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EVALUATION OF THE CHARACTERISTICS OF PLASTIC EXPLOSIVE ADHERED BY LIQUID NATURAL RUBBER

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Abstract. Plastic explosive (PBX) is an explosive that a polymer binder is used to reduce the sensitivity of high explosives for various applications. This paper presents the characteristics of the PBXs based on liquid natural rubber (LNR) and hexogen (RDX). The PBXs are prepared according to a modified formulation of the composition C-4. The plasticity of the PBXs is determined according to the MIL-STD-650 method 211.1. The uniaxial compression of the PBXs examined by the STANAG 4443. The test of the sensitivity of PBXs to friction is carried out by STANAG 4487. The thermal stability is tested by the STANAG 4556 at 100 ^{o}C for 40 hours. The results indicated that the plasticity is found to be more than 0.018 in accordance with the MIL-C-45010A. Further, the modulus of elasticity, yield strength, and strain can be adjusted by the composition of the LNR binder. In addition, the frictional sensitivity of the PBXs is significantly reduced to more 360 N of the load. The thermal stability is in the range of 0.156 to 0.225 ml.g^{-1} and completely meets technical requirements. Therefore, the direction of using LNR as a binder for PBXs gives acceptable results for further researches.

Keywords: liquid natural rubber, hexogen, PBX, plastic explosive, binder.

Classification numbers: 2, 2.9, 2.9.4.

1. INTRODUCTION

The plastic explosive (PBX) is a kind of composite explosives which is often produced from a polymer binder and a high explosive (RDX, octogen, pentrite etc.). The polymer binder is used to adhere to the particles of high explosives, to reduce the sensitivities of high explosives because these high explosives have the compressed difficulty and the high sensitivity to mechanic shocks. By using polymer binders, PBX can be shaped safely by compression, manual, and casting. Research and application of PBX are a new trend to replace trinitrotoluene (TNT) because TNT is more toxic to the environment.

In previous researches, several polymers are investigated to apply for PBXs. Charles W. Falterman *et. al*. developed the formulation of PBXs comprising a mixture of octogen, RDX, or diaminotrinitrobenzene and a resin having a silicone backbone [1]. Friedrich-Ulf Deisenroth *et. al*. showed a process for producing PBX based on polyurethane binder and RDX [2].

Composition C-4 (U.S. C-4) is adhered to by polyisobutylene binder and is widely used for U.S. Army. According to MIL-C-45010A, the composition C-4 requires a content of polyisobutylene binder in the range from 8.0 to 10.0% and plasticity more than 0.018 [3]. Brad Zatrow [4] presented the development of an alternate polyisobutylene binder for composition C-4. Hereby the plasticity of the samples with several polyisobutylenes was from 0.052 to 0.167. The chemical compatibility and adhesion of some PBXs adhered by polystyrene binder or nitrocellulose binder were investigated by Nguyen T. T. [5]. Formex P1 produced by France company contains a polymeric matrix of styrene-butadiene rubber bond PETN explosive [6]. Semtex 10 is a Czech plastic explosive that is used for underwater blasting and demolition of rocks. It contains pentaerythritol tetranitrate (PETN) as the filler mixed with plasticized nitrile rubber [7]. Preparation and characterization of a new high-performance PBX in comparison with traditional types were carried out by Ahmed Elbeih *et al*. [8]. Hereby, the styrene-butadiene binder rubber (SBR) used for adhering is an unsaturated polymer.

Liquid natural rubber is a liquid polymer made of natural rubber [9, 10]. This rubber has been applied as a binder for many fields such as paints, glues, and binders for solid rocket fuel [11] etc. Up to now, a PBX bonded by the LNR binder has not been reported. Applying a new polymer as a binder for PBXs, the explosive characteristics are considered such as plasticity, mechanical properties, sensitivity, energy, stability, and decomposition kinetics etc. In this paper, the PBXs are prepared from RDX and LNRs according to the formulation of U.S. C-4. The characteristics of the PBXs are evaluated to suggest the further application of LNR.

