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Research Article

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Design and analysis of a honeycomb filled anti-collision cylinder

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Abstract

A novel type of highway anti-collision cylinder is designed and the mechanical properties of the anti-collision cylinder under local impact are analyzed in this paper. The anti-collision cylinder includes center shafts, steel plates, stand columns, rotary cylinders, springs, supporting pedestals, and filled honeycombs. The designed anti-collision cylinder has good energy absorption efficiency, deceleration effect, relatively simple structure and low cost. The effects of impact speeds and different honeycombs filled on the anti-collision cylinder's failure modes, energy absorption and contact forces are studied. Aluminum alloy and nylon are used as the materials of the anti-collision cylinder to study the energy absorption capacity of the cylinders. The results obtained show that the collision cylinder filled hexagonal honeycomb has the largest specific energy absorption, followed by the semi-recessed honeycomb, and the re-entrant honeycomb has the smallest specific energy absorption. The impact velocity has significant effect on the impact failure mechanical properties of the anti-collision cylinder. The anti-collision cylinder made of nylon has anti-collision effect under low-speed impacts. Compared with the aluminum alloy anti-cylinder, the anti-cylinder made of nylon has greater ratio of the energy absorbed by the filled honeycomb to the total energy absorbed by the anti-collision cylinder. The research results obtained in this paper will provide new ideas for road safety protections.

Keywords: anti-collision cylinder, energy absorption, impact damage, 3-D honeycomb structure, dynamic responses

1. Introduction

1.1. Anti-collision cylinders on the highway

Highway crash guardrails are the transportation infrastructure that ensures road safety. When a vehicle is driving on the road, especially on the highway, once the vehicle has an accident, it is very danger, so the anti-collision devices are necessary to reduce the injury caused by accidents. Nowadays, the guardrails installed on the highway are basically semi-rigid guardrails. When the guardrails are hit by vehicles, the collision energy is absorbed through the deformation of guardrails to reduce the damage and injuries on vehicles and passengers. On the other hand, the driving direction of the vehicle is forcibly corrected to prevent the vehicle from rushing off the highway. However, the vehicles on highway have large kinetic energy and the function of guardrails is limited, which can easily cause vehicles to damage guardrails and rush out of the highway, or vehicles to rush out in the opposite direction and maybe hit other normal vehicles on the highway and resulting in greater accidents.

In order to enhance the protection capacity of the guardrail, a rotating cylinder-type guardrail

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was proposed to improve the guiding ability of the guardrail recently. However, such guardrails have almost no energy conversion at the moment of impact, and the vehicle still carries a large kinetic energy when it is bounced in reverse, which will also increase the severity of secondary accidents. Another anti-collision cylinder is filled with water, it transmits the impact force to the water in the cylinder, and the flip cover is opened under the pressure of the water to spray water to dissipate energy. In addition, in sections without avoidance lanes, the out-of-control vehicles have to reduce vehicle kinetic energy by hitting the guardrail. Although deceleration can be achieved by hitting semi-rigid guardrails, it may cause damage to vehicles and guardrails and injuries. Highway crash barriers have broad application prospects, but there are many shortcomings in existing highway anti-collision devices. The existing highway crash barriers have anti-collision effects, but their deceleration effect needs to be improved.

1.2. A review on energy absorption and honeycomb structure research

It is well known that honeycomb structure has strong energy absorption characteristics, crashworthiness, high specific strength, large specific stiffness, light weight, etc. Honeycomb cells in different geometric configurations will produce different mechanical properties, such as negative Poisson's ratio, this kind of honeycomb has high shear strength and energy absorption capacity. Therefore, honeycomb structures have been widely used in aerospace, transportation, vehicle engineering and other fields and the research on honeycombs in impact resistance, protection, crashworthiness and other aspects has become a hot spot. For example, Sherman et al. [1] developed both numerical and theoretical models to analyze the energy absorption behaviors of bio-inspired honeycombs. Wang et al. [2] proposed a novel re-entrant auxetic honeycomb structure and discussed the effects of the wall thickness and impact velocity on the crushing strength of the honeycomb. Niranjan et al. [3] studied the deformation mode, stress-strain response and energy absorption behavior of an optimal re-entrant auxetic honeycomb and compared with conventional re-entrant auxetic structure.

Zhang et al. and Wang et al. [4, 5] conducted the dynamic response of multilayer curved aluminum honeycomb sandwich structures under low-speed impact. Wu et al. [6] proposed numerical and experimental studies on the dynamic response and energy absorption characteristics of aluminum honeycomb sandwich panels under the impact of ice wedges. Nian et al. [7] proposed a novel self-similar graded honeycomb-filled thin-walled structure that exhibits better energy absorption characteristics than uniform honeycomb-filled round tubes. Sarkhosh et al. [8] experimentally studied the crashworthiness characteristics of four cases including cylindrical hollow composite tubes, aluminum honeycomb-filled tubes, polyurethane foam-filled tubes, and polyurethane foam/aluminum honeycomb-filled cylindrical composite. Over the past few decades, researchers have proposed many different types of two-dimensional honeycomb structures. Among the many forms of honeycomb structure, the most common and earliest studied is the hexagonal honeycomb structure. It is later known that the re-entrant honeycomb structure has a variety of unique mechanical properties. Based on the above two honeycomb structures, the researchers combined them to propose a novel semi-concave honeycomb structure, which has good stability because it has no lateral strain.

The aforementioned literature focused on two-dimensional honeycombs, while three-dimensional periodic honeycomb structure is more complex. When the 3D auxetic honeycomb compresses under impact loads, the honeycomb shows negative Poisson's ratio effect in other two

directions accompanied by a sharp increase in stiffness to strengthen the protection function. This is more suitable for applications in impact resistance. However, due to the difficulty of manufacturing, the development of 3D auxetic structure application is restricted. In recent years, an advanced additive manufacturing technology has developed rapidly, which has made the production of complex 3D structures possible. Some novel and modified three-dimensional honeycomb structures are proposed, such as rhombic dodecahedron honeycomb structures, double arrow auxetic structures and re-entrant hexagonal structures. Li et al. [9] designed a novel single-cell structure with re-entrant hollow skeleton, providing a new method for fabricating hybrid cellular honeycomb structures with various physical and mechanical properties. In the literature [10, 11], the impact responses of the auxetic sandwich structure were studied. Zhang et al. [12, 13] applied 3D double-arrowed structure as an energy absorber to enhance the passive safety of the car. Gao et al. [14, 15] conducted geometric parametric analysis on the 3D double-arrowed auxetic structures from macro to micro-sized scales to investigate the geometric parameter on the crashworthiness performance, and finally obtained the optimal geometric parameter configuration of the structure.

