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Study on Attenuation Characteristics of PTFE to Detonation Pressure

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Abstract. The characteristics of detonation wave propagation in the PTFE is analyzed by explosive theory, this paper has simulated the process of detonation wave's propagation in PTFE by dynamics program, the detonation wave's attenuation law in PTFE was obtained. In order to verify the rationality of the theoretical analysis and numerical simulation results, the detonation wave pressures were measured by the technique of manganin piezoresistance in different thicknesses of PTFE. It can be seen from the research contents that the calculation results are in good agreement with the test results, which shows the scientificalness and reliability of the simulation model and calculation method. The research contents provide the necessary technical support for the metrological study of detonation pressure test.

1. Introduction

Detonation pressure is one of the basic parameters of explosive detonation energy output, it refers to the pressure of C-J surface which is the end of the detonation reaction zone, and it has important significance for explosive design. Manganin piezoresistance method [1] is one of the standard methods for determination of explosion pressure, and it plays an important role in the evaluation of explosive pressure. PTFE film is used for insulating and protecting sensors during the experimentation, so that the performance of the sensors would not be affected by the high temperature and high pressure environment. Studies on the influence of film on experimental data have important significance for optimizing the experimental methods and devices, for determination of explosive pressure and scientific measurement, and in military explosive design and application.

Based on a theoretical analysis of the reflection and transmission effects at the interface between explosive and PTFE film, it can be inferred that detonation pressure may be attenuated by PTFE film. Secondly, the law of the TNT detonation pressure and wave's propagation in PTFE was achieved by simulation technology, and the attenuation characteristics of detonation pressure in PTFE were studied. The detonation pressure was measured by manganin pressure sensors, different thicknesses of PTFE films were selected and used to insulate and protect the sensors, data were well achieved under the conditions of different thicknesses. The results of the study show that the experimental data, theoretical analysis and numerical simulation results are in good agreement, which indicates that the study on attenuation characteristics of PTFE to detonation pressure can provide guidance for the optimization of the measuring methods, and the experimental data are scientific and effective. The study results can be further applied to the accurate measuring technique of the explosive science.

2. Theoretical Analysis and Numerical Simulation

2.1. Theoretical Analysis

According to the theory of detonation, detonation wave will experience rarefaction and transmission effects [2] [3] at the same time at the interface of explosive and PTFE film. The initial parameters of detonation wave at the interface and detonation wave's propagation in PTFE film need to be studied in this paper respectively.

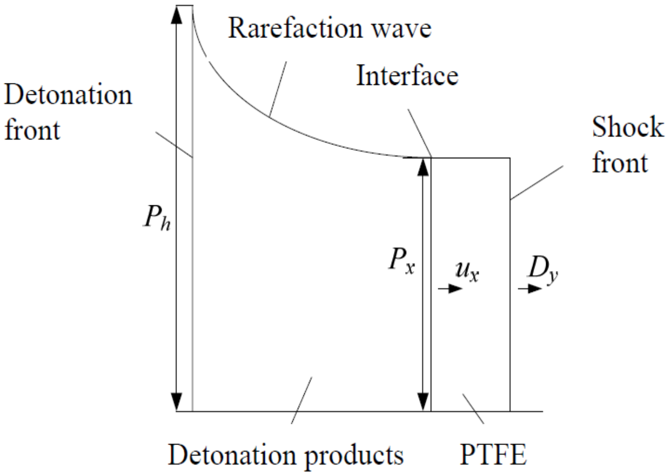

Figure 1. Schematic diagram of detonation wave propagation at interface

As shown in Fig. 1, when the detonation wave propagates to PTFE film, reflection and transmission experience at the interface of the two materials. In virtue of the PTFE's shock wave impedance (ρD) is less than the detonation's, so that rarefaction wave generates inside detonation products at the interface, which reduces the detonation pressure inside detonation products, detonation pressure decreased from P_h to P_x, P_x is the initial detonation wave pressure of PTFE.

