The Study of Thermodynamics of Thermoplastic Explosive at 71°C

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Abstract. A testing system was established to measure at 71°C the expansion pressure of a thermoplastic explosive with different charge quantities and of thermoplastic explosives with the same charge quantity but different formulations. It is indicated that the growth of expansion pressure of the thermoplastic explosive is non-linear with the increase rate of the charge quantity. And the expansion pressure has the possibility of decreasing when the charge quantity reaches a certain value. The expansion pressure will vary remarkably with the selection of polymer materials with differed dynamic mechanical properties as additives.

1. Introduction

With the application of polymer materials in explosive formulation becoming more and more extensive, its application technology promotes the rapid development of explosive charging technology in weapons, which ensures the steady improvement of damage performance of weapons. Thermoplastic explosive is favored by explosive researchers for its excellent comprehensive performance. Thermoplastic explosive is a high-energy mixed explosive which is made by taking a single explosive as the main component and adding various additives that can improve the performance of the explosive under certain temperature and pressure. It has the advantages of good dimensional stability, low vulnerability and anti-overload performance, etc. Therefore, it has been popularized and widely applied. However, thermal expansion is an inherent property of most polymer composites, which hinders the engineering application of thermoplastic explosives. In the environmental adaptability test of some types of weapons, the thermal expansion of the thermoplastic explosive charge leads to the overflow of small molecular materials over the shells, and even the deformation of the projectile is observed.

At present, in order to study the thermal expansion characteristics of polymer composites, researchers have carried out certain research work. The field of composite materials research has given extensive and in-depth attention to the thermal expansion characteristics of materials. Up to now, the studies on the thermal expansion characteristics of polymer composites have mostly adopted the method of measuring the expansion coefficient [1, 2]. Many universities and institutions in China have used this method to study the thermal expansion characteristics of their products. Li Yubin et al. from China Academy of Engineering Physics used a general-purpose linear dilatometer and a dynamic mechanical analyzer to test the expansion curves of φ5mm×50mm TATB-based composite samples and calculated the linear expansion in different temperature zones [3, 4]. And the DMA curve of the φ5mm×4mm sample was simultaneously tested. The study concluded that the morphological size of
TATB particles and the difference in dynamic mechanical properties of the polymer matrix have great influences on the expansion properties of the composites system. Wei Xingwen et al. studied the effects of temperature on the thermal expansion coefficient and thermal conductivity of HMX-based PBX using a thermal dilatometer and a flash thermal conductivity meter. However, the studies mentioned above largely remain in the state of basic research in the laboratory. The influences of thermal expansion of explosive charge on the engineering application have not been reported yet, and the parameters are of considerable practical significance for the research and development of weapons.

Based on the establishment of the measurement system of thermoplastic explosive charge expansion characteristics, this paper has conducted a preliminary study on the thermal expansion process of a certain type of thermoplastic PBX explosive charge, and obtained a certain amount of engineering application data. It provides the basis for the study of the law of expansion characteristic and the prediction of the expansion characteristic of charge in weapons.

2. Experiments

2.1. Experimental samples
In this paper, a formula thermoplastic explosive was prepared, and three sample casings of different sizes with a length-diameter ratio of 3:1 were processed. The thermoplastic explosives were filled into the casings by a casting process, and the mass of the three samples were 1265.6g (sample 1), 438.2g (sample 2) and 280.5g (sample 3) respectively, and the calculated density of the samples were 1.86g/cm³. The sample loading status photograph is shown in Fig. 1. In addition, in order to compare the thermal expansion characteristics of explosive charges with different formulations, a thermoplastic PBX explosive with a formulation different from the three samples was prepared, and its mass was 1275.2g (sample 4) with the same density.

![Figure 1. Sample loading status photograph.](image)

2.2. Experimental conditions and methods
For thermoplastic explosives, when the temperature is higher than that of phase transition, the state of its existence is a viscous fluid, and it can be considered that the charging expansion pressure is equal to inner wall of the sample, hence we can measure the pressure at some point or a small area to characterize the thermal expansion pressure on the casing which comes from the thermoplastic explosive charge.

Based on the above analysis, this paper designed a thermoplastic explosive charge expansion pressure test system, which includes expansion pressure measuring device, temperature controlling and heating device and data acquisition system. Among them, the expansion pressure measuring device includes a sample casing, a heating jacket, thermal insulation materials, pressure sensors, and temperature sensors, etc. The tested samples were loaded into the sample room which was heated by the heating jacket. The temperature control and heating device used a slow burning temperature control system; the pressure sensors measured the expansion pressure of the sample and transmitted the data to data acquisition system through the data line; the temperature sensors transmitted the real-
time value to the temperature controlling device to complete the precise control of the heating temperature. The test system composition diagram is shown in Fig. 2.

![Thermoplastic explosive expansion test system composition diagram.](image)

Figure 2. Thermoplastic explosive expansion test system composition diagram.

