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Experimental Investigation on the Explosive Substitute by Drop Test †

Ruoze Xie [1,2,*], Qingping Zhang [1,2], Zhifang Deng [1,2] and Xicheng Huang [1,2]

1 Institute of Systems Engineering, China Academy of Engineering Physics, Mianyang 621900, China; zhangqp@caep.cn (Q.Z.); dengzf@caep.cn (Z.D.); huangxc@caep.cn (X.H.)
2 Shock and Vibration of Engineering Materials and Structures Key Laboratory of Sichuan Province, Mianyang 621900, China
* Correspondence: xierz@caep.cn; Tel.: +86-816-248-5457

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Abstract: The drop tests of the experimental structure with explosive substitute material were carried out to study the dynamic deformation and failure of the explosive substitute. The PBX simulation material was designed as a cylindrical flat head structure, with the support structure of the PBX simulation material as an aluminum support ring, and with an affixed counterweight to the upper part of the PBX simulation material. The PBX simulation materials, the counterweight and the support ring, were glued together to form the drop test pieces. A special drop test system was designed, which realized the non-deflection of the falling posture of the drop test pieces and that the drop was pure free. The results show that in the drop impact tests, the critical height of the explosive simulant failure is about 600 mm to 700 mm when the counterweight of 19.62 kg is used.

Keywords: PBX; simulant; drop; impact; failure

1. Introduction

Polymer bonded explosive (PBX) is a solid high-energy explosive consisting of explosive particles and polymers, and has a very wide range of applications [1–3], ranging from rocket propellants to the main explosive charge in conventional munitions. The mechanical behavior of PBX is not only related to the structural integrity and reliability of the products, but also affects its combustion and detonation characteristics [4,5]. The study of PBX deformation is of great significance.

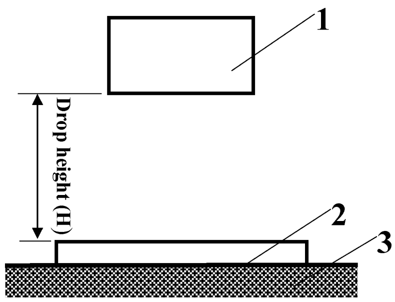
Many studies on the mechanical properties of PBX have been conducted. Xie Fengying et al. [6] used low-speed orthogonal cutting experiments and microscopic imaging methods to conduct an experimental study of the molding characteristics of the chip peeling, actual depth of cut, chip shape, and edge quality of the HMX-based polymer bonded explosive simulation material, and a phenomenological model of the cutting surface forming process was established. Zhao Jibo et al. [7] studied the friction coefficient between the GO-924 explosive and aluminum alloy, rubber and GO-924 explosive under different impact loading conditions using split Hopkinson pressure shear bar, and obtained the curve of the friction coefficient versus time for different material interfaces. For the constitutive model, Goudrean et al. [8] conducted a SHPB experiment on PBX-113, and gave the stress-strain curve for a tensile test with a strain rate of about 5350 s^{-1} and a compression test with a strain rate of about 1500–4000 s^{-1}. Linear and simple nonlinear viscoelastic constitutive models were used to fit the experimental results. GT Gray III et al. [9] applied three kinds of PBX explosives (PBX9501, X0242, and PBXN-9) to a strain rate of 10^3 s^{-1} in a temperature range of −55, −40, −20, 0, 17, 40, and 55 °C, to conduct SHPB experiments to investigate the mechanical properties under different external conditions. Chunghee Park et al. [10] used the INSTRON 8801 testing machine and Hopkinson pressure bar (SHPB) to perform compression experiments on a PBX simulation material with strain rates from 0.0001 s^{-1} to 3150 s^{-1} and studied the mechanical behavior of the material. Dai Xiaogan et al. [11] adopted the Steven test and Shen Chunying et al. [12] adopted the plug test to study the safety of explosives under impact conditions. Pengwan Chen et al. [13] used Brazilian experiments to study the effects of pressure, temperature and strain rate on the tensile mechanical properties of PBX, and analyzed the failure mechanism of PBX under different loading conditions. Luo Jingrun [14] studied in detail the damage, fracture and constitutive relations of PBX explosives.