Due to the excellent performance of the 3D honeycomb in terms of energy absorption capacity, it is widely used as energy absorber. Ma et al. [16] proposed a novel type three-dimensional hexagonal structure-filled crash box and found that the three-dimensional hexagonal structure has great advantages in terms of the energy absorption at varying inclination angles. The literature [17, 18] designed 3D honeycombs and studied the energy absorptions. Gong et al. [19] discussed the effect of Poisson's ratio on local impact resistance of honeycomb structure and showed that positive Poisson’s ratio honeycomb has better protection ability. Wang et al. [20] designed a crash box with negative Poisson's ratio by structural bionics to improve the crashworthiness and energy absorption. Wang et al. [21] showed that the fuselage section with the 3D NPR structure energy-absorbing structure they have designed has better energy absorption capacity than the one without it. Li et al. [22] proposed an innovative foam-filled honeycomb core structure crash box and provided new ideas for the design of the crash box. Kholoosi et al. [23] proposed an energy-absorbing design scheme for helmets made of graded honeycomb structure in order to reduce the impact load of helmets in traffic accidents and found that honeycomb structure absorbs energy for a longer duration and transfers impact force to the user with lower acceleration.

Although three-dimensional honeycomb structure is used as an energy-absorbing device in many fields, the application of 3D honeycomb structure in highway anti-collision cylinder is still limited, and its application field needs to be expanded. In this paper, the 3D honeycombs are filled in a novel type of highway collision cylinder. The highway collision cylinder designed in this paper is simple and not only has good energy absorption efficiency during impact, but also has deceleration effect. It will provide good protection for some vehicles with brake failure. The dynamic response and energy absorption characteristics of the anti-collision cylinder under impact of a car are studied. The finite element models of the anti-collision cylinder and the impact car are established. The influence of different impact speeds and different types of honeycomb filling on the failure mode of the anti-collision cylinder, the contact force and energy absorption effect of the car are discussed, respectively. The anti-collision cylinder designed in this paper will give a certain protective role in the safety of drivers and passengers. Therefore it has broad application prospects and will provide new ideas for the design of anti-collision cylinders.

2. Structural design and models

2.1. Design of the anti-collision cylinder

The honeycomb-filled highway anti-collision cylinder is mainly composed of central axis 1, steel plate 2, stand column 3, rotary cylinder 4 and spring 5. It is filled with honeycomb structure inside of the cylinder as shown in Figure 1. The steel plate is U-shaped. The steel plate and the central shaft are connected by springs. The parameters such as the number of coils and stiffness of the spring etc. are adjusted according to the road type and speed limit. The outer wall of the central shaft is connected with a rotary cylinder. The stand column is connected with the steel plate. The supporting pedestal is installed at the bottom of the stand column. The lower end of the central shaft is provided with a shaft shoulder for positioning the rotary cylinder. The rotary cylinder rotates around the central shaft for guidance and deceleration. The spring and the rotary cylinder cooperate to decelerate the runaway vehicle through the combined action of the deformation of the rotary cylinder and bending stretching of the spring.

The number of the central shafts and the rotary cylinders are same. The steel plates and stand columns are connected by bolts. The central shaft and the rotary cylinder are connected by a direct clearance fit and there is friction between the rotary cylinder and the central shaft. The steel plate and spring, shaft and spring are fixed with bolts. The steel plate can prevent the car from rushing out of the road. There are reflective strips on the rotary cylinder for warning.

The anti-collision cylinder is filled with honeycomb structure to enhance energy absorption capacity, to protect drivers and passengers, to avoid secondary accidents or reduces the intensity of the secondary accidents, to reduce the speed and damage of the vehicle. Therefore, the anti-collision cylinder designed has good application prospects.

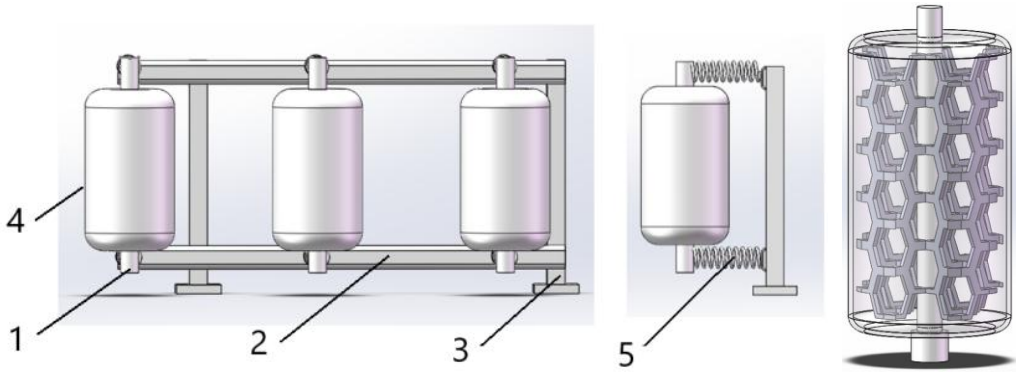


Figure 1. Structural composition diagram of the anti-collision cylinder

2.2. Geometric models of car and honeycombs

The outer radius of the cylinder wall is 26mm, the inner radius is 24.5mm, that is, the wall thickness of the cylinder wall is 1.5mm, and the cylinder height is 88.8mm. The size of the crash car model is shown in Figure 2. The length of the car is 80mm, the width is 30mm and height is 30mm. The impact surface of the car is provided with a rounded corner with a radius of 10mm, the car model is shelled inward and the shell thickness is 2 mm.

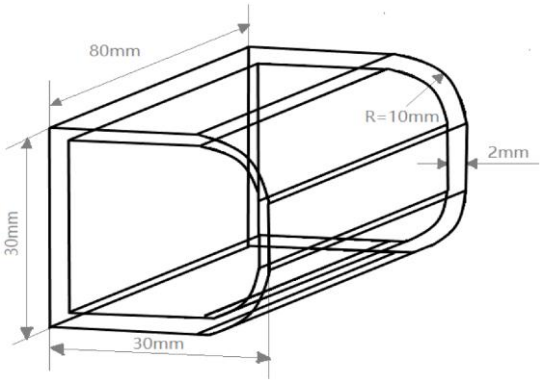


Figure 2. The model of the car

As shown in Figure 3, a 3D re-entrant honeycomb cell is obtained by assembling two vertically crossed 2D re-entrant honeycombs. Based on this element, 3D re-entrant honeycomb structure is designed. The filling honeycomb is cut off by a circle with radius of 24mm. There is a small gap between the honeycomb and the cylinder wall. Three different types of honeycomb filling in the cylinder are compared to study the energy absorption efficiency of the anti-collision cylinder. Three different 3D honeycombs are hexagonal honeycomb, re-entrant honeycomb and semi-concave honeycomb respectively, as shown in Figure 4. The parameters are h=10mm, l=7mm, t=1.5mm, and the out of plane depth is 1.5mm, θ= 30°. The unit cells of these different honeycombs have the same sizes and the volume of the honeycombs filled in anti-collision cylinder is the same.

