

# Characteristics of Center-blast Tube with V-grooves During Blasting

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**Abstract:** The prediction of fracture time and crack development of metal shell under the impact load is a very significant research direction in engineering. In this paper, a coupling method is used to solve the dynamic expansion fracture process of center-blast tube with V-grooves under the pressure. A one-dimensional two-fluid model was utilized to govern the transient combustion. The nonlinear mechanical behaviors were predicted based on the finite element software ABAQUS, and the pressure and the structure were coupled by applying a user subroutine interface VUAMP in ABAQUS. The coupling approach was validated by comparing the predicted results with experimental results. Based on the validated approach, the characteristics of expansion fracture and the process of crack propagation on the center-blast tube with V-grooves were studied, and the effect grooves depth were analyzed. The results show that the crack propagation on tube can be divided into two stages that stable propagation stage and unstable propagation stage. The burst pressure of the center-blast tube with V-grooves decreases with the increase of crack depth, and the burst pressure decreases by about 7MPa with every depth increase of 0.25mm.

**Keywords:** center-blast tube; V-groove; finite element analysis; expansion fracture; crack propagation

## 1. Introduction

The center-blast tube is an appliance for separating shrapnels, which relies on a central tube charging in high density propellant located on the axis to provide kinetic energy to propel the movement of the projectile [1-3], as shown in Fig.1. In order to effectively control the distribution, a groove can be prefabricated on the central tube to adjust the dynamic expansion and blasting process. In particular, the blasting pressure of central tube can determine the scattering speed of the projectile, and the uniformity of the fractured shell of the central tube affects the dispersion uniformity of the projectile. Therefore, it is of great significance to study the dynamic expansion fracture process of center-blast tube with V-grooves under the action of gunpowder gas pressure [4-7].

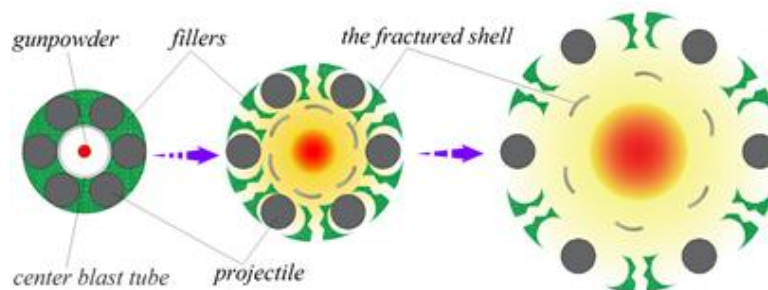


Fig.1 Schematic diagram of center-blast tube

The blast progress has been studied extensively. Taylor put forward the famous criterion of tensile fracture that the crack of expansion fracture of thin-walled shell starts from the outer wall and then spreads radially to the inner wall of metal until it penetrates through the shell [8]. Lamborn analyzed the influence of factors such as the geometrical shape of outer wall grooves, shell material strength and explosive quality on the shell expansion and fracture under the internal explosive load

[9]. Hiroe used experimental and numerical simulation methods to study the influencing factors of column shell rupture [10]. The numerical simulation method was used to study the expansion and bursting process of center-blast tube in recent years. The interior ballistic two-phase flow provides an important research method for analyzing the combustion flow law of central tube.

In this paper, the high burning rate propellant is used as the propelling energy, and a large length-to-diameter ratio center-blast tube distribution system is designed. The ballistic process in the constant volume stage and the bursting law of center-blast tube with V-grooves are studied.

## 2. Mathematical model

The device structure is designed as shown in Fig.2. An ignition device is placed in the front end shield to ignite the propellant. When the propellant is ignited, the gas will enter the central tube. As the pressure gradually rises, the center-blast tube would rupture, and the interior ballistic stage is completed. The parameter distributions along the axis of the tube are mainly focused. Considering the ratio of length to diameter of the tube and the related transient effects, a one-dimensional two-fluid model is utilized to govern the fluid field.

