Explosive property and mechanical characteristics of the trial PBX consisting of RDX and HTPB

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It has been tried to prepare the PBX consisting of RDX as high explosive and HTPB being used as binder in the field of composite propellant with a view to obtaining explosive elasto−plasticity. Since the PBX makes it possible for us to prepare the thin and tough explosives, one might expect that such a explosive would be applied to explosive working to accompany only deformation without destruction.

From such a viewpoint, various tests were performed on explosive properties and mechanical characteristics of the trial PBX.

It is evident from the testing results that the trial PBX has great practical utility in the field of explosive working.

1. Introduction

Essential properties required as a plastic bonded explosive (PBX) are high detonation velocity and high material strength of high polymer used as a binder. Therefore, hexogen (RDX), octogen (HMX) and penthrite (PETN) as explosive for PBX can be selected, and a various kinds of high polymers can be adopted as a binder. But it is preferable that such a binder has a excellent buffer capacity to impact, as well as rubberlike elasticity, because the material characteristics of PBX are resulted from characteristics of binder.

Consequently, provided an excellent elasto−plasiticity of the PBX can be achieved by making use of high polymer, it has become feasible to prepare string or flexible sheet explosive. It is contemplated that such a trial PBX is put into practice in the field of fuze utilizing as well as of explosive working and explosive forming.

From the above viewpoints, it has been tried to prepare the PBX consisting of RDX and HTPB (hydroxy−terminated polybutadiene)[1] being available component in the field of composite propellant[2) 3)] and to investigate explosive properties for the trial products.

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In this paper, experimental results on various explosive properties and material characteristics of the trial PBX are described.

2. Experiments

2.1 Test piece used in experiments

RDX (passing through 61μm screen, purity more than 99.8%) of a high explosive was used. HTPB was adopted as a binder. IPDI (Isophorone diisocyanate) of 7.1wt.% was mixed to HTPB as a curing agent. The mixtures of HTPB and IPDI will hereinafter be abbreviated as HTPB. The trial PBX was prepared by mixing RDX and HTPB, changing the ratio of RDX/HTPB=80/20~55/45 (wt.%) with 5% portion of RDX and HTPB, respectively. In addition, for the purpose of prevent accident, by adding with small amount portions of RDX in HTPB monomer of prescribed amount, the mixture was kneaded together over 30 minutes, then, cured in an electric desiccator at 70 ℃ for 24 hours.

2.2 Drop hammer test

In order to investigate impact sensitivity of the trial PBX, the drop hammer test was carried out in accordance with the standard ES−21 (1)[4]. The size of the test piece adopted in the drop hammer test was 2 mm cube. The test piece placed in a tin foil plate of 12 mm in diameter was held between two iron cylinder. In such a situation, an iron hammer of 5 kg in weight was dropped on the test piece. In accordance with JIS, 1/6 explosion height is ordinary estimated in cm and sensitivity of explosive to impact was evaluated by dividing the height from first class to eighth one. While, on the present test, 1/10 explosion height, that is, the height of one explosion (mm) in ten test, were measured in accordance with ASA (American Standard Association)[5] in order to make sure safety and to explore directly the degree of danger.

2.3 Ignition test

Ignition test (Krupp type)[6] of the trial PBX was performed to investigate sensitivity to heat. The size of the test piece was the same as that of the drop hammer test. After the trial PBX was placed in the testing hole, the ignition delay period was measured at various temperatures. From the results obtained, the ignition temperature at 4 second ignition delay period and the activation energy are determined.

2.4 Detonation velocity

Detonation velocities on the trial PBX products obtained by varing composition in the manner explained above were measured by the use of streak camera, and the test pieces for the measurements were prepared several ones every composition. The test pieces were packed into polystylene pipe of 12 mm in inner diameter, 16 mm in outside diameter and 230 mm in length with pressing in the time of pot life of HTPB, and cured in an electric desiccator at 70℃, 24 hours.

The detonation velocity can be decided from the length of explosive and the detonation time. The detonation time is computed from sweep rate of streak camera and the time lag caused by the sweep rate on a photographic film.