2. MATERIALS AND METHODS

2.1. Materials

Three samples of LNR have the average molecular weight of 98,600, 20,100, and 6,420 g/mol, which were prepared from natural rubber in our laboratory [12]. Hydrogen peroxide PA (≥ 30 %), toluene PA (≥ 99.5 %), methanol PA (≥ 99.5 %) and n-Hexan PA (≥ 95 %) were purchased from Xilong Company. Dioctyl sebacate (DOS) was made in Germany. Lubricating oil (LO) was a commercial-grade in accordance with TCCS 203:2015/IDEMITSU. The US C-4 was supplied by Ministry of National Defense. Hexogen was supplied by Chemical Company 95 in Viet Nam and had the properties as follows: more than 200 ^{o}C of melting point, a RDX mixture of three parts nominal Class 1 (75 wt.% of particle diameter from 75 to 850 micrometer) and one part nominal Class 5 (97 wt.% of particle diameter less than 45 micrometer) [13].

2.2. Preparation of sample

Table 1. Compositions of the prepared samples.

Samples	Polymer binder			Content of RDX in PBX, wt%
	Molecular weight, g/mol	Polymer/DOS/LO	Content, wt%	
PBX-1	6,420	95/4/1	9.8	90.2
PBX-2	20,100	72/22/6	9.8	90.2
PBX-3	98,600	25/59/16	9.8	90.2
U.S. C-4	94,200	25/59/16	9.8	90.2

The PBXs were made by mixing the ingredients in n-hexane. Firstly, the LNR binder was prepared from the LNRs by blending ingredients consisted of the LNR, DOS, and lubricating oil in n-hexane. Next, the RDX was added and blended well. Then, n-hexane was vapored from the mixture. The samples were dried at 65 ^{o}C for 4 hours under vacuum. The PBXs with different composition are shown in Table 1.

2.3. Test of plasticity

The plasticity (modulus compressibility) of the samples was tested in accordance with the MIL-STD-650 method 211.1 [14]. 50.05 ± 0.05 grams of sample was compressed in the mold to form a specimen with a diameter of 50.8 mm and a height of 19.05 mm. The specimen was compressed by the gravity of 5000 grams for 20 minutes. The plasticity was calculated as follows:

$$Plascity = \frac{A - B}{1.3}$$

where: A - the logarithm to the base 10 of the thickness of the specimen in millimeters at zero time; B - the logarithm to the base 10 of the thickness of the specimen in millimeters at the end of 20 minutes.

2.4. Determination of mechanical characteristics

The mechanical characteristics of the sample were determined according to the STANAG 4443 [15] on the device ST-1000C. The specimen was in a mold with 24.5 mm of diameter, 49 mm of length, and 1.3 g/cm^3 of density. The tests were carried out at a rate of 10 mm per minute. The initial tangent modulus (E_0), strain at 0.211 MPa of stress and strength at yield was calculated.

2.5. Test of sensitivity to friction

The test was used to evaluate the sensitivity of all types of explosives to friction by “BAM” Friction Tester. The explosive sample is held between a porcelain plate and a porcelain peg under a given load. Frictional forces are applied by a horizontal movement of the porcelain plate. An electric motor drives an eccentric disc and a connecting rod which is fastened to the carriage of the plate. Movement of the plate relative to the peg is a forward and backward motion of 10 mm each, with an average velocity of 5 cm/s. The peg fixture also carries the load arm, which has six equally spaced notches for the attachment of one of nine weights. By various combinations of weight and position on the load arm one can apply loads from 5 to 360 Newton on the test substance. The relative sensitivity to friction is indicated by the lowest load expressed in Newton that leads to ignition, crackling or explosion at least once in a series of six tests. The lowest load and the type of reaction observed are registered on the datasheet [16].

2.6. Thermal stability under vacuum

The thermal stability of samples was tested at a temperature of 100 ^{o}C for 40 hours on Vacuum stability tester in accordance with the STANAG 4556. The curve of the relation between gas pressure and heating time was recorded. The status of the test tubes before and after heating is recorded to calculate the volume of gas released as a result of sample decomposition.

3. RESULTS AND DISCUSSION

3.1. The plasticity of PBX adhered by liquid natural rubber

The plasticity is an important parameter of PBXs and is primarily influenced by polymer binder, explosive morphology, and their interaction. In this work, the LNR-based binders are used with different molecular weights and components for preparing samples. The plasticity of obtained samples is evaluated in comparison with the US-C-4 explosive and MIL-C-45010A standard. The results are given in Table 2.

Table 2. The plasticity of PBXs.