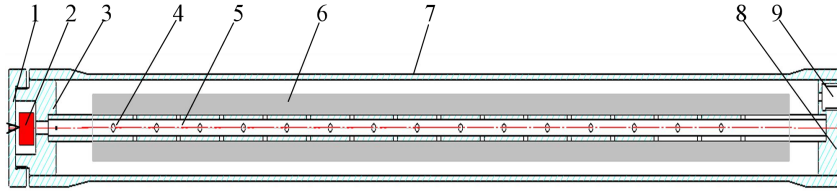


Fig.2 Experimental device for center blast tube

1-front end shield; 2-ignition device; 3-ignition base; 4-vent holes; 5-flash tube; 6-propellant; 7-center blast tube; 8-rear end cover; 9-pressure tap

### 2.1 Interior ballistic two-phase flow model governing equation

According to the physical description of the constant volume stage of center-blast tube, the flow field is regarded as a one-dimensional gas-solid two-phase flow model, the combustion is governed by the follow formula.

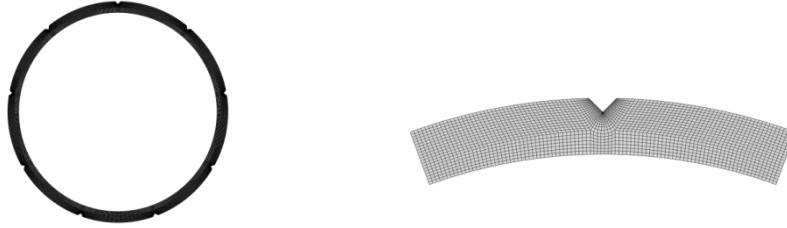
$\frac{\partial(A\phi\rho_g)}{\partial t} + \frac{\partial(A\phi\rho_g u_g)}{\partial z} = Am_c + A_{ign}m_{ign}$	(1)
$\frac{\partial(A\phi_p\rho_p)}{\partial t} + \frac{\partial(A\phi_p\rho_p u_p)}{\partial z} = -Am_c$	(2)
$\frac{\partial(A\phi\rho_g u_g)}{\partial t} + \frac{\partial[A\phi\rho_g u_g^2]}{\partial z} + A\phi\frac{\partial p}{\partial z} = -Af_s + Am_c u_p + A_{ign}m_{ign}u_{ign}$	(3)
$\frac{\partial(A\phi_p\rho_p u_p)}{\partial t} + \frac{\partial[A\phi_p\rho_p u_p^2]}{\partial z} + A\phi_p\frac{\partial p}{\partial z} = Af_s - Am_c u_p$	(4)
$\frac{\partial[A\phi\rho_g E_g]}{\partial t} + \frac{\partial[A\phi u_g(\rho_g E_g + p)]}{\partial z} + p\frac{\partial(A\phi)}{\partial t} = -AQ_p - Af_s u_p + Am_c H_c + A_{ign}m_{ign}H_{ign}$	(5)

where  $\phi$  is the porosity of the gas-phase,  $\rho_g$ ,  $\rho_p$  are the gas density and the grain density,  $u_g$ ,  $u_p$  are the gas velocity and the grain velocity,  $p$  is the pressure,  $e_g$  is the internal energy of the gas-phase and  $E_g = e_g + u_g^2/2$ ,  $m_{ign}$  is the mass flow rate of gas from the igniter,  $f_s$ ,  $Q_p$  are the inter-phase drag and inter-phase heat transfer respectively,  $H_c$  is the stagnation enthalpy in the chamber,  $H_{ign}$  is the stagnation enthalpy of the gas flow from the igniter,  $R_p$  is intergranular stress.

In order to solve the above calculation equations of gas phase and grain elements, a series of other auxiliary equations need to be provided, such as gas phase state equation, propellant combustion equation, interphase heat transfer equation, and grain surface temperature equation.

## 2.2 Finite element model

The cohesive force crack model is established based on extended finite element method by software ABAQUS. The burst characteristics and crack propagation process of the center-blast tube with prefabricated grooves are studied under the action of pressure. The finite element model is established as shown in Fig.3.



