# Research on Effect of Elastic Modulus on Material Load-relieving Ability

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**Abstract.** The load-relieving material is described by Mooney-Rivlin model. Dynamical response of projectile-based CCD camera is derived by total Lagrangian Increment Method, and the results is simulated numerically by finite element method. The rule of variation of load-relieving materials' elastic modulus on its maximum compression and camera lens' maximum stress are analyzed. The analyzed results show that when choosing materials, its elastic modulus should be within a limited range in data association, so as to the maximum stress which is action on projectile-based equipments don't exceed its limit load, and also relative displacement is in agreement with structure assembly requirement of projectile-based equipments.

With the development and extensive application of the information technology, various countries step up the manufacture of the new-type ammunition, a batch of new-type ammunition has appeared, such as TV Recon Projectile, TV Terminal Guided Projectile, Floating Interfere Projectile and so on. The configuration of new-type ammunition is a lot more complicated than the routine ammunition, and there are accurate electronic devices and all kinds of photoelectric sensors in projectile-based device, such as guided head、optical device、TV reconnaissance device and all kinds of sensor and so on. The shot receives the function of the pressure in the course of launching, the projectile body produces high acceleration, and so as to projectile-based devices receive instantaneous, high-energy strong impact within short time. Such high overload environment produces very great influence on the structure integrity of projectile-based devices, and may be the structure to destroy, all kinds of devices to mangle, so as to the system to be unable to work normally. To ensure that the projectile-based equipment in the safe and reliable during shooting, engineering is often used to use disk spring, silicone rubber foam, foam aluminum as load-relieving material to reduce the role of the projectile-based equipment of the maximum stress, so as to achieve the high over loading problem in launching.

At present, research on projectile-based equipments against high overload, the main focus on projectile-based equipment reinforcement and load-relieving material development of engineering design and single projectile-based equipment resistance to overload capacity test and so on, involves effect of load-relieving material performance on projectile-based equipments against high overload less. According to simulation, the effect of elastic modulus on material load-relieving ability is analyzed.

## 1 Material constitutive structure mode and numerical method

1.1 Load-relieving constitutive models

Considering the influence of high speed dynamic impact, one type of load-relieving subassembly is designed by composite rubber pad for protecting projectile-based CCD camera. Mooney-Rivlin model is selected as constitutive models of load-relieving subassembly. It is

$$W(I_1, I_2) = \sum_{i,j=0}^{n} C_{ij}(I_1 - 3)^i (I_2 - 3)^j \qquad (1)$$

In the formula: $W$ is the strain energy density; $C_{ij}$ is the Rivlin coefficient; $I_1$、$I_2$ is the first and

the second Green strain invariant. It is

$$I_1 = \lambda_1^2 + \lambda_2^2 + \lambda_3^2 \qquad\qquad (2)$$

$$I_2 = (\lambda_1\lambda_2)^2 + (\lambda_2\lambda_3)^2 + (\lambda_3\lambda_1)^2 \qquad\qquad (3)$$

The second parameter Mooney-Rivlin model is used as the finite element model of load-relieving rubber pad, and then the formula (1) changes to

$$W = C_{10}(I_1 - 3) + C_{01}(I_2 - 3) \qquad\qquad (4)$$

In the formula: $C_{10}$ and $C_{01}$ are Rivlin coefficient that is constant parameter.

The Mooney-Rivlin strain energy function is widely used as constitutive relations in finite element analysis of rubber material. It is

The formula (5) can be got from the relation between Kirchoff stress tensor $t_{ij}$ and Green strain tensor $\gamma_{ij}$. It is

$$t_{ij} = \frac{\partial W}{\partial I_1}\frac{\partial I_1}{\partial \gamma_{ij}} + \frac{\partial W}{\partial I_2}\frac{\partial I_2}{\partial \gamma_{ij}} + \frac{\partial W}{\partial I_3}\frac{\partial I_3}{\partial \gamma_{ij}} \qquad\qquad (5)$$

For nearly incompressible materials, such as rubber-like material, $I_3=1$, the relation between principal stress $t_i$ and principal strain $\lambda_i$ can be got from formula (5). It is

$$t_i = 2(\lambda_i^2 \frac{\partial W}{\partial I_1} + \frac{1}{\lambda_i^2}\frac{\partial W}{\partial I_2}) + P \qquad\qquad (6)$$

In the formula: $P$ is the random fluid hydrostatic pressure.

