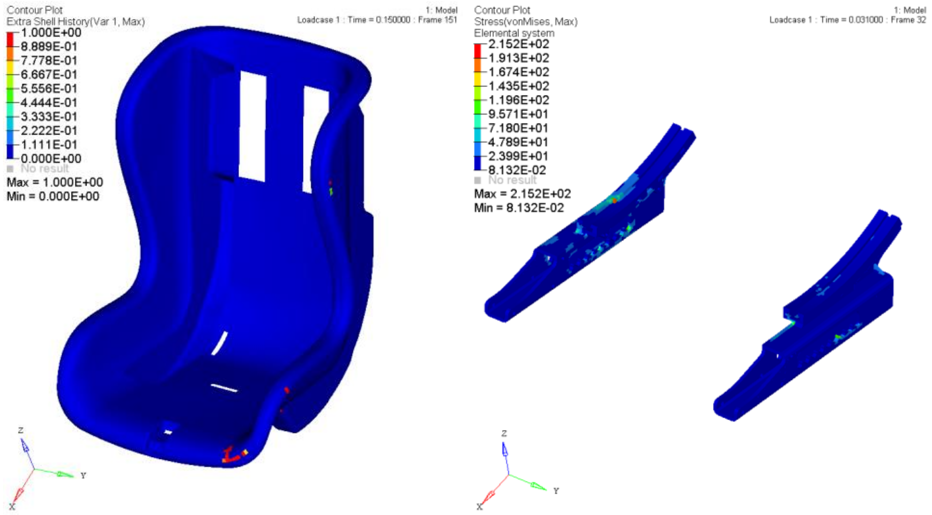
a)

b)

Fig. 9 Q3 dummy upright side collision simulation analysis curve a)dummy head joint acceleration; b)Side door displacement

Table 2 Simulation results of Q3 dummy upright side collision

	Side door displacement/mm	Head (3ms) joint acceleration/g	HPC(15)
Regulatory value	250	80	800
Simulation value	232	36.5	52.3



a)

b)

Fig. 10 Q3 dummy upright side collision(misoperation)seat force situation

a)the maximum damage factor cloud map of the seat inner plate; b)the maximum Von Mises stress cloud diagram of the slide rail mechanism

5. Conclusion

In order to solve the problem of overweight children's safety seat, this paper developed a lightweight carbon fiber child safety seat, and studied its structure and collision performance. The total weight of the seat is 6.86kg, which is more than 30% less than the conventional seat. The carbon fiber child safety seat has good collision safety performance. The maximum displacement of the head in frontal collision is 418.4mm, which is far below the regulatory value. The chest and head acceleration also meet the regulatory requirements. At the same time, it can meet the requirements in the latest ECE R129 regulations on side collision protection. Studies have shown that the application of carbon fiber composites to the design of child safety seats is available, and can greatly improve the performance of child safety seats while reducing weight.

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