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Research paper

Mechanical and Sensitivity Properties of Cast PBXs Containing Agglomerated TATB

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Abstract: The aim of this study was to investigate the effects of agglomerated TATB on the mechanical and sensitivity properties of cast polymer-bonded explosives (PBXs). By introducing agglomerated TATB, cast PBXs with a high solids content can be obtained. The mechanical properties of TATB-based cast PBXs were evaluated by tensile and compression tests. The experimental results showed that the addition of the agglomerated TATB clearly enhanced the ductility and fracture toughness, but decreased the strength of the PBXs. However, the strength increased with the decreasing particle size of the agglomerated TATB. When TATB-crystal was replaced by agglomerated TATB in the cast PBXs, a significant drop in the initial modulus and stress were observed. Samples with a higher content of agglomerated TATB were less sensitive to impact stimuli. The desired mechanical and sensitivity characteristics may be achieved for TATB-based cast PBXs by introducing agglomerated TATB.

Keywords: cast PBXs, TATB, mechanical properties, sensitivity properties

1 Introduction

Plastic bonded explosives (PBXs) are widely used for military proposes [1, 2]. The mechanical properties of PBXs are of great interest theoretically and industrially because of their significant influence on safety and reliability [3-5]. The structure of the explosive particles has important effects on the mechanical and sensitivity properties of PBXs [6-8]. Siviour *et al.* [9] reported the effect of particle size on the mechanical properties of hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX) based PBXs. Ramavat *et al.* [10] reported the influence of particle size and shape on the shock sensitivity of RDX. 1,3,5-Triamino-2,4,6-trinitrobenzene (TATB) is an insensitive high explosive with a moderately energetic output and excellent thermally stability. TATB-based PBXs have been reported, such as LX-17 (92.5 wt.% TATB), PBX-9502 (95 wt.% TATB) and PBX-9503 (80 wt.% TATB) [11-13]. Studies have been carried out on the mechanical properties of TATB-based PBXs. Ling *et al.* [5] used styrene copolymer to enhance the creep properties of TATB-based PBXs. Xiao *et al.* [14] reported the mechanical properties of TATB/fluorine-polymer PBXs.

The crystal size of TATB is relatively small, therefore, it is difficult to design cast PBXs containing a high content of TATB [15]. In the present study, agglomerated TATB was used as a component in cast PBXs. By introducing agglomerated TATB, cast PBXs with a high content of TATB can be prepared more easily. This paper presents a study of the effect of agglomerated TATB on the mechanical and sensitivity properties of cast PBXs. The mechanical properties of the TATB-based cast PBXs, such as tensile strength and compressive strength, were investigated. The impact and friction sensitivities were also studied. The main objective of this study was to determine the influence of the agglomerated TATB on the mechanical and sensitivity properties of cast PBXs.

2 Experimental Section

2.1 Materials

TATB (8-12 μm) was synthesized by the Institute of Chemical Materials, CAEP, China, with a mass fraction purity >99%. Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX) was purchased from Beihua Guanlu Chemical Industry Co., Ltd. China; the average particle size of HMX was 80 μm. Fluoropolymer ($[(F_2C\text{-}CH_2)_1(F_2C\text{-}CFCl)_1]_n$, F_{2311}) was purchased from Zhonghao Chenguang Chemical Industry Co., Ltd. China. The average molecular weight (M_W) of the fluoropolymer was about $2.74 \cdot 10^5$ g/mol. Acrolein-pentaerythritol resin was purchased from Liming Research Institute of Chemical Industry Co., Ltd. China, with a mass density of 1.24 g·cm^{-3}. Diethyl sulfate was used as a curing agent for the acrolein-pentaerythritol resin and was supplied by Chengdu Lianhe Chemical Reagents Company, Chengdu, China.

2.2 Sample Preparation

Agglomerated TATB with 3 wt.% polymer binder (F_{2311}) was prepared by a solvent-slurry process [16] and was used as an energetic filler in the cast PBXs. The agglomerated TATB is shown in Figure 1. Four different particle sizes of agglomerated TATB (0.2, 0.3, 0.4 and 0.5 mm) were obtained by the dry sieve method; the aperture sizes of the meshes were 0.15, 0.25, 0.35, 0.45 and 0.55 mm. Cast PBXs containing different energetic fillers were prepared by vacuum casting methods. The casting temperature was 328.15 K and the end of mix viscosity was about 60-75 Pa·s. Acrolein-pentaerythritol resin was selected as a binder for the cast PBXs, which were mixed with the energetic filler using a vertical kneading machine, followed by casting of this mixture into moulds whose sizes were designed for the characteristic measurements. After curing, cast PBXs, whose density was about 98% of the theoretical density, were obtained. All samples were checked carefully by X-ray to ensure that there was no damage due to volumetric contraction.