2.5 Critical diameter test on detonation

Critical diameter test was made to investigate propagation of detonation on the trial PBX. On the test, the trial PBX consisting of 55 %wt. RDX and 45 %wt. HTPB was used. This is because the trial PBX has most insensitivity to impact on the drop hammer test and almost most minor amount of RDX in the all products. Schematic diagram and testing dimentions of the PBX of conical type is shown in Fig. 1. For the

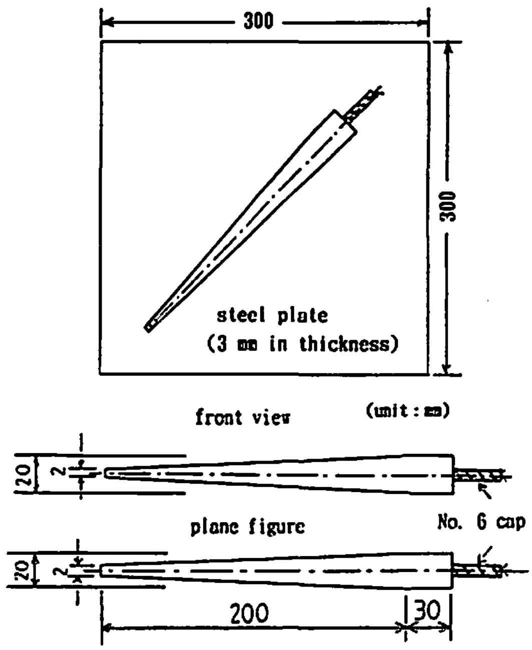

Fig. 1 Schematic diagram and size of the PBX on critical diameter test

purpose of estimation of critical diameter on detonation, initiation of the trial PBX was achieved by using of No.6 cap on a steel plates (3 mm in thickness). Besides, on the above PBX, in order to examine the accelerating detonation owing to PBX of large diameter to PBX of small diameter, the rod−shaped PBX of 4 mm diameter was detonated with the same manner as that in the critical diameter test.

2.6 Mechanical characteristics of the cured PBX

It is said that the trial PBX has characteristics in strength of materials superior to those of the other explosives (ex. TNT, dynamite).

Therefore, the tensile[7] and compression tests on the RDX/HTPB explosive were examined. On the examination, every PBX prepared by varying with 5 % portions of ratio of RDX and HTPB as explained already. The examination was established by the use of UTM 3 −B type testing machine made by Orientic Co., Ltd.

The tensile testing piece is of dambell shape, and measuring portion has cross−sectional area of 10 mm × 7 mm with 100 mm in length . The compression testing piece is 10 mm cube. Both tensile and compression tests were run out several times on every composition ratio of RDX/HTPB=80/20∼55/45.

Table 1 Special quality of the trial PBX consisting of RDX and HTPB

RDX/HTPB wt%	Uncured state	Cured state
80/20	RDX in wetting somehow press to pack	non flexibility, fragile possible to cut by knife
75/25	large plasticity press to pack	slight plasticity possible to cut by knife
70/30	glutinous, sticky press readily to pack	flexibility cut readily by knife
65/35	glutinous, fulidity press readily to pack	flexibility, soft cut readily by knife
60/40	millet jelly, fluidity possible to pour into vessel	increasing flexibility cut readily by knife
55/45	millet jelly, large fluidity pour readily into vessel	large flexibility devil' stongue jelly

3. Results and consideration

3.1 Characteristics of PBX in preparing

The physical properties of the trial PBX before and after curing are given in Table 1. The cured PBX in which being contained 80% RDX is brittle and is easily cracked. Those containing 60 or 55% RDX is difficult to work because of obvious soft even after being cured. Nevertheless, the trial PBX was inseparable.

In the case of binder having rigidity such as EP815 or polystylene, the curing leads to all of the rigid products and then, brittle fractures occur. From the viewpoint of easiness in processing the trial products consisting of the composition ratio of RDX/HTPB=75/25~65/35 are best, whereas after curing those of the composition ratio of 70/30~60/40 are easy to handle.

3.2 Drop hammer test

Experimental results of the drop hammer test of the trial PBX were indicated in Fig. 2. The experimental points obtained are 1/10 explosion heights in mm.

As is seen in Fig. 2, in the range of RDX/HTPB=80/20~65/35, 1/10 explosion height indicates appreciable low height and slight variation over the range from 180 mm to 220 mm. These results suggested that this kind of the trial PBX is comparatively apt to be explosives. The trial PBX consisting of RDX/PBX=60/40 has proved to be insensible to impact from the fact that 1/10 explosion height (610 mm) rose steeply.