According to the continuity condition, the velocity of the interface is equal to the sum of the detonation products velocity and the rarefaction wave particle velocity

$$u_x = u_h + u_1 \tag{1}$$

Where u_x is the interface velocity, u_h is the detonation products velocity, and u_l is the rarefaction wave particle velocity.

According to Eq. (1) and the detonation theory, we can get the following equation

$$u_x = \frac{D}{k+1}\left\{1+\frac{2k}{k-1}\left[1-\left(\frac{P_x}{P_h}\right)^{\frac{k-1}{2k}}\right]\right\} \tag{2}$$

Where u_x is the particle velocity at the interface, D is the shock wave propagation velocity, k is the adiabatic exponent, P_x is the pressure at the interface, and P_h is the detonation pressure of the explosive.

According to the basic theory of shock wave

$$P_x - P_0 = \rho_0 (D - u_0)(u_x - u_0) \tag{3}$$

Where ρ_0 is the initial density of TPFE, P_x is far greater than P_0, and u_0=0.

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According to Hugonio equation

$$D = a + b u_x \tag{4}$$

Where a and b are constant coefficients.

Will (2) (3) (4) simultaneous, we can obtain the initial pressure and initial velocity at the interface, which will derive the initial pressure of the incident detonation wave. It must be noted that the above analysis is carried out in accordance with the one-dimensional method, without considering the influence of the boundary of the rarefaction wave in practice, so the results obtained should be slightly larger than the actual value.

When detonation wave gets into PTFE, the complex propagation attenuation process begins. Based on the previous research, it is generally believed that the attenuation of shock wave can be approximated to exponential decay

$$p = AP_x \exp(-Bx) + C \tag{5}$$

Where p is a value of pressure in PTFE, A, B, C are corresponding coefficients.

2.2. Numerical Simulation

The numerical simulation uses AUTODYN program [4], which uses explicit time integration algorithm, which is suitable for the calculation of transient nonlinear dynamics problems of explosion and impact. As Fig. 2 shows, the mesh size is 0.5mm×0.5mm, and the column explosive is detonated by the center point detonation method. The Lagrange algorithm is used for the column explosive and PTFE, and the contact process is solved by Lagrange/Lagrange algorithm. In Lagrange method, the grid is the material grid, each calculation unit is the material unit, and the calculation unit is deformed with the deformation of the material. The Lagrange method is fast, the algorithm is mature, and the calculation accuracy is sufficient.

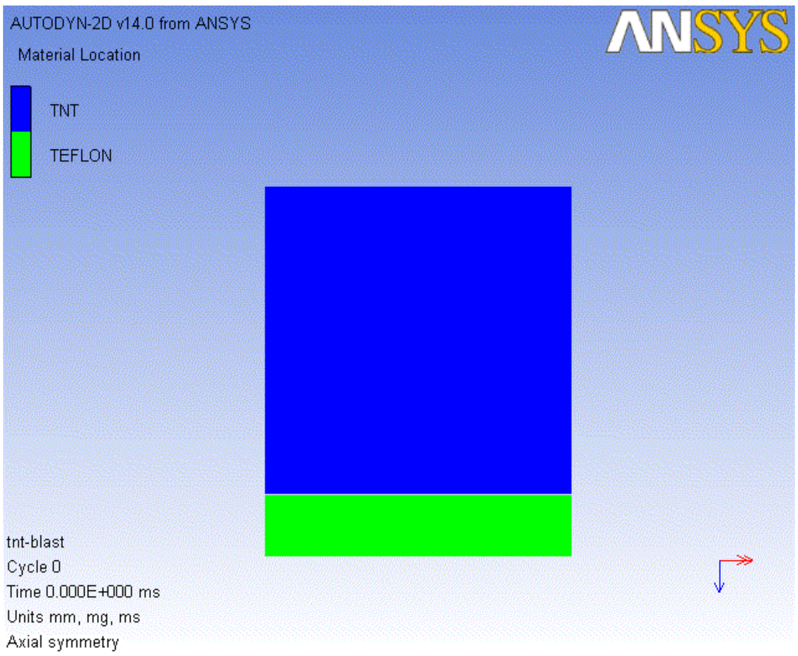

Figure 2. Schematic diagram of simulation model

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The model consists of TNT explosive and PTFE, the explosive size is consistent with the experiment, the thickness of PTFE is set to 10mm. Standard JWL equation is used to the detonation products