Samples	Plasticity
PBX-1	0.175
PBX-2	0.158
PBX-3	0.153
U.S. C-4	0.151
Requirement of MIL-C-45010A	≥ 0.018

As shown in Table 2, the PBX's samples have a plasticity that conforms to the MIL-C-45010A [3] and is equivalent to U.S. C-4 explosive. The PBX-3 is prepared according to the formulation of U.S. C-4 but replacing polyisobutylene with LNR has the same plasticity as U.S. C-4. This shows that the physical interaction between LNR binder and RDX compared with polyisobutylene binder and RDX is not significantly different. When reducing the molecular weight of LNR, it is necessary to reduce the content of plasticizers and lubricating oil so that their plasticity is equivalent. Thus, by adjusting the composition of the adhesive from LNR, it is possible to create PBXs of similar plasticity.

3.2. The uniaxial compression properties of PBX adhered by liquid natural rubber

In addition to the plasticity of explosives, the uniaxial compressive properties also need to be considered. For this PBX, the uniaxial compressive properties demonstrate the ability to create manual shapes for practical use. In this experiment, the samples were prepared and compressed at a rate of 10 mm/min (Figure 1). The modulus of elasticity, the yield strength, and strain at a chosen stress are given in Table 3.

Table 3. The modulus of elasticity, the yield strength, and strain at a chosen stress.

Mechanic properties	PBX-1	PBX-2	PBX-3	U.S. C-4
Modulus E_0, MPa	1.765	0.872	0.900	0.914
Yield strength, MPa	0.211	0.165	0.118	0.125
Strain at 0.21 MPa, %	45	47	50	47

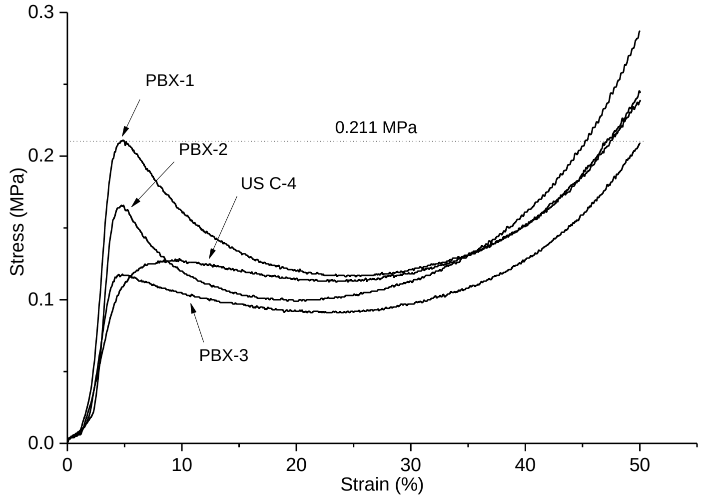

Figure 1. Curve of stress-strain of the explosive samples at a rate of 10 mm/min.

The results show that the stress-strain curve of the samples is the same in shape. The compressive stress increases sharply to a maximum when the distortion is increased by a few percents, then decreases and continues to increase when the distortion is approximately 25%. However, samples with higher rubber content have more elastic modulus and higher yield stress. The strain at selected stress for comparison does not differ too much. The uniaxial compressive properties of the PBX of the LNR binder are similar to those of U.S. C-4 adhered by polyisobutylene binder. The stress values of the samples are small, so these samples can be easily shaped by hand.

3.3. The sensitivity of PBX adhered by liquid natural rubber to friction

One of the important roles of binders is to reduce PBX's sensitivity to friction in comparison to high explosives. The sensitivity of PBXs to friction is a measure of safety in use and transportation. In this work, the sensitivity of explosive samples was tested by the “BAM” friction test. The lowest load for ignition, crackling or explosion of PBXs is used to assess friction sensitivity and is shown in Table 4.

Table 4. The sensitivity of the samples by “BAM” friction test.

Samples	RDX	PBX-1	PBX-2	PBX-3	U.S. C-4
Load, N	216	360	360	360	360
Reaction	Crackling	No	No	No	No

As shown in Table 4, the load that causes PBX's reaction to friction is significantly higher than the original RDX, meaning that the friction sensitivity to the PBXs is reduced when bound by the LNR binder. This is explained by the lubrication of the LNR binder for RDX particles with contact material. The friction sensitivity of PBXs is almost equivalent to that of U.S. C-4 explosives and complies with the requirements of the German Explosives Law and

Transportation Regulations [17]. Thus, it can be affirmed that the safety of the PBXs with friction is accepted for use and transportation requirements.