By the way, 1/10 explosion height on powdered TNT is 350 mm. TNT is the class of compound explosive being commonly employed and is insensible to impact.

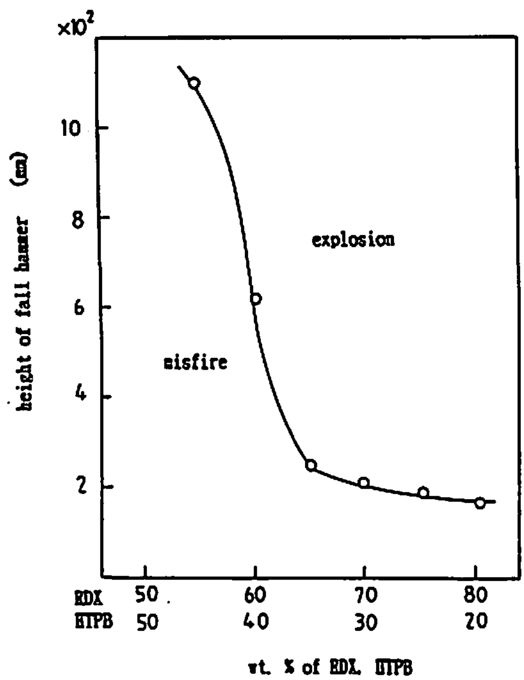

Fig. 2 Plots of 1/10 explosion height vs. composition ratio of RDX/HTPB on drop hammer test

3.3 Ignition test

On the ignition test, the trial PBX consisting of RDX/HTPB=80/20 burst into flames, while those consisting of other composition were noninflammable and mostly decomposing smoke and gases of explosive are observed. In the latter cases, a carbonic