$$P = A(1-\frac{\omega}{R_1 V})e^{-R_1 V} + B(1-\frac{\omega}{R_2 V})e^{-R_2 V} + \frac{\omega E}{V} \tag{6}$$

Where A, B, R_1, R_2 and ω are all parameters of the JWL equation of state.

The equation of state of PTFE is based on the shock equation, which is based on Eq. (4).

3. Measurement Method

Fig. 3 is the diagrammatic sketch of system for detonation pressure. In this experiment, the diameter of 40mm pressed TNT explosive, manganin pressure sensor and PTFE film were employed. A manganin pressure sensor was sandwiched between two thin PTFE films, and then the packed sensor was sandwiched between two TNT explosive cylinders tightly, so that the air gap between them was minimized to prevent interference on the test results. In order to determine the attenuation characteristics of PTFE film with different thicknesses on the detonation pressure, the measurement was divided into 5 groups, each group of PTFE film had different thicknesses of 0.1mm, 0.2mm, 0.5mm, 1.0mm and 2.0mm.

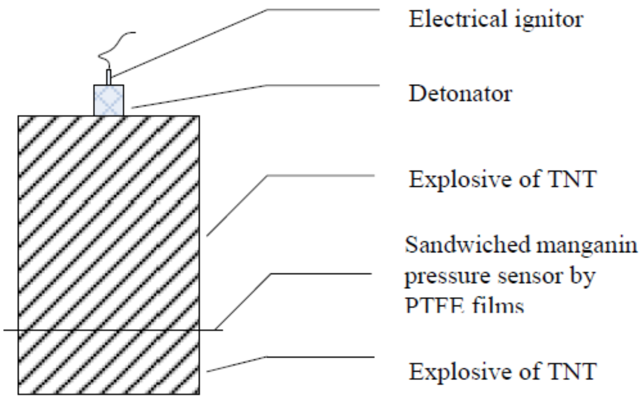
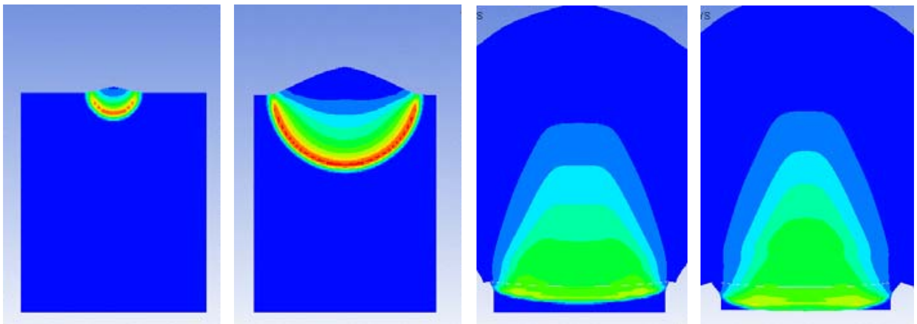


Figure 3. Diagrammatic sketch of system for detonation pressure

4. Results and Discuss

According to the literature data, the measured value of TNT detonation pressure is about 19GPa. In this study, the pressing density of TNT explosive is 1.60 g•cm^{-3}, the numerical simulation result at the PTFE thickness of 0mm is 19.3GPa, whose value is consistent with those in the literature.



t=1.004μs t= 3.002μs t=9.001μs t=10.000μs

Figure 4. Schematic diagram of calculation at different time

Fig. 4 demonstrates the statuses of the detonation wave at different times obtained by numerical calculations. When t=1.004μs, the sample is in the initial stage of detonation, and the detonation is not uniform. When t=3.002μs, the sample is in the stage of detonation, and it is found that the detonation wave is transmitting as spherical basically, which is determined by the initiation mode of the explosive. When t=9.001μs, the detonation wave reaches the PTFE and reflecting and penetrating waves are generated. The pressure of reflecting wave is lower than the pressure of detonation wave, which is rarefaction wave. When t=10.000μs, the shock wave has already spread a certain distance in the PTFE, and caused the crushing phenomenon at the boundary of the PTFE, and obvious rarefaction wave appears in the broken position.