Figure 1. An image of agglomerated TATB

Seven TATB-based PBXs were prepared and these PBXs consisted of three different solid phase parameters: content of agglomerated TATB (45-60%), content of TATB-crystal (10-25%) and particle size of agglomerated TATB (0.2-0.5 mm). To test the density, five samples with the same formulation were prepared. Density analysis of the samples indicated that variations in the solid phase parameters did not result in density gradients and the densities of the samples were almost a constant. Table 1 lists the average density of the five samples with the same formulation; the relative standard deviations (RSDs) of the five samples were 0.11-0.16%.

Table 1. Formulations of the seven TATB-based PBXs used in this study

Formulation	Content of				Particle size of agglomerated TATB [mm]	Average density [g/cm^3]
	resin [wt.%]	agglomerated TATB [wt.%]	HMX [wt.%]	TATB (8-12 μm) [wt.%]		
PBX-1	20	45	10	25	0.2	1.836
PBX-2		50		20		1.835
PBX-3		55		15		1.834
PBX-4		60		10		1.835
PBX-5		50		20	0.3	1.836
PBX-6					0.4	1.837
PBX-7					0.5	1.836

2.3 Mechanical properties testing

The specimens for quasi-static tensile and compression tests were shaped by molding. Tensile specimens were the standard dumbbell-shape [17] and were 60 mm in length with cylindrically tapered ends and a gauge length of 15 mm diameter, 30 mm long. Compression specimens were of cylindrical shape (diameter 20 mm × length 40 mm), and to minimize frictional confinement graphitic molybdenum-sulfide lubricant was rubbed onto the ends of the specimens. Quasi-static tensile and compression tests were conducted with a universal testing machine (CMT5305, SANS, China) equipped with two knife-edge extensometers. Tests were conducted in strain rate control using the averaged strain output of the two extensometers. All tests for the explosives were conducted at 20 mm/min and 25 °C. To verify repeatability, five samples with the same formulation were prepared and tested for each formulation (PBX-1 to PBX-7) in Table 1. The mechanical property results were analyzed to determine the trends between content and particle size of the agglomerated TATB in the PBXs.

2.4 Glass transition temperature measurement

The glass transition temperatures (T_g) of the explosives were measured by a LINSEIS L75 Vertical Bench Top Platinum Series dilatometer.

The samples (6 mm diameter and 5.69 ±0.07 mm length) were cooled down to –100 °C, then held to stabilize the temperature and heated to 0 °C. The cooling and heating rates were both 2 °C/min.

2.4 Sensitivity tests

Impact sensitivity was tested using a BAM impact sensitivity instrument, and an exchangeable drop weight was used to perform impact tests using standard test conditions [18], the volume of each solid powder sample was 50 mm^3. The probability of initiation was determined by Probit analysis [19, 20], and only 50% probability of initiation was specified. A BAM friction test apparatus was used to determine the sensitivity to friction using standard test conditions [18]. The sample (10 mg) was spread on the rough surface of the porcelain plate, and sample initiation was observed through smoke, sound or smell. Using Probit analysis [19, 20], 50% probability of initiation is specified.

3 Results and Discussion

3.1 Dispersion of the agglomerated TATB in the PBX

Specimens for mechanical properties testing were machined to investigate the dispersion of the agglomerated TATB in the PBX. Figure 2 shows a cross-section of the PBX and the agglomerated TATB is marked by red dots in the right photo. As is shown, the image illustrates the existence of agglomerated TATB being well dispersed in the PBX.

