Structural Design and Impact Simulation of Glass Fiber Fragile Cover of Rocket

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Abstract. The fragile cover of rocket not only has the characteristics of sealing and high-temperature resistance, but also can break according to preset scratches when hit by the rocket’s head. In this paper, a penetrating glass fiber fragile cover with scratches is designed, and six structural types are set up with the number of layers laid by glass fiber as independent variables. Based on Hashin failure criterion and damage evolution law, the finite element method is used to simulate the process of rocket breaking through fragile cover and gas flow impinging fragile cover. The results show that the fragile cover will break along the preset scratches, which does not produce debris to interfere with rocket launch. As the number of glass fiber cloth layers increases, the Mises stress of the rocket’s head increased when the fragile cover broken. The impact of the gas flow on the fragile cover of the adjacent pipe is not uniformly distributed, and the maximum value of the Mises stress appears at the scratches of the cover body. As the number of glass layers decreases, the failure index value of the fragile cover under the impact of gas flow increases. The research provides a reference for the design of rocket glass fiber fragile cover.

1. Introduction
The three commonly used automatic launching box fragile covers include mechanical switch covers, integral throwing covers and penetrating frangible covers [1-3]. The penetrating frangible cover is directly broken by the impact force of the rocket’s head to achieve automatic opening. Compared to the other two fragile covers, the penetrating frangible cover has simpler structure, convenient maintenance, short operation time and high reliability. The penetrating fragile cover had been successfully applied to rockets and multi-tube rocket launches, such as the US “Patriot” rocket and the Italian “Aspen” rocket [4]. Sun developed a MY-29 fragile rocket launcher cover with a porcelain-like material [5]. Wei made a new type of fragile composite structure according to the principle of topological interlocking [6].

However, the common fragile cover would produce debris after it ruptures, and the debris in the multi-tube bundle launch might have an impact on the launch of the subsequent rocket. Based on this, a penetrating glass fiber fragile cover was designed in this paper. The simulation of rocket breaking through the fragile cover and the gas flow impinging the fragile cover were carried out, the rupture effect of the frangible cover was analyzed, which provided a reference and guidance for the development of the frangible cover.
2. Materials and structures of fragile cover

Glass fiber cloth has a characteristic that it is easy to tear in both warp and weft directions, and difficult to tear in other directions. The plain cloth with 0.2 mm thick was used as material. Taking a layer of intact fiberglass cloth as a basic part, the scratched fiber cloth was superimposed and bonded to the basic layer in sequence to form a fragile cover body with preset scratches. The epoxy resin was used for bonding the glass fibers of each layer. Because the scratches is filled with resin, the strength is lower than the other parts of the cover, so it formed the tearing line of the cover. The laying process and principle was shown in Figure 1. The multi-layers glass fiber cloth was molded by compression in the mold, and the structure of the fragile cover and mold is as shown in Figure 2. In order to get the best number of layers, six structural schemes were designed, these were also the working condition of the simulation, which were shown in Table 1.

![Figure 1. Glass fiber cloth laying method](image1)

![Figure 2. Schematic diagram of fragile cover and mold structure](image2)

### Table 1. Penetrating fiber glass frangible cover structure scheme

| No. | Structure type                                      |
|-----|----------------------------------------------------|
| 1   | Base layer + 1 layer of scored fiberglass cloth     |
| 2   | Base layer + 2 layers of scored fiberglass cloth    |
| 3   | Base layer + 3 layers of scored fiberglass cloth    |
| 4   | Base layer + 4 layers of scored fiberglass cloth    |
| 5   | Base layer + 5 layers of scored fiberglass cloth    |
| 6   | Base layer + 6 layers of scored fiberglass cloth    |