Explosives may encounter unexpected accidents such as falling accidents during transportation, storage, use, etc. Under these impact loads, the major accidents may cause the explosives to burn or explode. The problems of structural strength, damage, and destruction of the structural components of explosives have developed into a focus of attention for all parties. Because PBX explosives are consumables and dangerous goods, it is dangerous to conduct direct impact tests on them; on the other hand, it is costly and difficult to carry out systematic research on them, unlike for inert materials. Therefore, it is usually necessary to carry out impact tests of experimental parts of explosive simulation materials first. It provides a reference for the research on the safety of the abnormal fall of explosive structural parts. Therefore, the research on the deformation and damage under the abnormal impact environment of explosive simulation materials has become an urgent problem to be resolved.

In this study, a special drop device was designed to carry out the drop test of the experimental piece with PBX simulation material. The dynamic deformation and damage of the explosive simulation material sample was analyzed. The experimental data were obtained as information for the corresponding numerical simulation, and for the safety protection design as well.

2. Experiment

The drop device was used to release the drop test piece from different heights. The test piece was allowed to fall freely on the target (aluminum plate), see Figure 1. The PBX simulation material in the experimental piece was impacted and deformed until it was destroyed; simulating the deformation and destruction process of explosive components during an accidental impact accident when the product was experiencing impact abnormalities. The structural strength of the explosive components is examined, and the damage of the explosive components is studied, which provides a reference for the safety protection design of explosive components.



1. drop test piece;2. target;3. rigid base

Figure 1. Diagram of the drop test.

2.1. PBX Simulation Material

The explosive used in the experiment was a PBX simulation material with a density of 2.63 g/cm^3. Figure 2 is the stress-strain curve of the PBX simulation material obtained in the static compression experiment. Its static pressure strength is 71 MPa.

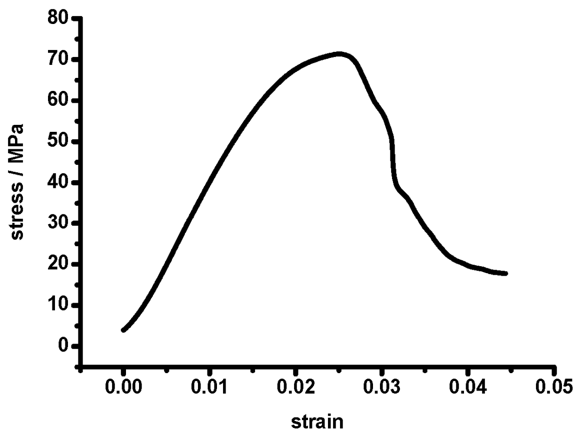


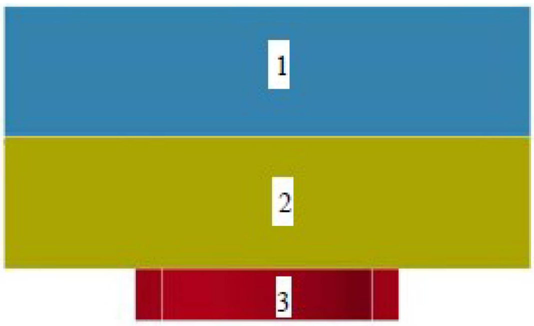
Figure 2. Static compression stress-strain curve of PBX simulation material.

2.2. Drop Test Piece

The drop test piece consisted of three parts: The PBX simulation material, the counterweight, and the support ring. The PBX simulation material were designed as a cylindrical flat head structure, the support structure of the PBX simulation material as an aluminum support ring, and the upper part of the PBX simulation material is attached with a counterweight. The PBX simulation material, the counterweight and the support ring were bonded together by using 502 glue to form the drop test pieces. The material of the counterweight was 45 steel, and the material of the support ring was ZL101 aluminum.

The drop test piece is shown in Figure 3.

The PBX simulation material of the drop test piece was a Φ200 mm × 50 mm cylindrical flat head structure with a mass of 4.13 kg. The structural dimensions of the support ring were: Inner diameter Φ90 mm, outer diameter Φ100 mm, height 40 mm. The counterweight was a cylindrical steel block with the same outer diameter as the PBX simulation material. The size and weight of the counterweight block were Φ200 mm × 80 mm and 19.62 kg.