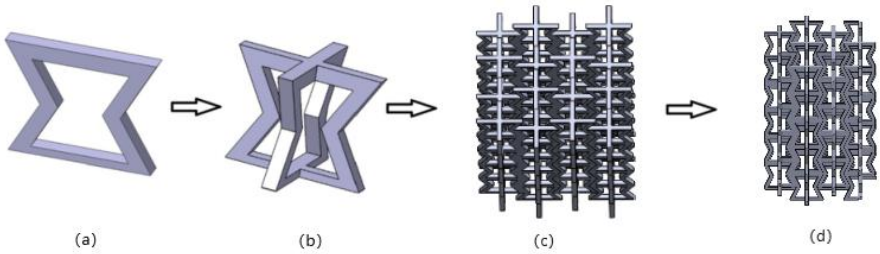


Figure 3. Design of 3D auxetic honeycomb

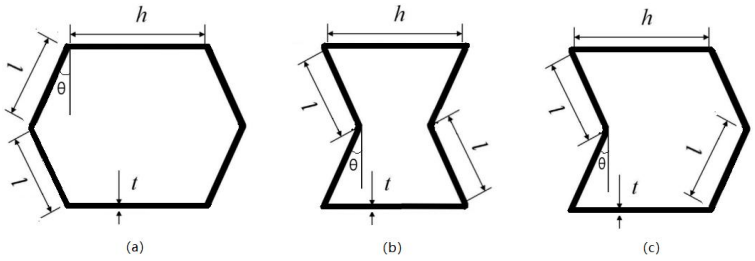


Figure 4. The cells of different honeycombs

2.3. The finite element models

The explicit nonlinear finite element software LS-DYNA is used to study the dynamic crushing behavior and energy absorption characteristics of the honeycomb structures in the anti-collision cylinder. Solid elements are used in the finite element model of the structure as shown in Figure 5. The 3D honeycomb structure is placed in the cylinder that is held in place by a shaft. The anti-collision cylinder is hit by a moving car. The impact direction of the car is radial impact. The option *CONTACT_ AUTO_ SURFACE_TO_SURFACE defines the contact relationship between the wall of the anti-collision cylinder and the car. The static coefficient of friction is set as 0.3 and a

dynamic coefficient of friction is set as 0.2. In addition, the option *CONTACT_AUTOMATIC_SINGLE_SURFACE is defined to achieve self-contact of the honeycomb core. Define rigid shaft with fixed constraint boundary conditions as （$U_x=U_y=U_z=U_x=U_y=U_z=0$）. The car is set as a rigid body, and the range of the car impact speed is 15-25m/s. Stiffness-based hourglass control is used to avoid pseudo-zero energy deformation modes. The honeycomb and the car are tetrahedral meshed with a mesh size of 2mm, and the impact area is meshed to refine the mesh size of 1mm. Table 1 shows the number of elements and nodes. This paper mainly compares the mechanical properties of different honeycombs filled anti-collision cylinder and the mechanical properties of anti-collision cylinder at different impact speeds.

Table 1 Number of elements and nodes of three types of honeycomb filled anti-collision cylinder

	None	HS	RS	HRS
Nodes	41229	53855	63417	60782
Elements	160748	195383	221072	218282

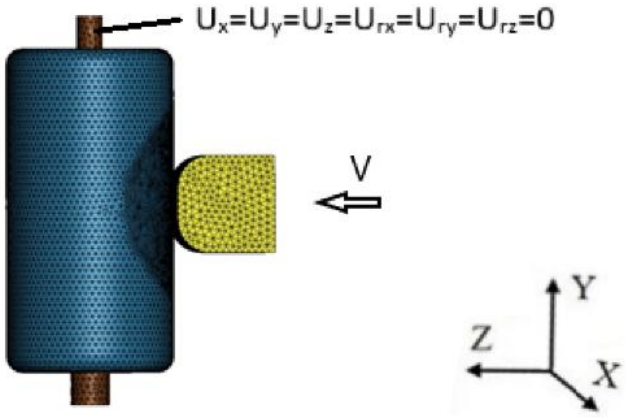


Figure 5. The finite element models

2.4. Constitutive and the failure models of materials

Aluminum alloy has the advantages of low density, good corrosion resistance and high strength, therefore the aluminum alloy is chosen as the material of the anti-collision cylinder under medium -high speed impacts. The J-C model with *MAT_015 (MAT_ JOHNSON_COOK) in the ANSYS/LS-DYNA material library is utilized to simulate the material model of the anti-collision cylinder.

The shaft and car are set as rigid bodies. The structural steel in the Ansys-workbench material library is selected as the material of the car. The mass of the car is 1.51Kg. The anti-collision cylinder uses materials 2024-T3 aluminum alloy [24]. The density of 2024-T3 aluminum alloy is 2700kg/m^3, the elastic modulus is 73.1GPa and Poisson's ratio is 0.33. The 2024-T3 aluminum alloy adopts the J-C model [25]. The J-C model takes into account the effects of material strain, strain rate and temperature, so it is widely used in impact dynamics research.

Without considering the influence of temperature during impact, the yield stress of the material can be expressed as follows [25]

$$\sigma_Y = \left(A + B\bar{\varepsilon}_p^n\right)\left(1 + C\ln\dot{\varepsilon}^*\right) \tag{1}$$

where A is the initial yield stress of the material at the reference strain rate $\dot{\varepsilon}_0$, B and n are the hardening modulus and hardening index of the material at the reference strain rate, respectively. C is the strain rate hardening parameter of the material, $\bar{\varepsilon}_p$ is the effective plastic strain, and $\dot{\varepsilon}^*$ is the strain rate.

The degradation of material stiffness is simulated by damage degree D. When there is no damage occurs D=1, and D=0 if the material fails. The damage degree D can be expressed by the following formula

$$D = \sum \frac{\Delta\varepsilon_p}{\varepsilon^f} \tag{2}$$

where $\Delta\varepsilon_p$ is the equivalent plastic strain increment in one time step, ε^f is the failure strain at the current moment

$$\varepsilon^f = \left[D_1 + D_2\exp\left(D_3\sigma^*\right)\right]\left(1 + D_4\ln\dot{\varepsilon}^*\right) \tag{3}$$

where D1~D4 are the failure parameters of the material, σ^* is the stress triaxiality $\sigma^* = p/\sigma_{\text{eff}}$ and p is the hydrostatic pressure. σ_{eff} is the Von Mises equivalent stress. Table 2 shows the J-C model material parameters of 2024-T3 aluminum alloy.