3. Failure criterion and the law of damage evolution

Due to the heterogeneity and anisotropy of the fiber glass woven fabric, the form of failure is more complicated. The failure criterion of fiber reinforced composite is Hashin failure criterion, which includes 1-direction fiber stretch and shear under fracture, 1-direction fiber compression buckling, 2-direction fiber stretch and shear under fracture, 2-direction fiber compression buckling [7, 8]. The criteria form corresponding to the failure mode was shown in Table 2.
Table 2. Failure mode

| Failure mode | Criterion form |
|--------------|----------------|
| 1-direction stretching ($\hat{\sigma}_{11} \geq 0$) | $F^c_1 = \left(\frac{\hat{\sigma}_{11}}{X_t}\right)^2 + a \left(\frac{\hat{\tau}_{12}}{S}\right)^2 \geq 1$ |
| 1-direction compression ($\hat{\sigma}_{11} \leq 0$) | $F^c_1 = \left(\frac{\hat{\sigma}_{11}}{X_c}\right)^2 \geq 1$ |
| 2-direction stretching ($\hat{\sigma}_{22} \geq 0$) | $F^c_2 = \left(\frac{\hat{\sigma}_{22}}{Y_t}\right)^2 + a \left(\frac{\hat{\tau}_{21}}{S}\right)^2 \geq 1$ |
| 2-direction compression ($\hat{\sigma}_{22} \leq 0$) | $F^c_2 = \left(\frac{\hat{\sigma}_{22}}{Y_c}\right)^2 \geq 1$ |

$X_t$, $c$: 1-direction stretching/compression strength, $Y_t$, $c$: 1-direction stretching/compression strength, $S$: shear strength, $a$: contribution coefficient, $\hat{\sigma}$: true carrying capacity, $\hat{\sigma}_{11}$, $\hat{\sigma}_{22}$, $\hat{\tau}_{12}$: effective stress component.

$$\hat{\sigma} = M \sigma$$

Where, $\sigma$ is nominal stress, $M$ is damage operator.

$$M = \begin{bmatrix} \frac{1}{1-d_1} & 0 & 0 \\ 0 & \frac{1}{1-d_2} & 0 \\ 0 & 0 & \frac{1}{1-d_{12}} \end{bmatrix}$$

Where, $d_1$ is damage condition of the 1 direction fiber, $d_2$ is damage condition of the 2 direction fiber, $d_{12}$ is shear damage condition. The expression is:

$$d_i = \begin{cases} d_i' & \text{if } \hat{\sigma}_{ii} > 0 \\ d_i'' & \text{if } \hat{\sigma}_{ii} < 0 \end{cases}$$

$$d_2 = \begin{cases} d_2' & \text{if } \hat{\sigma}_{22} > 0 \\ d_2'' & \text{if } \hat{\sigma}_{22} < 0 \end{cases}$$

$$d_{12} = 1 - (1-d_1')(1-d_1'')(1-d_2')(1-d_2'')$$

Before the damage occurred, $d_1'$, $d_2'$, $d_1''$, $d_2''$ were 0. After the damage occurred, the evolution began, and the effect of the damage operator began to be significant.

4. Finite element simulation model

The thickness of the frangible cover was small, and the mesh would be distorted during the process of breaking in simulation, so the 4-node reduced integral shell unit was selected, and the Simpson integral method was used in the thickness direction to obtain the stress and strain of each single layer material. The mesh was refined due to stress concentration at the location of the tear line of the frangible cover. The meshing was shown in Figure 3. The material parameter of the rocket’s head is as follows, Young modulus is $E=6.9 \times 10^{10}$ Pa, Poisson ratio is $\nu=0.31$. Glass fiber plain cloth breaking energy is $W=93$ KJ/m2, Poisson ratio is $\nu=0.14$. The parameters of glass fiber reinforced resin epoxy composite are shown in Table 3. In addition, the boundary condition is set to fixed the launcher, so as to fix the fragile cover, and the contact mode is surface to surface contact.
Figure 3. Fragile cover and rocket’s head mesh model