1. counterweight; 2. PBX simulation material

3. support ring

Figure 3. Drop test piece.

2.3. Test Items

The test items included the drop height of the drop test piece, the strain at different positions on the lower surface of the PBX simulation material during the drop impact, the pressure between the PBX simulation material and the support ring, and shooting of the drop impact process of the test piece. The deformation of the PBX simulation material after the test was observed.

The location of the measurement point on the PBX simulation material is shown in Table 1, where the strain measurement points S1 and S2 are circumferential measurement points, and S3 and

S4 are radial measurement points. S1 and S2, S3 and S4, pressure measurement points P1 and P2 are symmetrical points. The location of measuring point is shown in Figure 4.

Table 1. Location of measuring points on PBX simulation material.

Type	Number		Measuring Point	Remarks
Strain	Circumferential	S1	10 mm from the outer edge of the support ring	—
		S2	10 mm from the outer edge of the support ring	Symmetrical to S1
	Radial	S3	10 mm from the outer edge of the support ring	—
		S4	10 mm from the outer edge of the support ring	Symmetrical to S3
Pressure	P1		Between the PBX simulation material and support ring	—
	P2		Between the PBX simulation material and support ring	Symmetrical to P1

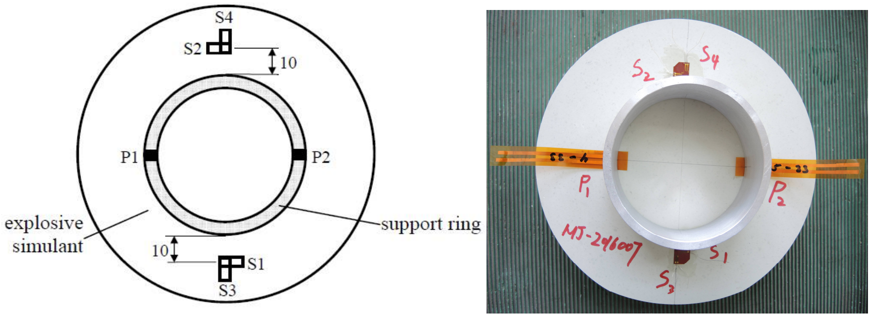


Figure 4. Location of measuring point.

2.4. Drop Device

The rigid base of the drop test was 760 mm high. The impact target consisted of several aluminum plates (aluminum plate size was 600 mm × 500 mm × 50 mm, three pieces were laminated and the material was 5A06) and stacked on the base. The perimeter of the upper part of the base was designed with a protective frame and bullet-proof glass to prevent spatter from falling impact and rolling off of experimental parts after impact, which would cause injury to personnel and equipment.

The counterweight of the experimental piece was connected to the suspender through an electromagnet that could carry 100 kg. The suspenders were connected through the two fixed pulleys at the middle and end of the top beam of the frame and the hooks of the lifting mechanism. When the experimental piece was raised to the required height and stabilized, cut the suspender and let the test piece naturally drop. As shown in Figure 5.

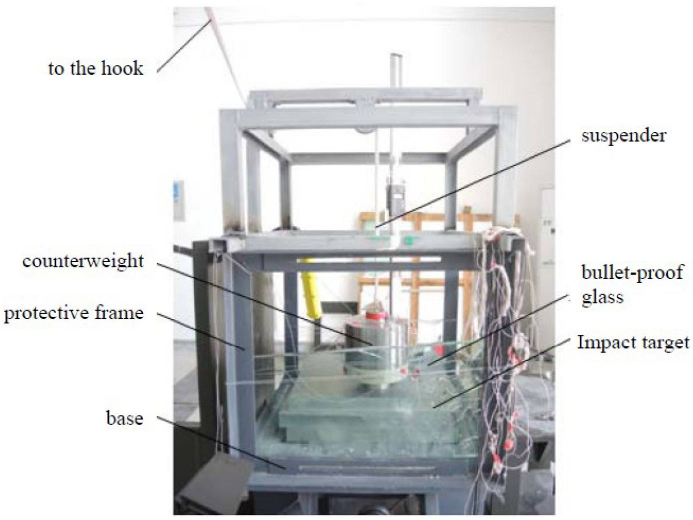


Figure 5. Dropping test device.