Table 2 J-C material parameters of aluminum alloy

A(MPa)	B(MPa)	n	C	$\dot{\varepsilon}_0$/s^{-1}	D_1	D_2	D_3	D_4
369	684	0.73	0.0083	1	0.112	0.123	-1.5	0.007

3. Reliability verification

3.1. Performance evaluation index

In order to evaluate the impact energy absorption effect of energy-absorbing structures and improve the protective effect of the structure, it is necessary to select appropriate energy-absorbing characteristic evaluation indicators. The collision evaluation indicators are used to evaluate the energy-absorbing efficiency of the energy absorption system in the initial design stage of the energy absorption system.

The crashworthiness of structures can be evaluated by the total energy absorbed (EA), peak crushing force, average crushing force, crushing force efficiency and specific energy absorption (SEA) [26, 27]. The total energy absorption under the same relative density are computed most. But for complex structure it is difficult to calculate the relative density, SEA can be compared. These indicators are explained below.

Total energy absorbed

The total energy absorbed in the collision is equal to the area under the force displacement curve defined as follows

$$EA = \int P\mathrm{d}\delta \tag{4}$$

where P and δ represent crushing force and corresponding displacement respectively.

Specific energy absorption

When weight effect is considered in the design, SEA is more suitable for describing the energy absorption capacity of a structure, representing the energy absorbed per unit mass of the structure, as shown below

$$SEA = \frac{EA}{M} \tag{5}$$

The SEA describes the material utilization of a structure during energy absorption. In general, the higher SEA means the higher the energy absorption efficiency of the honeycomb structure. In this paper, EA and SEA are mainly used as energy absorption indicators to characterize the energy absorption efficiency of the honeycomb filling anti-collision cylinder.

3.2. Effective validation of the model

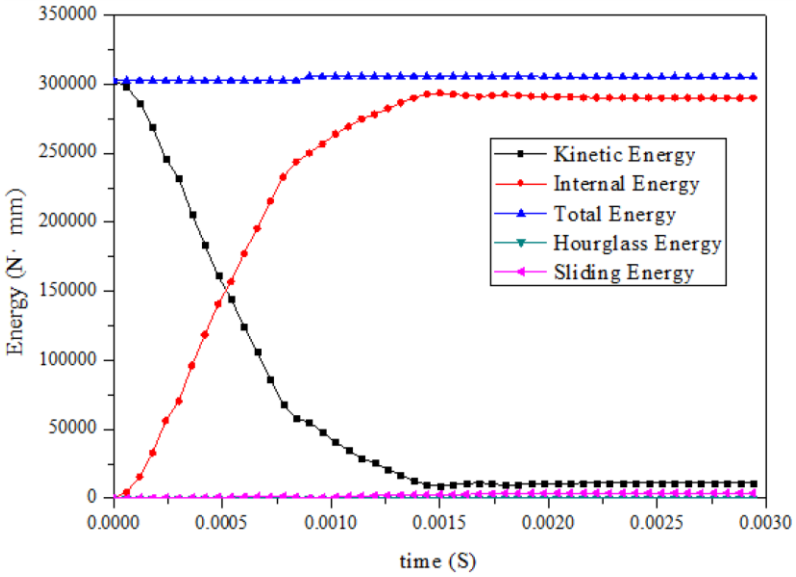
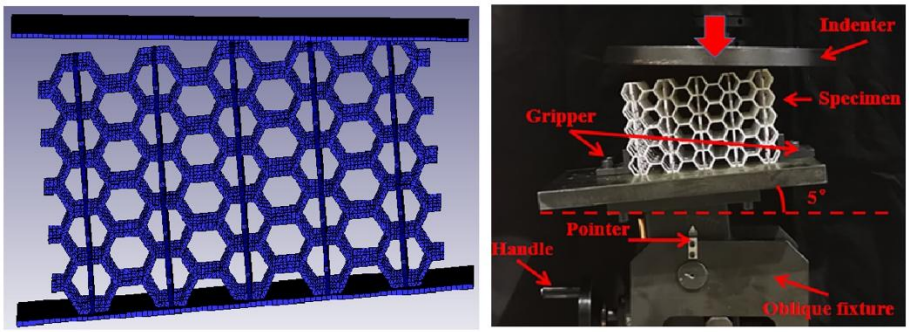


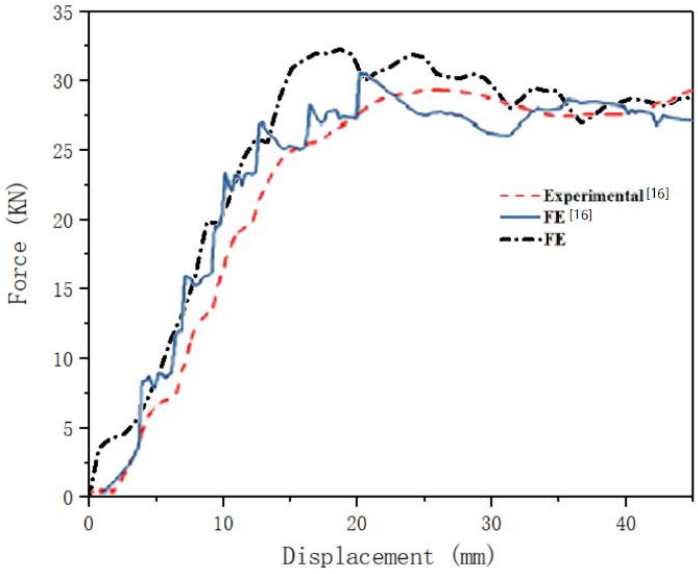
Figure 6. Energies of the anti-collision cylinder

The hourglass energy is an important indicator of grid quality for the element model [28]. It can be seen from Figure 6 that the hourglass energy is less than 5% of the total internal energy to meet the requirements. Figure 6 shows that the total energy of the system is conserved, that is, the kinetic energy of the car during the collision process is completely converted into the internal energy of the system. The energy is absorbed mainly through the deformation of honeycomb structure and cylinder wall.