(a) The overall model

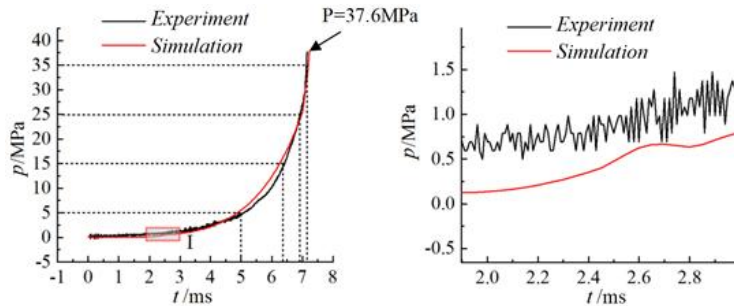
(b) The parts of grooves

Fig.3 Finite element model of center blast tube with prefabricated V-grooves

## 3. Results and Discussions

### 3.1 Validation and pressure analysis

The effectiveness of the two-phase flow computational model is verified in the constant volume phase. Fig.4 shows the comparison curves of obtained experimental results and numerical results. It can be seen that the simulation results are in good agreement with the experimental results, indicating that the established model and the numerical method are reasonable and effective. The calculated pressure is not coincide with the experimental pressure completely, and it is mainly caused by a large number of assumptions made in the physical model and the simplification of the actual physical process.



(a) Pressure-time curve

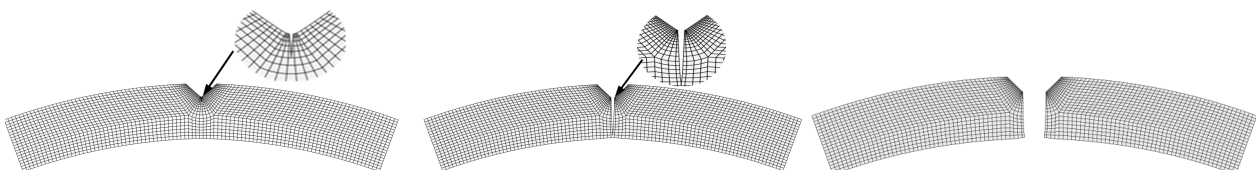
(b) Enlarged view of area I

Fig.4 Experiment and simulation pressure-time curves

The pressure measured was 37.6MPa when the center-burst tube, and the bursting pressure of the center tube is 35.7MPa through finite element simulation. The error between numerical simulation and experiment is 5.05%. The numerical method can accurately predict the bursting pressure of center-blast tube.

### 3.2 Crack propagation of center-blast tube with prefabricated V-grooves

Fig.5 shows the process of crack propagation at different times, the fracture position of the center-blast tube appears at the V-shaped groove. With the increase of pressure, the crack expands towards the inner wall of center-blast tube.



(a)  $t=6.82\text{ms}$

(b)  $t=7.2\text{ms}$

(c)  $t=7.215\text{ms}$

Fig.5 Development of cracks in prefabricated grooves at different times

Fig.6(a) shows the curve of crack length changing with the pressure in the tube, and Fig.6(b) shows the curve of crack length over time. As can be seen from Fig.6, the pressure in the central tube is 10.17MPa at the initiation of crack. Then, the blasting process of central tube under the action of gas pressure can be divided into two stages. The crack length increases exponentially with increasing gas pressure before the crack length reaches 0.65 mm. Since the central tube (aluminum alloy) is a ductile material, its fracture resistance will increase with the increase of the crack length, and cracks on the tube wall are in a stable growth stage. When the crack length exceeds 0.65mm, the crack length of both the pressure loading curve and the time loading curve both increase sharply, indicating that the crack is in the stage of unstable expansion. At this stage, the prefabricated grooved central tube reaches the inherent strength limit, and no need to increase the pressure load, then the crack would be unstable and propagate toward the inner wall of the central tube. When the crack length exceeds 0.65 mm, the crack length curves rise sharply, indicating that the crack is in the stage of unstable growth. At this stage, the central tube with prefabricated groove reaches the strength limit.