1.2 Dynamic analysis basic theory of display algorithm

The paper uses total Lagrangian Increment Method that is the main finite dynamic analysis algorithm in LS-DYNA.

Considering the hourglass effect and damp reason, the motion equations of finite element model system is

$$\mathbf{M\ddot{x}} = \mathbf{P} - \mathbf{F} + \mathbf{H} - \mathbf{C\dot{x}} \qquad\qquad (7)$$

The explicit central difference method is used as the time integral, the formulas are:

$$\begin{cases} \mathbf{\ddot{x}}(t) = \mathbf{M}^{-1}\left[\mathbf{P}(t_n) - \mathbf{F}(t_n) + \mathbf{H}(t_n) - \mathbf{C}\mathbf{x}(t_{n-1/2})\right] \\ \mathbf{\dot{x}}(t_{n+1/2}) = \mathbf{\dot{x}}(t_{n-1/2}) + \frac{1}{2}(\Delta t_{n-1} + \Delta t_n)\mathbf{\ddot{x}}(t_n) \\ \mathbf{x}(t_{n-1}) = \mathbf{x}(t_n) + \Delta t_n \mathbf{\dot{x}}(t_{n+1/2}) \end{cases} \qquad (8)$$

In the formula: $\mathbf{\ddot{x}}(t_n), \mathbf{\dot{x}}(t_{n+1/2}), \mathbf{x}(t_{n+1})$ are the position vectors of $t_n, t_{n+1/2}, t_{n+1/2}$ time node, $\mathbf{M}$ is the system mass matrix, $\mathbf{P}$ is the system load vector, $\mathbf{F}$ is the element stress field equivalent node vector (stress divergence), H is the system architecture hourglass viscous damping force matrix, $\mathbf{C}$ is the damping matrix.

## 2 The establishment of load-relieving material finite element analysis model

2.1 The establishment of load-relieving material physical model

To analyze load-relieving ability of load-relieving material, the input and output stress of the test-piece is tested by the Hopkinson bar experiment equipment. The test-piece is made of camera and composite rubber pad. To testing easily, the camera is fixed on the base of protecting cover. The finite element model of load-relieving subassembly and projectile-based device are shown in picture 1. The whole mass of the test-piece is 185g, the elements choose ANSYS-LS-DYNA/SOLID164 elements, among them, the number of round rubber pad elements are 2000, the number of the three glass elements are 3900, the number of the camera (without glasses) elements are 20720. The details are shown in picture1, the number of all elements are 48780.
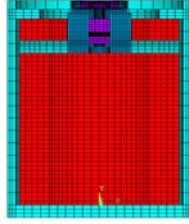
Fig.1    The finite element model

2.2 Material parameters

Based on the different properties of material and considering the stress and strain under the load condition, the material properties must be set in different way: The sleeve of test-piece, camera base, clapboard are made of aluminum alloy material that is linear elastic material, camera glass is made of glass material that is linear elastic material, camera is made of engineering plastic material that is linear elastic material. Load-relieving rubber pad is set to Mooney-Rivlin incompressible material. The input and output bar are made of aluminum alloy material that is linear elastic material.