In order to further verify the accuracy of the finite element simulated method in this paper, the same three-dimensional hexagonal honeycomb model in the literature [16] is selected for verification. The force-displacement curve of the honeycomb structure under the action of oblique pressure is compared and analyzed. The finite element model in this paper and the experimental model in literature [16] are shown in Fig. 7(a) and 7(b) respectively. It can be seen from Figure 7(c) that the numerical simulation result in this paper is in good agreement with the experimental result in literature [16], which verifies the correctness of the finite element impact model in this paper.



(a) The finite element model in this paper (b) Experimental set in [16]



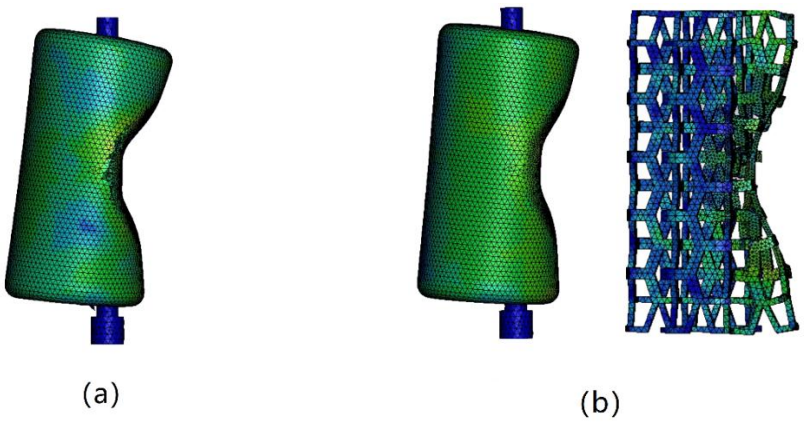
(c) Comparison

Figure 7. Compare with literature [16]

4. Results and discussions

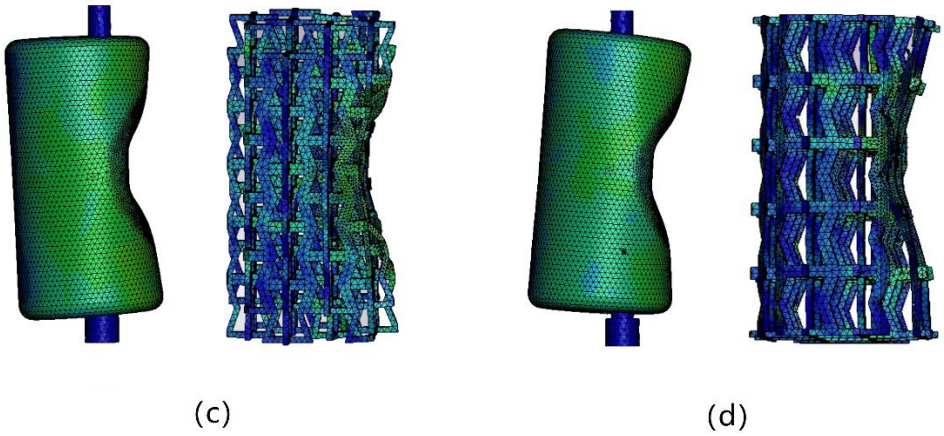
4.1 Effect of different filled honeycombs on mechanics of the anti-collision cylinder

In this section, three kinds of honeycomb-filled anti-collision cylinders and empty cylinders are numerically simulated, respectively. The impact speed of the car is 20m/s. The deformations of the anti-collision cylinder of the three-kind filled-honeycombs are shown in Figure 8, it can be found that the deformed modes are consistent. The shape of the pit is same as the shape of the car, the pit of the hexagonal honeycomb-filled cylinder is the largest, and the re-entrant honeycomb's is the smallest, because the relative density of the hexagonal honeycomb is the smallest and the relative density of the re-entrant honeycomb is the largest under the same volume of unit cells. This also indirectly indicates that the relative density has a great influence on the deformation of the honeycomb. It can be seen from Figure 8 that the cylinder without honeycomb filling has cracks. The fit between the cylinder and the shaft is damaged. The wall of the cylinder is not damaged with honeycomb filled and there is a slight damage where the shaft fits the cylinder wall. It is indicated that honeycombs can effectively protect the cylinder wall.



(a) (b)

(a) Empty cylinder (b) Cylinder filled with hexagonal honeycomb



(c) Cylinder filled with re-entrant honeycomb (d) Cylinder filled with semi-concave honeycomb

Figure 8. Deformation of honeycomb and cylinder wall

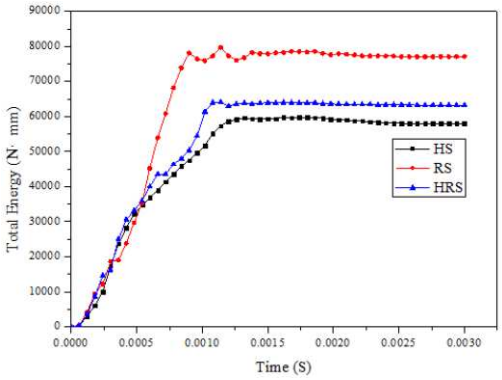


Figure 9. Energy absorption

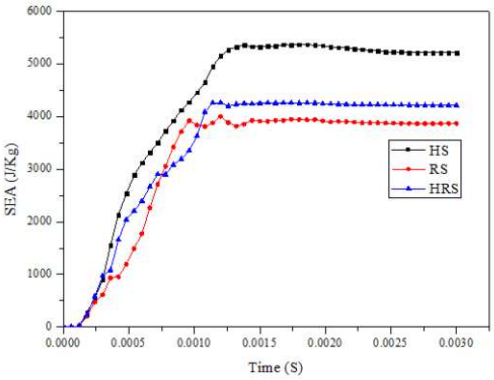


Figure 10. Specific energy absorption

It is known that the energy absorption is a very important indicator for anti-collision structures. This section compares the EA and SEA of the three honeycombs-filled anti-collision cylinders. When the anti-collision cylinder is hit, the concave deformation of the cylinder wall and the honeycomb in the cylinder will absorb some energy firstly, and then the honeycomb and the cylinder wall will be destroyed one after another to absorb energy, and the kinetic energy of the car will be converted into the deformation and the kinetic energy of the cylinder wall and the honeycomb. When installed on the highway guardrail, the anti-collision cylinders can be rotated during the impact, which can absorb some energy. The total energy absorption curve of the three different anti-collision cylinders is shown in Figure 9, it can be seen that the EA continues to increase with increase of time, this corresponds to the fact that the honeycomb and the wall of the cylinder are successively destroyed to absorb energy. The energy reaches a maximum at about 0.0015s, and then remains unchanged. At this moment, the collision is over, the total energy remains constant and the filled honeycomb is densified. If the anti-collision cylinder is made of elastic materials, the energy absorbed by the anti-collision cylinder will decrease after reaching the peak and will transmit some elastic potential energy to the car.