2.5. Test System

The drop height of the test piece was measured by a digital height scale measuring 1000 mm.

The drop posture of the experimental piece and the hitting process were monitored by a high-speed camera. The high-speed camera model was PHANTOM V12.1, and the shooting frequency was 5000 frames per second.

The pressure between the PBX simulation material and the support ring was measured by a PVDF piezoelectric pressure gauge (hereinafter abbreviated as PVDF). The sensitive head size was 3.18 mm × 3.18 mm, the area was 0.1 cm^2, the measured thickness was 0.08 mm, and the base size was 90 mm × 13 mm. The matching integrator capacitance was 0.01 μF.

The strain on the PBX simulation material specimen was measured by Strain rosette gauge, with pull positive, with a sensitivity factor of 2.16 and a resistance of 120 Ω. The strain instrument model was DC-96A, and the parameter was normalized to 1 V for 500 με. Waveform memory model was TOP POLAR9300T, using a frequency of 1 MHz.

3. Experimental Results and Discussion

Figure 6 shows the typical process of falling impact of the experimental piece taken by high-speed camera (taking the specimen No. 009 as an example).

Figure 6. Drop test piece impact process.

The figure shows that the drop test piece smoothly hits the target and the PBX simulation material cracks around the support ring. Some of the PBX simulation material collapses and splashes, and then it rebounds and dumps.

Table 2 shows the drop impact parameters of the test piece.

Table 2. Drop impact parameters of the test piece.

No. of PBX Simulation Material	Counterweight kg	Drop Height (H) mm	Temperature °C	Humidity %
010	19.62	450	25	55
015	19.62	500	27	38
016	19.62	600	27	36
009	19.62	700	24	45

Figure 7 shows the morphology of the PBX simulation material after the drop impact test. It can be seen that when the drop height is 500 mm, the surface of the PBX simulation material has only a slight indentation, and is basically not damaged. When the drop height is 600 mm, the surface of the PBX simulation material along the support ring is slightly damaged, but there iss no bulk material collapse. When the drop height is 700 mm, the PBX simulation material remains intact within the support ring. There are some large break outside the support ring, and the end face was broken into pieces. The critical height of PBX simulation material drop damage is about 600~700 mm.

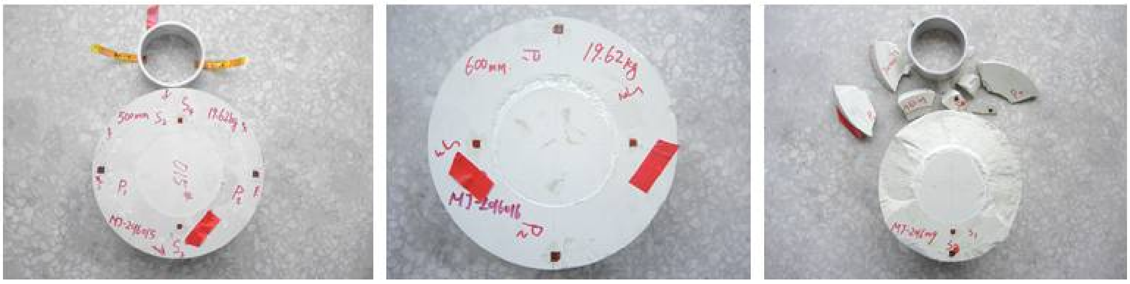


Figure 7. Morphology of PBX simulation material after drop test.

Figure 8 shows the strain history of the PBX simulation material surface during a drop impact. It can be seen that when the impact begins, the support ring impacts and compresses the PBX simulation material. In the periphery of the support ring, a tensile strain is generated in the radial direction of the simulated material surface, and in the circumferential direction, compressive strain develops. With the development of deformation, the strain on the surface of the PBX simulating material undergoes a tension-compression transition, which indicates that the strain on the surface of the PBX simulating material during the impact is an alternating process.