Fig. 5 is the curve graph of peak pressure values of detonation waves calculated at different thicknesses of PTFE, it shows that with the increase of the distance, the peak pressure of shock waves gradually decay. The earlier stage of the curve graph decays faster, the rate is in accordance with the basic exponential decay. Simulation results of the output pressure of different thicknesses of the PTFE for exponential fitting, achieve the following equation

$$p = 10.87\exp(-x/4.94) + 8.48 \tag{7}$$

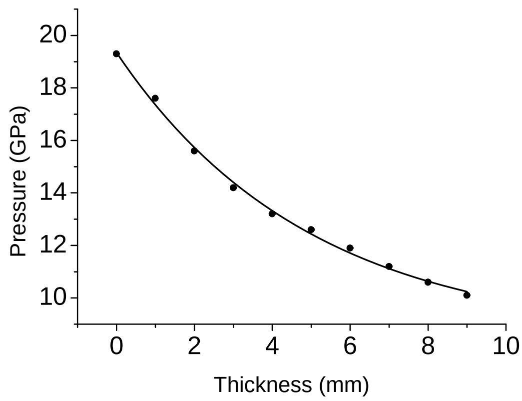


Figure 5. Curve graph of peak pressure values of shock waves calculated at different thicknesses of PTFE

According to the measurement methods described in the third part of this paper, the detonation wave pressures of the samples were measured, the data obtained are listed in Table 1. Comparing the experimental data with the values calculated by Eq. (7), we can see that the experimental values are very close to the calculated at the corresponding position of PTFE, the error is less than 5%, indicating that the simulation model and method can satisfy the engineering needs.

Table 1. Comparison of simulation results and test results of detonation wave pressure

Thickness of PTFE film/mm	0.1	0.2	0.5	1.0	2.0
Results of simulation/GPa	19.1	18.9	18.3	17.4	15.7
Results of experiments/GPa	18.6	18.1	17.5	16.8	15.2

It can be seen from table 1, the test data of the detonation wave pressure is generally less than the pressure results in the simulation. The reason lies in the assembly technology during the measuring process. There is a certain air gap between explosive and PTFE, and the same as between PTFE and manganin sensor, the air gaps have certain attenuation effect on detonation wave [5]. However, the gap between the two sets of data is small, and has a certain regularity, which can be optimized through the improvement of experiment and data processing technology. In general, the difference between simulation results and experimental results is very small, the numerical simulation results can provide effective guidance for the experimental work, and can assist the optimization of measurement technology.

5. Conclusion

(1) In general, the difference between simulation results and experimental results is very small, the numerical simulation results can provide effective guidance for the experimental work, and can assist the optimization of measurement technology. The experimental results show that the conclusion is accurate. The simulation model and method used in this paper can guide the actual operation process, and can be used as an effective means to study the propagation law of detonation wave in PTFE.

(2) The incident and the detonation wave propagation in PTFE were measured by manganin pressure sensor, and the shock wave peak pressures at different thicknesses were obtained, the pressure value decreases exponentially with the increase of thickness. We should choose thinner PTFE film in detonation pressure measurement so as to avoid causing significant effect on the experimental data.

(3) In the detonation pressure measuring process, we used manganin pressure sensor, and 0.1mm PTFE film was used to protect the sensor. The film itself has a weak influence on the test results, it basically does not affect the validity of the test data, but during the test assembly process, we must remove the influence of air layer on the test.

Acknowledgments

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