It can be seen from Figure 9 that the re-entrant honeycomb-filled anti-collision cylinder has the largest energy absorption, the semi-concave honeycomb-filled cylinder is the second, and the

hexagonal honeycomb-filled cylinder is the smallest. The the relative densities of these three kinds of honeycombs from large to small order are re-entrant honeycomb, semi-concave honeycomb and hexagonal honeycomb.

In order to eliminate the influence of the relative density of the honeycomb on the total energy absorption and find out the honeycomb structure which is the best energy absorption capacity at the same quality, the SEA is computed to evaluate their energy absorption efficiency. It can be seen from Figure 10 that the SEA is the opposite of the EA, the hexagonal honeycomb-filled cylinder has the largest specific energy absorption, the semi-concave honeycomb-filled cylinder is the second and the re-entrant honeycomb-filled cylinder is the smallest. It is indicated that hexagonal honeycomb has the best energy absorption effect among the three. The results in the literature [16] are also confirmed this.

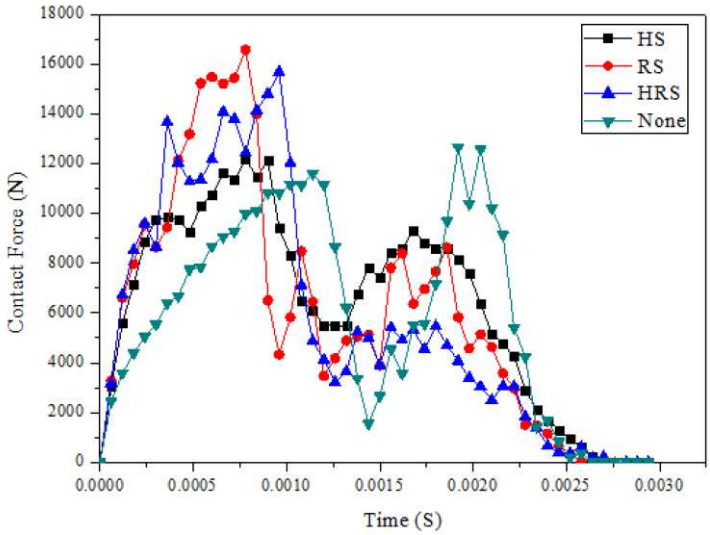


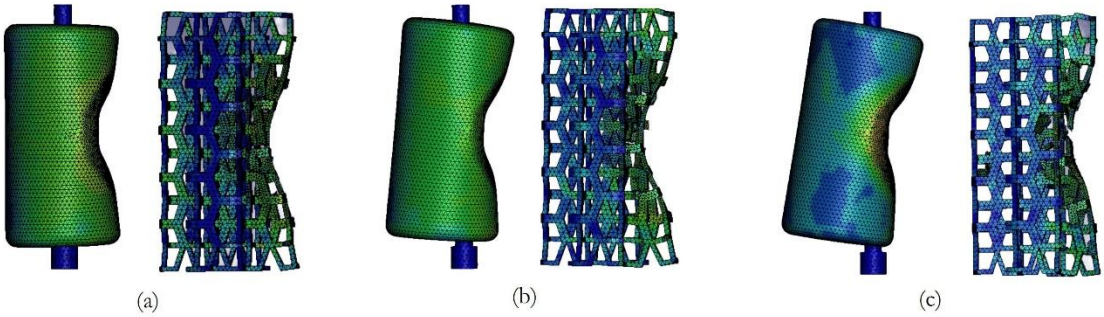
Figure 11. Comparison of contact forces

Figure 11gives the contact forces during impact, the time history of contact force on the car is obtained by numerical calculation. It can be observed that the contact force curves of anti-collision cylinders filled with three different types of honeycomb are relatively consistent. The contact forces increase to the first peak and then decrease. Because after the first peak of the force, the anti-collision cylinder moves backward, and the cylinder wall starts to be damaged at the place where the shaft fits the anti-collision cylinder. The contact force reaches a minimum value at about 0.00125s, and it is found from Figures 9 and 10 that the energy basically reaches a maximum at this moment, indicating that the filled honeycomb is densified. After the first peak and decrease, the contact forces then increase again to reach the second peak and finally decreases to 0 and it is the material that bears the impact at this stage because the honeycomb has been densified.

The re-entrant honeycomb-filled anti-collision cylinder has the largest peak contact force in the first peak forces, followed by semi-recessed honeycomb and hexagonal honeycomb, and the empty cylinder is the smallest. It shows that the bearing capacity of the re-entrant honeycomb is better, and the empty cylinder is the lowest. In the second peak force, the empty cylinder has the largest peak contact force, followed by hexagonal honeycomb, re-entrant honeycomb, and semi-recessed honeycomb is the smallest. The larger the second peak, the greater the kinetic energy of the car at this moment, and the worse the deceleration effect of the anti-collision cylinder. The

impact contact time of these honeycomb-filled anti-collision cylinders is basically the same, but the re-entrant honeycomb-filled anti-collision cylinder reaches the peak at the earliest and the empty cylinder reaches the peak at the latest, which indicates that the honeycombs in the cylinder can improve the bearing capacity of the anti-collision cylinder. In conclusion, the filled honeycomb can effectively protect and reduce the damage of the cylinder body.