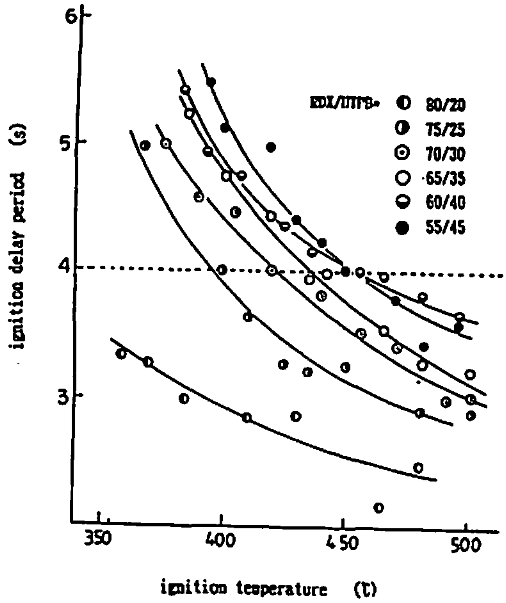

Fig. 3 Plots of ignition delay period vs. ignition temperature

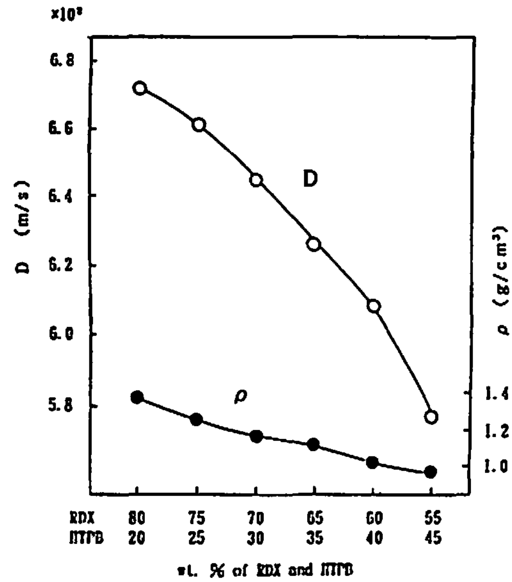

Fig. 5 Plots of detonation velocity vs. composition ratio of RDX/HTPB

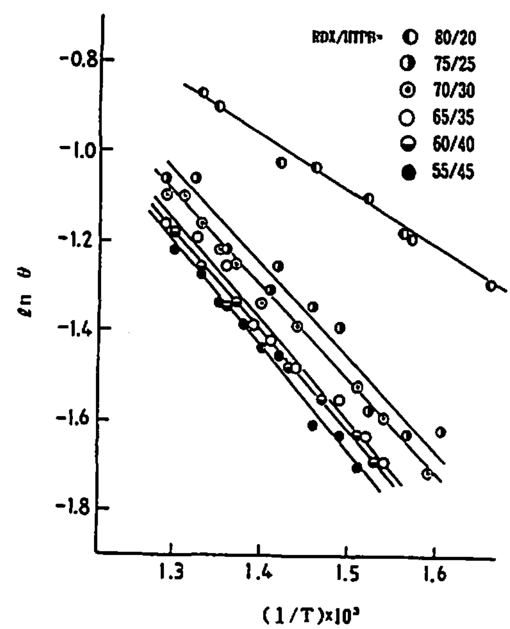

Fig. 4 Arrhenius plots on RDX/HTPB
T : ignition temperature(K)
θ :ignition delay period(s)

residue remained in the testing hole after test. The results of ignition test are shown in Fig. 3. As is seen from Fig. 3, ignition point over the range of RDX/HTPB=75/25~55/45 are distributed closely. Attempting to determine temperatures at 4 second ignition delay period after placed in the testing hole, the ignition temperatures on RDX/HTPB=70/30 and 60/40 can be estimated as 420 and 460 ℃ by a dotted line in the figure, respectively.

Arrhenius plots of the ignition temperature versus the ignition delay period temperature are indicated in Fig. 4. It can be found from Fig. 4 that the activation energy for the trial PBX are 101.3, 174.4, 184.4, 216.0, 217.0 and 228.4 KJ/mol to RDX/HTPB=80/20, 75/25, 70/30, 65/35, 60/40 and 55/45, respectively. It is understood that the activation energies increase accompanying with increasing in HTPB content or decreasing in RDX content. This is dependent on increasing in energy required to ignite HTPB in proportion to HTPB content. In the case over the range from 80 to 75 of RDX content, the activation energy increases steeply, in spite of as little as 5% decreasing of RDX. Even if the increments of HTPB is 5 wt.%, an amount of air bubble mingled with the trial PBX decreases steeply, the trial PBX becomes, itself, dense. Because of the heat conduction of the trial PBX becomes difficult, the activation energy of the trial PBX seems to be large. This suggests that the presence of HTPB is effective exceedingly in the vicinity of 80 to 75 of RDX content. It is proved that the trial PBX containing of component less than 75% RDX is safety to heat.

3.4 Detonation velocity

Fig. 5 illustrates the plots of the detonation velocities measured versus the composition ratio of the trial PBX. An approximately linear relationship exsists between the detonation velocity and the composition, compared with variation in specific gravity with the composition over the range from 60 to 75 wt.% RDX. The detonation velocity decreases steeply in the range from 60 to 55 wt.% RDX. The detonation of this PBX might be depended on sympathetic detonation of RDX because of increments of HTPB in RDX/HTPB=55/45. Since the measured values of thedetonation velocities on the trial PBX were beyond 5,500m/s. This kind of PBX may be adopted to high explosive in practice comparing to TNT as a compound explosive, various dynamites as explosive mixtures being used usually.

3.5 Critical diameter test on detonation

Critical diameter on detonation on the trial PBX consisting of RDX/HTPB=55/45 was measured. As can be seen in Fig. 6, the trial PBX was detonated completely even 2 mm diameter. Therefore, it is assumed that trial PBX containing RDX more than 55%wt. is able to detonate sufficiently up to 2 mm diameter. To confirm the above assumption, the detonation velocities of the trial PBX having the same dimention as that used on the critical diameter test on steel plate were measured by the use of streak camera. The result obtained is shown in Fig. 7. It can be seen from the figure that the detonation of the trial PBX has no influence by changes in diameter, because the detonation spreads with constant velocity. The detonation velocity of the PBX, determined experimentally, is 5,700m/s. Furthermore, the rod-shaped PBX as large as 4 mm diameter was detonated by using No. 6 cap on trial, because the

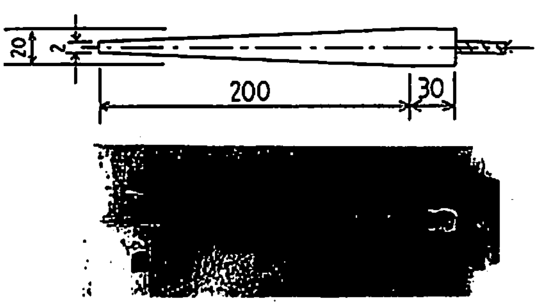

Fig. 6 Detonation trace of the PBX adopted to critical diameter test on detonation