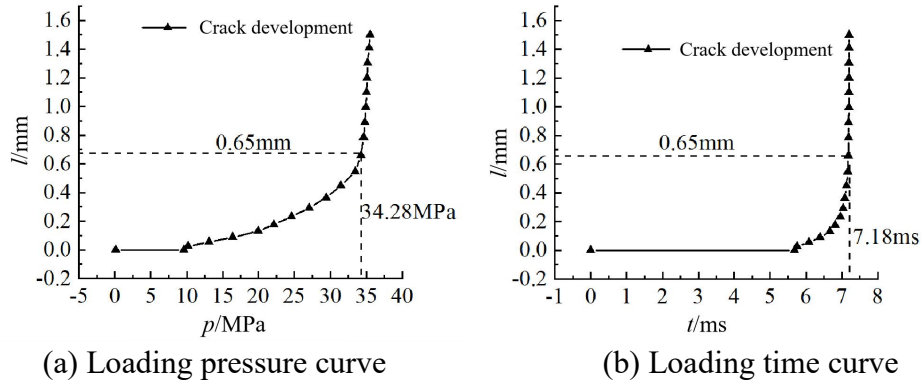
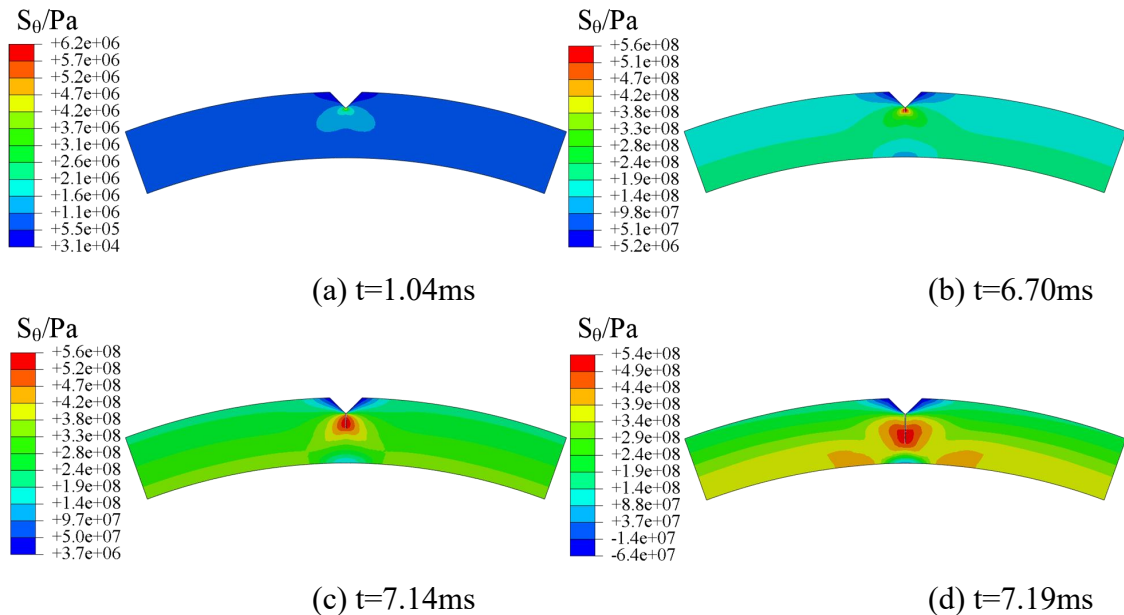


Fig.6 Crack length curves

Fig.7 shows the distribution of tensile hoop stress of the central tube at different times. At  $t=1.04\text{ms}$ , there is no crack initiation, but a stress concentration occurs at the tip of the V-grooves. The hoop stress is several times larger than the stress away from the tip, which produces a "fracture source" at the tip of the V-grooves. Fig.7 (b)~(c) show the stage of stable crack propagation. From the initiation of crack to the expansion of crack toward the inner wall of central tube, the maximum stress in the tube is concentrated near the crack tip. Fig.7 (d)~(e) show the stage of unstable crack propagation. The crack rapidly expands to the inner wall of central tube. When the crack extends to the inner wall of the central tube, the central tube bursts.