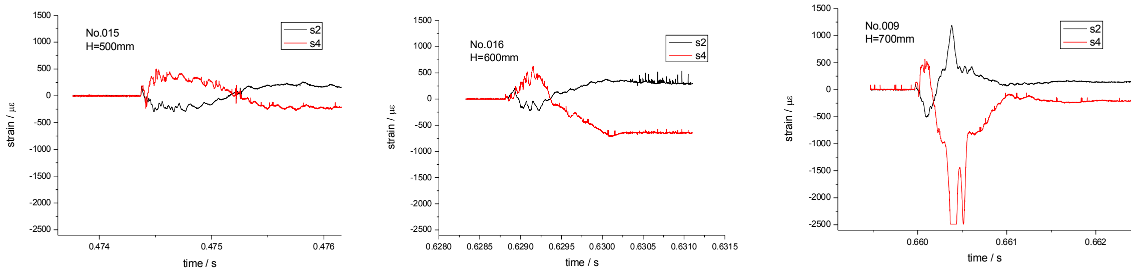


Figure 8. Strain of PBX simulation material surface during impact.

Figure 9 shows the pressure between the PBX simulation material and the support ring during a drop impact. It can be seen that when the height is 500 mm and 600 mm, the pressure curve has a rounded top, and when the drop height is 700 mm, the pressure curve shows a peak at the top and then quickly falls back. This is due to the structural damage to the PBX simulation material and the rapid decline in bearing capacity; with the increase in the drop height, the maximum pressure increases in turn, which is 160 MPa, 195 MPa and 356 MPa respectively.

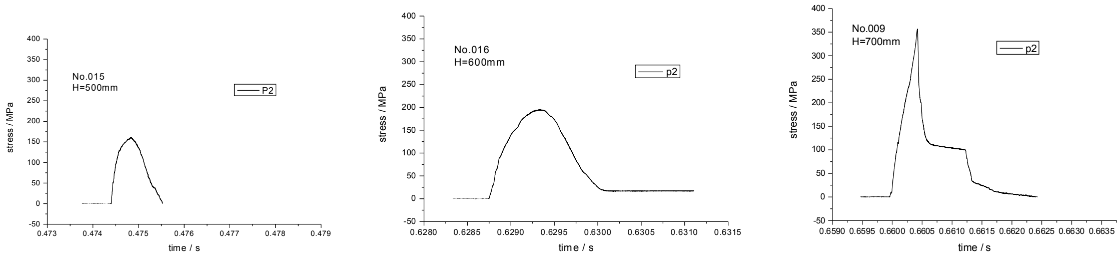


Figure 9. Pressure between PBX simulation material and support ring.

Figure 2 shows that the static pressure strength of the PBX simulation material is 71 MPa. Comparing with the maximum pressure in Figure 9, it can be seen that the maximum pressure of the PBX simulation material in the case of a drop impact is much greater than its static pressure strength. In a considerable range that the impact pressure exceeds the static pressure strength, the PBX simulation material can still withstand the load without breaking. It is not suitable to use the uniaxial strength criterion to evaluate the bearing capacity of the explosive parts. This is because the dynamic compression strength of the PBX simulation material is greater than its static compression intensity;

on the other hand, it is due to the fact that the PBX simulation material is in a structure that is subjected to a complex pressure state and requires the application of a damage model under a complex stress state [15].

4. Conclusions

A dedicated drop test system was designed to perform drop tests on structural parts with PBX simulation materials. The drop impact characteristics of PBX simulation materials were studied. The results show that:

(1) The drop test system ensures that the test piece's drop attitude has no deflection and pure free fall, and achieves a stable positive collision between the test piece and the target plate;

(2) The critical height of drop and damage of PBX simulation material is about 600 mm~700 mm;

(3) The strain on the surface of the PBX simulation material during impact is an alternating process;

(4) It is inappropriate to use the uniaxial strength criterion to evaluate the loading capacity of the explosive components in the structure. It is necessary to apply the damage model under a complex stress state.

Author Contributions: X.R. and Z.Q. conceived the study and designed the experiments; X.R. and D.Z. performed the experiments; X.R. and H.X. analyzed the data; X.R. wrote the paper.

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