3.4. Thermal stability of PBX adhered by liquid natural rubber

The thermal stability of composition explosives exhibits chemical compatibility between materials as well as the ability to safely store for long periods. The volume of released gas after heating is the parameter to assess stability. The smaller this parameter is, the greater the thermal stability of PBX is and it is required to be less than 2 $ml.g^{-1}$. The curves of the relation between gas pressure and heating time at 100 ^oC for 40 hours is shown in Figure 2.

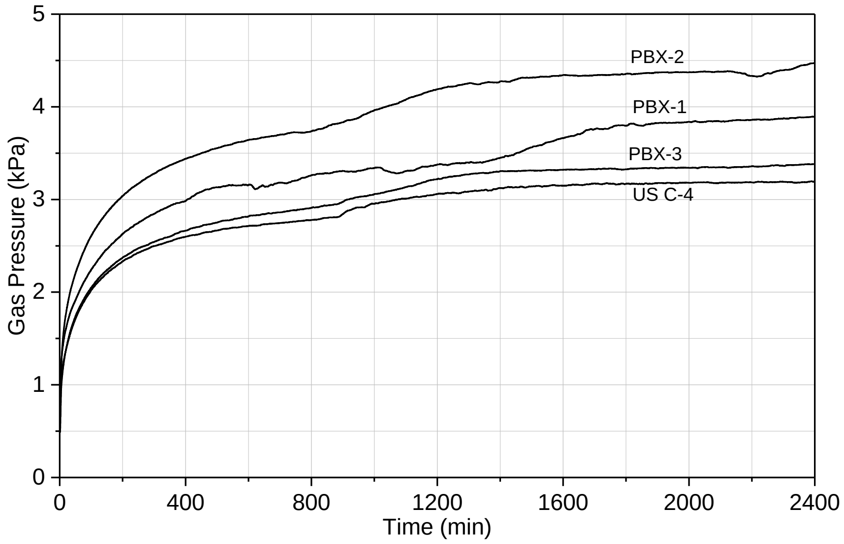

Figure 2. Curves of the relation between gas pressure and heating time by vacuum stability test at 100 ^oC for 40 hours.

Under these experimental conditions, the law of relation between released gas pressure and heating time agrees with logarithm function for all samples. There are differences in the thermal decomposition rate of PBXs adhered by LNR binder is comparable to the U.S. C-4. The released gas volume and rate of pressure increase of samples are calculated as shown in Table 5.

Table 5. The released gas volume and rate of pressure increase of samples by vacuum stability test at 100 ^oC for 40 hours.

Samples	Released gas volume, $ml.g^{-1}$	Rate of pressure increase (500 to 2400 min), $kPa.min^{-1}.g^{-1}$	Correlation coefficient (R)
U.S. C-4	0.134	1.13×10^{-4}	0.98
PBX-1	0.193	1.89×10^{-4}	0.98
PBX-2	0.225	1.81×10^{-4}	0.95
PBX-3	0.156	1.29×10^{-4}	0.97
Requirement of MIL-C-45010A	≤ 2	-	-

The released gas volume of the samples is much smaller than the required value. This means that the PBXs bound by LNR binder have high chemical stability. Unlike U.S. C-4 bound by saturated polymers, the presence of unsaturated bonds in LNR may be the cause of gas volume and decomposition rate of PBXs higher than those of the U.S. C-4. Thus, the thermal stability of these PBXs is relatively good but lower than that of U.S. C-4.

4. CONCLUSION

The PBXs adhered by LNR binder have plasticity and thermal stability in accordance with the MIL-C-45010A standard. Inside, the thermal stability of these PBXs is slightly lower than that of U.S. C-4 explosive. The shape of the stress-strain curves of these PBXs are similar to those of U.S. C-4 explosive. In addition, the modulus of elasticity, and yield strength allows for easily forming these PBXs by hand. The sensitivity of the PBXs to friction is accepted for use and transportation requirements. It can be concluded that the investigated characteristics of the samples are in accordance with the requirements, of which the PBX-3 model is most compatible with the U.S. C-4. These are very important initial information suggesting further research on other characteristics to apply LNR on a larger scale.

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