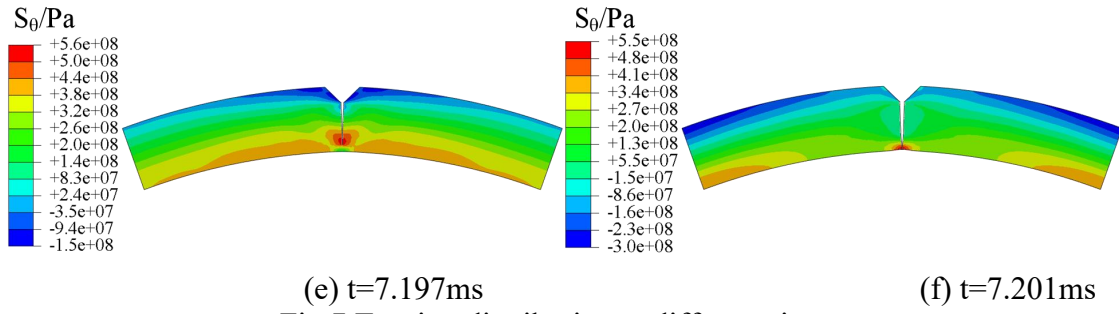


Fig.7 Tension distribution at different times

### 3.3 Influence of prefabricated V-grooves depth on central tube

The blasting process of the V-grooves central tube is simulated and analyzed at different depths at the position of  $X=0.3051\text{m}$ . The depths of prefabricated V-groove are 0.5mm, 0.75mm, and 1.0mm, respectively. Fig.8 shows a comparison diagram of the crack depth and loading curve of prefabricated V-shaped grooves with depths of 0.5mm, 0.75mm and 1.0mm. The greater the depth of prefabricated V-groove is, the smaller the loading pressure becomes on the inner wall of central tube when the crack at the tip of the V-grooves is initiated. It shows that under the same loading pressure, the greater the depth of prefabricated V-groove is, the easier it is to initiate the crack at the tip of V-groove. The reason is that the greater the depth of prefabricated V-groove becomes, the easier it is to generate stress concentration at the tip of V-groove. Moreover, the greater the depth of prefabricated V-groove is, the smaller the burst pressure of central tube is. For every 0.25mm increase in the grooved depth, the prefabricated V-grooves central tube burst pressure decreased by about 7MPa.

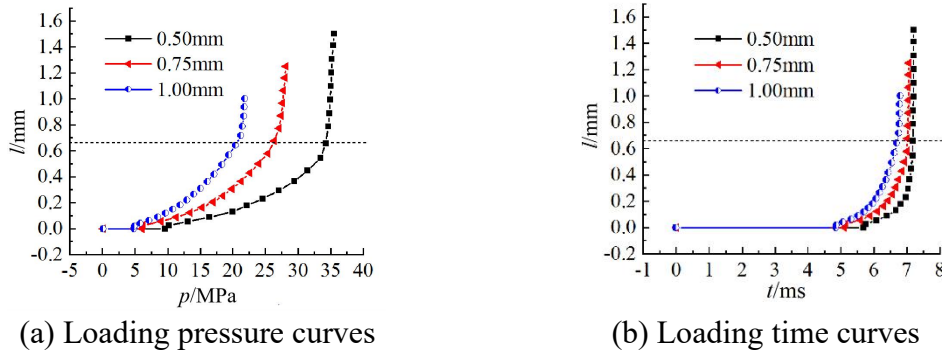


Fig.8 Crack length at different depth grooves

## 4. Conclusion

In this paper, the gas pressure distribution obtained from the calculation of ballistic process of center-blast tube is used as the loading condition, and the numerical simulation of expansion and explosion process of prefabricated grooved central tube under the action of gas pressure of propellant is carried out based on the extended finite element method. Comparing the experimental and calculation results, the fracture characteristics and crack propagation process of central tube with prefabricated V-grooves are studied, and the influence of groove depth on the bursting is analyzed. The conclusion is as follows:

In the fracture process of center-blast tube with prefabricated grooves under the action of gas pressure, the crack initiates at the prefabricated groove and expands to the inner wall of central tube. The crack propagation on the tube wall is divided into two stages, the stable propagation stage and the unstable propagation stage.

As the depth of prefabricated V-grooves increases, the loading pressure required for crack initiation becomes smaller, and the total time becomes shorter. Moreover, the burst pressure of

central tube with prefabricated V-grooves decreases with the increase of the crack depth. For every 0.25mm increase in the grooved depth, the burst pressure of central tube decreases by about 7MPa.

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