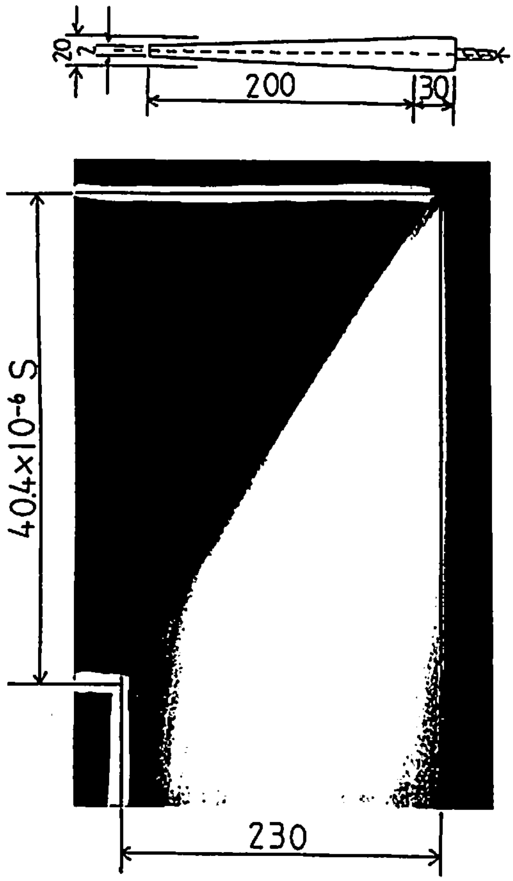

Fig. 7 Size and streak camera photograph on critical diameter test

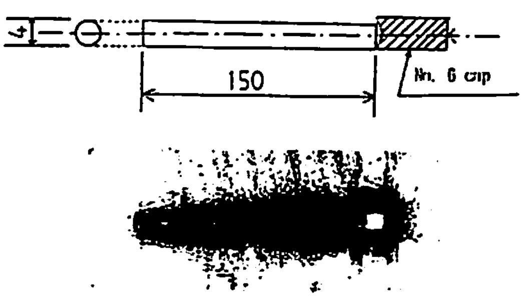

Fig. 8 Size and detonation trace of the fine diameter PBX on detonation

detonation of the PBX of small diameter can be regarded as being spread by accelerating detonation owing to PBX of large diameter. As shown in Fig. 8, the detonation of the trial PBX spreaded completely despite the diameter as large as 4 mm.

3.6 Mechanical characteristics of the cured PBX

The results of the mechanical tests are indicated in

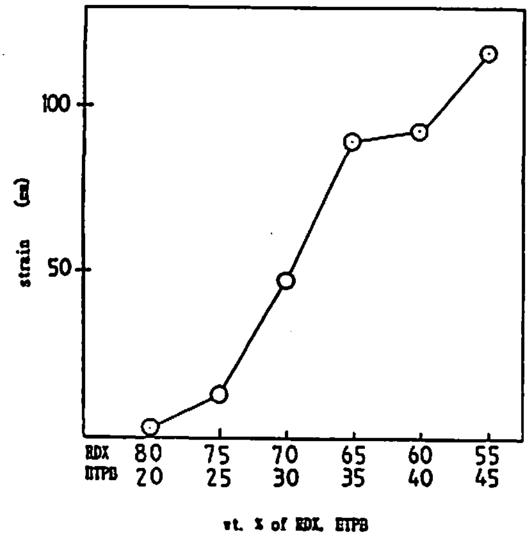

Fig. 9 Plots of strain vs. composition ratio of RDX/HTPB

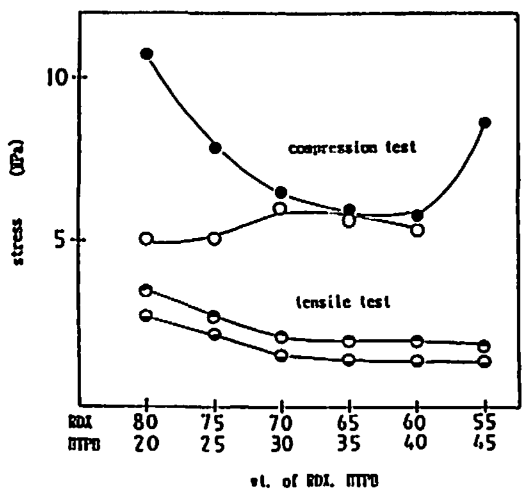

Fig. 10 Plots of stress vs. composition ratio of RDX/HTPB
●:50% compression stress
○:max. stress in compression
◓:shearing stress
◒:max. stress in tensile