4.2 Effect of different impact velocity on mechanical properties of anti-collision cylinder



(a) Impact speed is 15m/s (b) Impact speed is 20m/s (c) Impact speed is 25m/s

Figure 12. Deformation of anti-collision wall and filled honeycombs

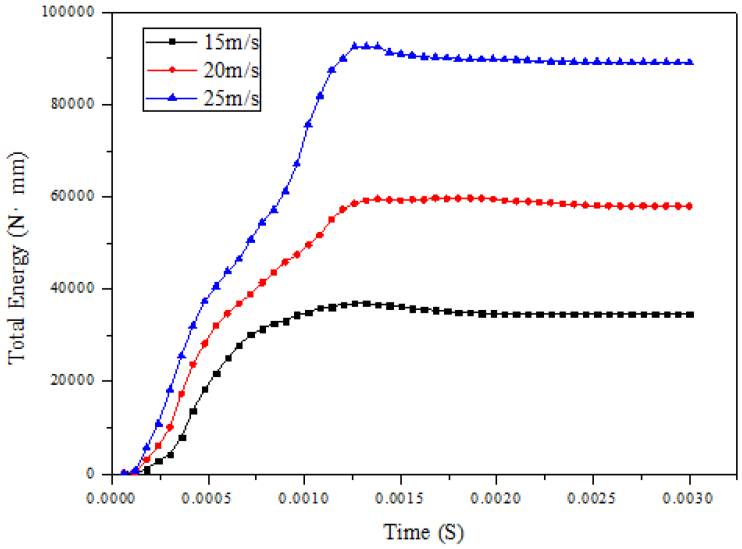


Figure 13. Absorption energy under different impact speed

Figure 12 shows the deformations of the anti-collision cylinder wall and the honeycombs inside at different impact speeds of the car. When the speed is 15 m/s, the deformation of the cylinder wall and honeycomb is not big, but the honeycomb begins to be damaged and the anti-collision cylinder is not damaged. When the speed of the car is 20 m/s, the deformation of the cylinder wall and honeycomb is larger, the damage degree of the honeycomb increases, and the wall of the anti-collision cylinder is damaged at the place where it fits with the shaft. When the speed of the car is 25 m/s, the deformation of the cylinder wall and honeycomb is the largest, and some of the honeycombs are knocked away, and the wall of the anti-collision cylinder is the most damaged at the place where it fits with the shaft, and small cracks appears in the cylinder body. The anti-collision cylinder can be protected better by increasing the relative density of the filled honeycombs. Figure

13 shows the time-energy curve of the hexagonal honeycomb filled in the anti-collision cylinder at different impact velocities of the car. It can be seen from figure 13 that the greater impact speed of the car, the more energy absorption of the honeycomb in the collision cylinder.

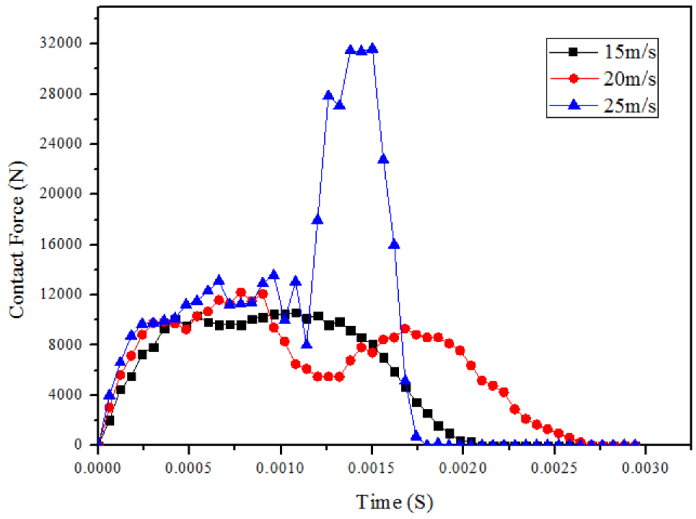


Figure 14. Contact force under different impact speeds

Figure 14 shows the contact force-time curve of the car at different impact speeds. It can be seen that the contact force curves at the three impact velocities tend to be consistent at the beginning of the impacts. With the impact increase, the contact forces at different speeds show different trends. At speed of 15 m/s, the contact force increases at first and decreases to 0 slowly after reaching the peak. When the impact speed is 20 m/s, the contact force is consistent with the trend of 15 m/s at the beginning and end, but there is a drop in the middle of the curve, which is caused by the destruction of the anti-collision cylinder and the rebound of the car. When the impact velocity increases to 25 m/s, the contact force rises slowly at first and decreases slightly at about 0.0011s, and then rises sharply to a certain peak, and then begins to decline. The reason maybe that the honeycomb is compacted, and its stiffness becomes larger.

5. Low speed impacts

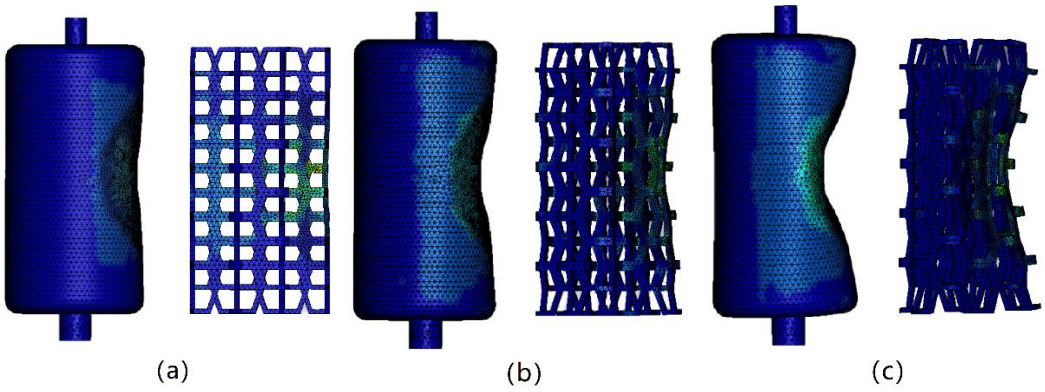
For some mountain roads and highways with low speed limits, the impact energy is relatively low, therefore the anti-collision cylinder can be designed of crash-resistant plastic materials such as nylon. The modified nylon material has excellent toughness, wear resistance and impact resistance. In this section, the numerical simulation is given for the anti-collision cylinder made of nylon under low speed impacts. The material parameters of nylon are shown in Table 3. The material constitutive model is an elastoplastic model, * MAT_003 (MAT_PLASTIC_KINEMATIC) is selected, and the rest of the parameters are the same as the above settings.

Table 3 material parameters of nylon PA6GF33

Density($g \cdot cm^{-3}$)	Young's Modulus(Mpa)	Poisson's Ratio	Yield Strength(Mpa)	Tangent Modulus(Mpa)
1.39	10000	0.4	100	5000

Figure15 shows the deformations of the anti-collision cylinder made of nylon under low speed impact. It is found that the deformation of the anti-collision cylinder gradually increases with the increase of speed. It can be seen that the plastic nylon anti-collision cylinder can also play good

energy-absorption and protection effects under low-speed impacts.