The expansion pressure test system of thermoplastic explosive charge designed in this paper heats the projectile body through temperature control and heating device. The parameters of the device are as follows:

1. Temperature range: room temperature ~ 71°C.
2. Average heating rate: (1~5)°C/min, accuracy ± 0.2°C.
3. Constant temperature section control accuracy: room temperature ~ 71°C, error ≤ ± 1°C.

Pressure sensor parameters selected in the system:

1. Pressure range: 0~50MPa;
2. Comprehensive accuracy: 1%;
3. Operating temperature range: -20~80°C.

3. Results and discussion

3.1. Sample test results of thermal expansion pressure

The samples were tested by the experimental methods described in 2.2, and the expansion pressure curve generated under the heating condition was obtained. The curve of the relationship between the charge expansion pressure and temperature of the sample is shown in Fig. 3. The expansion pressure measurements of each sample at the temperature of 71°C are listed in Table 1. Fig 4 is a graph showing the charge expansion pressure-temperature relationship of Sample 4.

| Sample serial number | Expansion pressure /MPa |
|----------------------|-------------------------|
| 1                    | 36.1                    |
| 2                    | 14.6                    |
| 3                    | 7.7                     |
| 4                    | 18.9                    |

Table 1. Expansion pressure values of the samples at 71°C.
3.2. The effect of the charge quantity on the test results

It can be seen from the test results listed in Fig. 3 and Table 1, thermoplastic explosive charge has a strong pressing force on the casing, and the expansion pressure generated by the 1kg class charge at 71°C is 36.1MPa. For the internal structure of warhead, the expansion pressure may cause changes in the state of the components such as the detonating sequence and the detonating mechanism, and bring certain dangers to the reliability and even safety of the weapon. Some measures must be taken to weaken or eliminate the expansion pressure.

In this paper, the experimental study on the expansion pressure of different charge explosives at 71°C were carried out, and the curve shown in Fig. 5 was obtained. It is shown in Fig. 5 that the expansion pressure of the samples grows rapidly with the increase of the charge quantity, but the rate of increase decreases. According to the practical application of thermoplastic explosive, it can be inferred that the expansion pressure will not grow with the increase of the quantity of charge indefinitely. Instead, it will reach the maximum at a certain quantity of charge, and then begin to reduce. Unfortunately, due to the limitation of site conditions, this paper is unable to carry out large quantity charge experimental verification.
3.3. Comparison of test results of different kinds of thermoplastic explosives
As the continuous phase of thermoplastic explosives, the dynamic mechanical properties of polymer materials will have a certain influence on the expansion properties of the composite system [5]. Therefore, this paper selects two different kinds of thermoplastic explosives for experimental study to compare the similarities and differences of the expansion pressure generated under the heated conditions. As is illustrated in Fig. 3 and Fig. 4 that since different thermoplastic explosives use polymer materials with different dynamic mechanical properties, the thermal expansion process curves and values of expansion pressure apparently differ. By selecting polymer materials with different properties as additives for thermoplastic explosives, the expansion pressure generated by the heating of the charge can be reduced.

4. Conclusion
(1) The expansion pressure generated by heat of the thermoplastic explosives studied in this paper grows continuously with the increase of the charge quantity, but the rate of the growth is not in linear relationship with the increase of the charge quantity.

(2) In the formulation design of thermoplastic explosives, by selecting polymer materials with different dynamic mechanical properties as additives, the expansion pressure characteristics can be significantly changed, and the expansion pressure generated by the heat of the charge can be reduced.

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References
[1] Xiao-ling Liao, He-jun Li, SUN Guo-dong, LI Ke-zhi. The thermal expansion behavior of 3D C/C composites [J]. NEW CARBON MATEALS, 2 (2010) 60-64.
[2] Guo-ping Wei, Bo-quan Zhu, Yue-nan Zhu. Effect of MgO content and distribution characteristics on the thermal expansion properties of Al2O3-MgO castables [J]. JOURNAL OF MATERIALS ENGINEERING, 2 (2010) 429-432.
[3] Yu-bin Li, Ming Shen, Jing-ming Li. Thermal Expansion of TATB-filled Polymeric Material [J], ENERGETIC MATERIALS, 3 (2003) 24-27.
[4] Kolb J R, Rizzo H F. Growth of 1,3,5-triamino-2,4,6-trinitrobenzene (TATB). I. Anisotropic thermal expansion of TATB [J]. Propellants and Explosives, 1979, 4:11.
[5] Xing-wen Wei, Xiao-yu Zhou, Pei Wang, Xiao-zhen Tu, Xi Wang. Influence of Temperature on
Thermal Conductivity of HMX Based Expansion Coefficient and Thermal Polymer Bonded Explosive, Chinese Journal of Explosives & Propellants, 6 (2012) 33-37.