Figs. 9 and 10. Fig. 9 depicts plots of strain to the every composition of the trial PBX. As shown in the Fig. 9, although the strain of the composition of RDX/HTPB=80/20 is small, that of the composition less than 70% of RDX content increases abruptly. Since the compositions of RDX/HTPB=75/25~65/35 are well−balanced ratios, strain become large in proportion to increase in the amounts of HTPB. While, the compositions of RDX/ HTPB=65/35~60/40 result in the limiting ratio. In the case of the ratio of 60/40~55/45, the strain appears to approach an inherent value of HTPB. Therefore, it is suggested that large strain on 55/45 composition depends on rubberlike property of HTPB, because the strain increase without crack. Fig. 10 shows plots of the stress value at that time broke off the test piece on tensile test against the composition ratio and of the stress value at that time of 50% compression on compression test too, in addition to maximum stress within a proportional limit of test piece on both the tensile and compression test.

Both the breaking stress and the maximum stress on tensile test show a similar tendency to composition ratio of the trial PBX. On the 80%~70% RDX, as their characteristics are dominated by the amount of RDX in the trial PBX, there is a little effect of HTPB. Nevertheless, below 70% RDX the characteristic of HTPB appears to be dominating cause of the whole, therefore, it can be considered that there is not very much change.

In the cases of the compositions less than 70% RDX, both the stresses are constant regardless of the compositions. Consequently, in the above range, it became evident that the tensile strength of the trial PBX depends significantly on material strength of HTPB and is independent of RDX content. From the fact that the value of 50% compression stress is large relative to the small value of the maximum stress within a proportional limit, the compression of the trial PBX can be regarded as being progress as it is cracking in an early stage.

That is to say, the trial PBX having high content of RDX is vulnerability. In the case of the RDX/HTPB=55/45, it was difficult to distinguish the maximum stress on the recording paper because of the easiness in deformation.

It can be said that the trial PBX consisting of RDX and HTPB is excellent in absorptiveness to striking energy because of its abundant elasto−plasticity. It may be said in this connection that, the compound explosive cyclotol (RDX/TNT/wax) employing usually has the maximum compressive strength of 5.0 MPa, and the maximum tensile strength of 1.2 MPa[8].

4. Conclusion

Explosive properties and mechanical characteristics of the trial PBX consisting of RDX and HTPB have been examined by taking into consideration of the compositions enable to product with various experiments. On the present experimental results, the following points should be marked.

(1) Pressing for pack of the trial PBX in the preparing stage becomes easily, as the fluidity of the composition increases with an increase in HTPB contents over 30 wt.%. On the other hand, from the results of the drop hammer test and the mechanical characteristics, the explosive properties of the cured PBX can be maintained proper flexibility over the range of RDX/HTPB=75/25 ~65/35.

(2) The trial PBX consisting of RDX/HTPB=55/45 becomes most insensitive to impact on the drop hammer test, and it has the most activation energy on the ignition test. While, on the RDX/HTPB=55/45, from the results of the critical explosive diameter test and the thin and thicken explosive test, it can be expected to initiate completely by the use of No. 6 cap and detonated in stationary even as small as 2 mm diameter.

In toto results from experimental tests, it can be considered that the trial PBX consisting of the composition ratio of RDX/HTPB=70/30 and its neighborhood is applicable to explosive working.

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RDXとHTPBから成る試作PBXの火薬的性質と機械特性

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弾性と可撓性を備えた爆薬を製造する目的で，爆薬成分としてＲＤＸを，バインダー成分として推進薬の分野で汎用されているＨＴＰＢを用いて高分子混合型爆薬（ＰＢＸ）を試作した。これが出来れば細くて折れにくい爆薬の製造も可能となり，破壊を起こさず変形のみを起こさせる爆発加工の分野に応用出来るものと考えられる。これらの観点に立って，ＲＤＸ/ＨＴＰＢ系爆薬の火薬的性質と機械的特性について実験し，検討した結果，これらの特性に優れており，実用に値するものであることが分かった。

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