(a) Impact speed is 2m/s (b) Impact speed is 5m/s (c) Impact speed is 10m/s

Figure15. Deformation of the anti-collision cylinder and the filled honeycomb

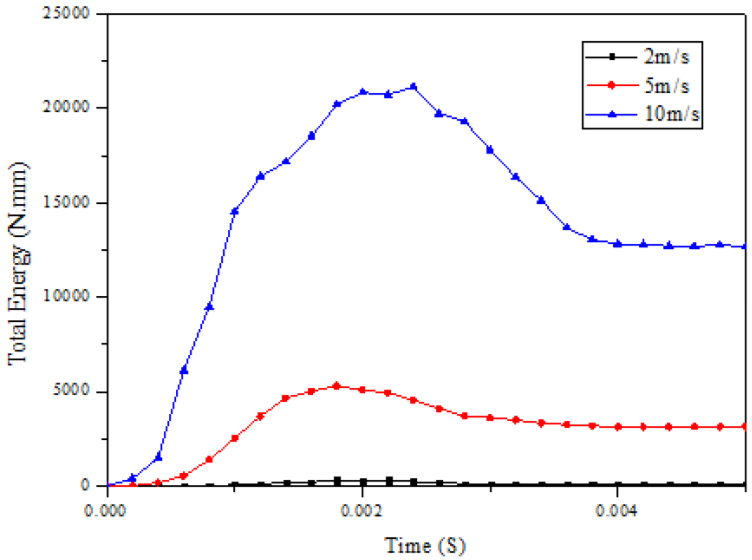
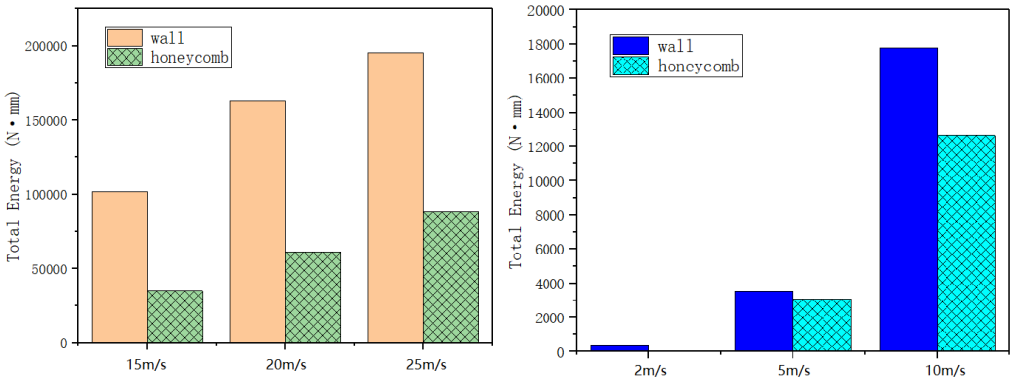


Figure 16. Total energy of nylon anti-collision cylinder under low speed impacts

The time-energy curve of the hexagonal honeycomb-filled collision cylinder at low impact speeds is shown in Figure 16. It can be seen from the figure that the larger the speed of the car, the more energy absorption by the honeycomb filled in the anti-collision cylinder. The honeycomb has almost no energy absorption under speed of 2m/s, because the deformation of the anti-collision cylinder is small, and the honeycomb is almost no deformation. It can be found that the energy curve will decline after rising to the peak first, because the nylon has a certain elasticity as a plastic, which will convert part of the elastic potential energy into the kinetic energy of the car, and there is no such phenomenon when the aluminum alloy is used as the material of the anti-collision cylinder.



(a) Anti-collision cylinder made of aluminum alloy (b) Anti-collision cylinder made of nylon

Figure 17. Energy absorption of filled honeycomb and cylinder wall

The total energy absorption of honeycombs and the cylinder wall is computed respectively. Figure 17(a) shows the energy absorption of the anti-collision cylinder made of aluminum alloy under high speed impacts. Figure 17(b) is the energy of the anti-collision cylinder made of nylon under low speed impacts. It is found that the higher speed, the more energy absorption of the anti-collision cylinder. As shown in Figures 17(a) and 17 (b), when nylon is used as the material of the anti-collision cylinder, the ratio of the energy absorbed by the honeycomb to the total energy absorbed by the anti-collision cylinder becomes larger than that of used aluminum alloy. The maximum proportion is 46.6% when the impact speed is 5m/s. It can be inferred that the smaller the stiffness of the material, the greater the proportion of energy absorption of the filled honeycomb in the collision cylinder.

6. Conclusions

In this paper, a novel type of highway anti-collision cylinder is designed. The effects of car impact speeds and different filled honeycombs on the anti-collision cylinder's failure modes, energy absorption and contact force between the anti-collision cylinder and the car are studied. Aluminum alloy and nylon are used as the materials of the anti-collision cylinder to study their energy absorption capacity. Based on the preliminary simulation results and analysis, the key results are as follows:

(1) The anti-collision cylinder designed in this paper is relatively simple and low cost, so it can be manufactured and used for road safety protection. The anti-collision cylinder has a good energy absorption efficiency and deceleration effect. The mechanical properties of the anti-collision cylinder under the action of local impact are analyzed by numerical calculation.

(2) It is indicated that the filled of honeycombs in the cylinder can improve the bearing capacity of the anti-collision cylinder, and it can effectively protect the cylinder body. The greater impact speed of the car, the more energy absorption of the honeycomb in the collision cylinder. Increasing the relative density of the filled honeycomb can protect the anti-collision cylinder better. Among the three honeycomb-filled anti-collision cylinders, the hexagonal honeycomb filled cylinder has the largest specific energy absorption, followed by the semi-concave honeycomb filled cylinder and the re-entrant honeycomb filled cylinder is the smallest. The re-entrant honeycomb reaches the peak at the earliest and the cylinder without honeycomb filled reaches the peak at the latest.

(3) During medium-high speed impacts, the impact damage modes of the anti-collision cylinder depend on the impact speed of the car. When the impact speed is 15m/s, the wall of the anti-collision

cylinder and the honeycomb filled inside have great deformation, and a small part of the honeycomb is damaged. With the increase of impact speed, the deformation of the honeycomb and the cylinder wall increases, and the damage of the anti-collision cylinder is also relatively serious. The damage of the cylinder wall starts from the place where the cylinder wall and the shaft fit. This will provide some guidance for the structural design of the anti-collision cylinder.

(4) For the low-speed impacts, the plastic nylon anti-collision cylinder can also play a good effect on the energy absorption and protection. Compared with the cylinder made of aluminum alloy, the cylinder made of nylon has lager proportion of energy absorption by the filled honeycomb to the total energy absorbed by the cylinder. It can be inferred that the smaller the stiffness of the material, the greater the proportion of energy absorption of the filled honeycomb in the collision cylinder.

In addition, the anti-collision cylinder proposed in this paper can rotate around the shaft, which can change the impact direction of the vehicle, so that the driving direction of the car can extend along the direction of the highway after impact, and reduce the damage to the vehicle caused by direct impact, and protect the passengers to a greater extent. Moreover, the anti-collision cylinder can also reduce the impact speed of the car, especially for vehicles with uncontrollable speed such as brake failure. It is obvious that the combined action of multiple anti-collision cylinders will play a better protective effect on the highway.

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Ethics, Consent to Participate, and Consent to Publish declarations: not applicable.

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