2.3 Load conditions

As calculation, the impact load is work on the end face of the input bar, and then the curve of impact load changing with time is got by Hopkinson bar experiment. The curve fits for multi-linear trapezoidal broken line, as shown in picture 2.
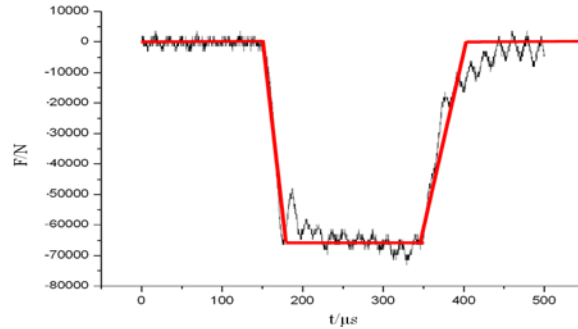

Fig.2    Impact load

## 3 The calculation results and analysis

When the maximum load force is 56000N and the load time is 300μs, the relation curve of maximum compression and elastic modulus is shown in picture 3, the relation curve of maximum stress and elastic modulus is shown in picture 4.
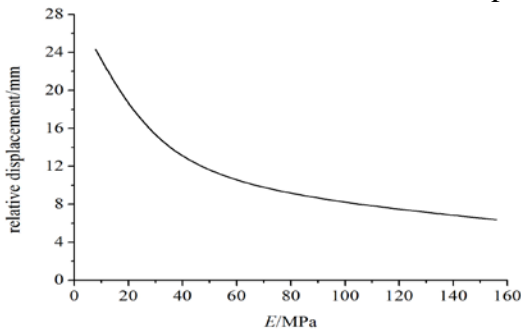



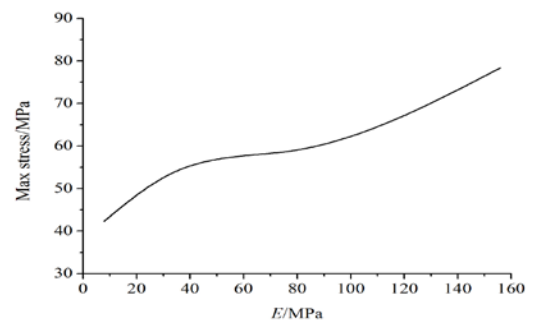Fig.3    The relationship of maximum compression and elastic modulus    Fig.4    The relationship of maximum stress and elastic modulus

The figure 3 shows that with increasing elastic modulus, the maximum compression of rubber pad decreases generally in the exponential form, and when the elastic modulus below 20MPa, the maximum compression is above 19mm. Considering the connection between camera and fixed position needs lines that fall off easily from fixed position, the elastic modulus of load-relieving material must be big enough. The figure 4 shows that with increasing elastic modulus, the cure of maximum stress takes on three sections. When the elastic modulus is less than 50MPa, the stress increases with the elastic modulus. When the elastic modulus is between 50MPa and 80Mpa, the

stress is almost unchanged. When the elastic modulus is more than 80MPa, the stress increases with the elastic modulus, but the slope of curve in the section is less than in the first section. The reason is that when increasing elastic modulus, the stiffness of load-relieving material increases, and if the stiffness is too much bigger or smaller, the load-relieving ability reduces. Therefore, when choosing materials, its elastic modulus should be within a limited range in data association, so as to the maximum stress which is action on projectile-based equipments don't exceed its limit load, and also relative displacement is in agreement with structure assembly requirement of projectile-based equipments.

## 4 Conclusion

According to SHPB impact experiment, the finite element model of projectile-based CCD camera and rubber pad is established on the condition of high impact, and dynamical response of projectile-based CCD camera is simulated by LS-DYNA software. The rule of variation of load-relieving materials' elastic modulus on its maximum compression and camera lens' maximum stress are analyzed. The analyzed results show that with increasing elastic modulus, the maximum compression of rubber pad decreases generally in the exponential form, and maximum stress takes on three sections: increase-rise slight-increase. Therefore, when choosing materials, its elastic modulus should be within a limited range in data association, so as to the maximum stress which is action on projectile-based equipments don't exceed its limit load, and also relative displacement is in agreement with structure assembly requirement of projectile-based equipments. The paper theoretical analyses the effect of elastic modulus on material load-relieving ability, so the results should be validated by tests.

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