Table 3. Glass fiber material property parameters

| E1/GPa | E2/GPa | G12/GPa | Xc/MPa | Yc/MPa | Xp/MPa | Yp/MPa | S/MPa |
|-------|-------|--------|--------|--------|--------|--------|-------|
| 17.7  | 17.7  | 3.53   | 294.5  | 294.5  | 245.2  | 245.2  | 68.6  |

5. Results and discussions

5.1. Simulation of rocket breaking through fragile cover

The speed of the rocket was set as 12 m/s, which is the maximum value of the exit speed of all kinds of rockets. The explicit dynamics method was used for analysis and calculation. The Hazin failure criterion was used to judge the failure of each layer of glass fiber cloth and to simulate the damage and rupture. The process of the rocket breaking through the fragile cover was shown in Figure 4. Instead of paying attention to the stress value, we pay more attention to the rupture process of the fragile cover, which forms four parts obviously as expected.

Figure 4. The process of the rocket breaking through a four-layer frangible cover

Table 4. Maximum Mises stress on rocket’s head

| Design | 1    | 2    | 3    | 4    | 5    | 6    |
|--------|------|------|------|------|------|------|
| Maximum stress / MPa | 50.8 | 46.8 | 87.5 | 68.3 | 185.6 | 101.2 |

The penetrating fiber glass frangible cover could be broken along the preset scratches and did not generate any flying debris, which did not interfere with the launch of subsequent rockets. The impact force of the rocket’s head is different when the rocket was breaking through the fragile cover of
various schemes. Table 4 listed the maximum values of the Mises stress in the rocket’s head for various schemes. It could be seen from the Table 4 that as the number of layers of the glass fiber cloth increased, the stress value of the rocket’s head increased. According to the known data, the maximum stress value that the material of the rocket’s head casing could withstand was 90 MPa, so the stress on the schemes No. 5 and No. 6 was too large, which would affect the safety of the launch.

5.2. Simulation of gas impact

According to the impact effect of gas flow in rocket nozzle, the launching process was simulated [9, 10]. The pressure cloud at the moment when the fragile cover of adjacent tubes was subjected to the greatest impact during the entire launching process was shown in Figure 5. It could be seen from the figure that the impact on the frangible cover of the adjacent tube was not evenly distributed, and the maximum stress appears at the preset scratches of the cover. According to the Hashin criterion, the failure index value $F_1^1$ of each layer of glass fiber cloth under the impact of gas flow was calculated, which maximum value was shown in Table 5. Some failure index of schemes No. 1, No. 2, and No. 3 was greater than 1, which meant the frangible cover would be destroyed under the impact of gas flow.

6. Summary

In order to obtain the impact performance of rocket fragile cover, a penetrating glass fiber fragile cover was designed in this paper, the numerical simulation was carried out to simulate the rocket breaking through the fragile cover and the gas flow impinging fragile cover. The stress value of the rocket’s head increased with the number of glass fiber layers increased when an hit occurred. After the glass fiber layers reaches a certain number, the normal flight of the rocket was affected. As the number of glass fiber layers decreased, the value of the failure index of the frangible cover increased, and the damage was more likely to occur under the impact of the gas. The design schemes No. 1, No. 2, No. 3, No. 5, and No. 6 could not meet the safety of the rocket’s head or be damaged by the gas flow when

| No. | $F_1^1$ | $F_1^c$ | $F_2^1$ | $F_2^c$ |
|-----|---------|---------|---------|---------|
| 1   | 2.69    | 1.78    | 2.77    | 1.91    |
| 2   | 1.13    | 1.18    | 1.13    | 1.18    |
| 3   | 0.81    | 1.03    | 0.27    | 0.23    |
| 4   | 0.28    | 0.26    | 0.28    | 0.26    |
| 5   | 0.21    | 0.24    | 0.1     | 0.08    |
| 6   | 0.06    | 0.07    | 0.06    | 0.07    |

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the adjacent tube was launched. However, the scheme No. 4 could meet the safety of the rocket’s head, which did not generate flying debris when it was broken. It could withstand the gas flow impact emitted by the adjacent rockets, thereby meeting the launch performance requirements.

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