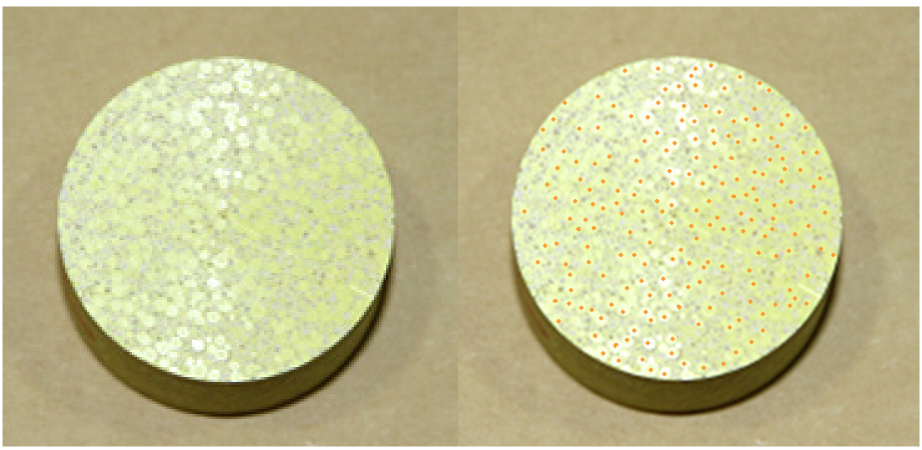

Figure 2. The image of TATB based PBX

3.2 Results from tensile tests

Figure 3 shows the tensile stress-strain curves of the PBXs with different agglomerated TATB contents. Because the curves of the five samples with same formulation were nearly overlapped, Figure 3only shows one curve for each formulation. In Figures 4 and 5 the values were at the maximum load. The uncertainty of the tensile strength testing results was evaluated and the results showed that the expanded uncertainty of tensile strength was 0.042 MPa when the confidence level was 0.95 [21], the relative standard deviations (RSDs) of the five samples were 2.7-3.8%. Figure 4 shows the effect of agglomerated TATB content on the tensile mechanical properties when the average particle size of the agglomerated TATB was 0.2 mm. Figure 5 shows the effect of agglomerated TATB particle size on the tensile mechanical properties when the content of agglomerated TATB was 50 wt.%. It can be inferred from Figures 4 and 5 that the tensile mechanical properties are notably affected by the filler content and filler size of agglomerated TATB. The strain value increases but the stress decreases with an increase in content or particle size of agglomerated TATB in the PBXs. So the ductility and fracture toughness can be enhanced by an increase in agglomerated TATB content or particle size. Moreover, the tensile mechanical properties are more significantly affected by the content of the agglomerated TATB. The particle size of agglomerated TATB is larger than plain TATB (no agglomeration), and the high content or large particle size of agglomerated TATB may result in lower specific surface areas, which is the most prominent reason for a lower tensile modulus and mechanical strength of PBXs. Meanwhile the fluoropolymer in the agglomerated TATB may lower the bonding between the polymer matrix and TATB crystals, leading to a lower mechanical strength of the PBXs.

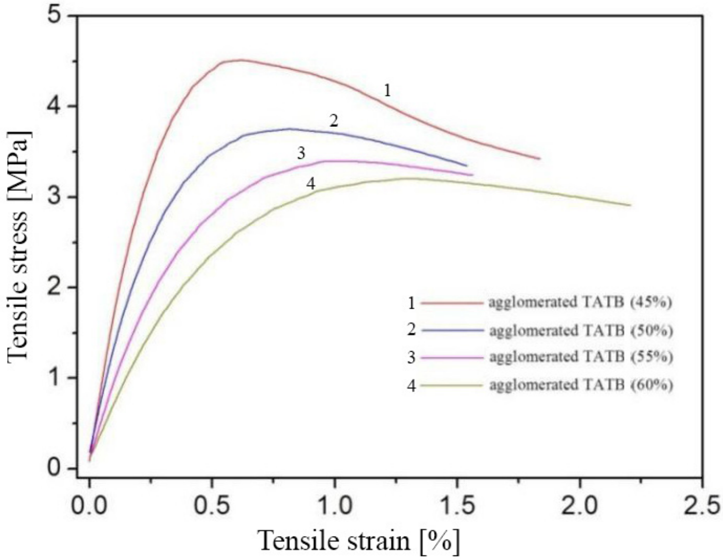

Figure 3. Tensile stress-strain curves of PBX 1 to PBX-4 with different agglomerated TATB content

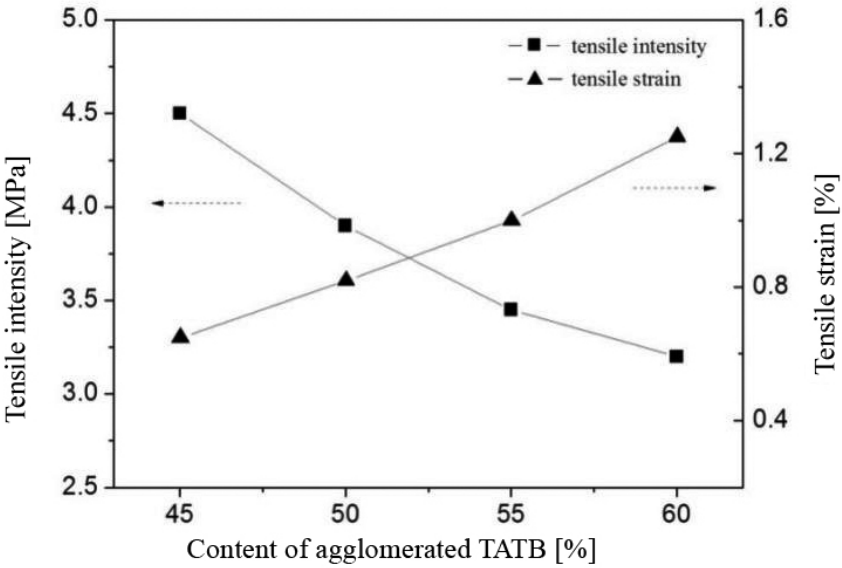

Figure 4. Tensile properties of PBX 1 to PBX-4 with different agglomerated TATB content

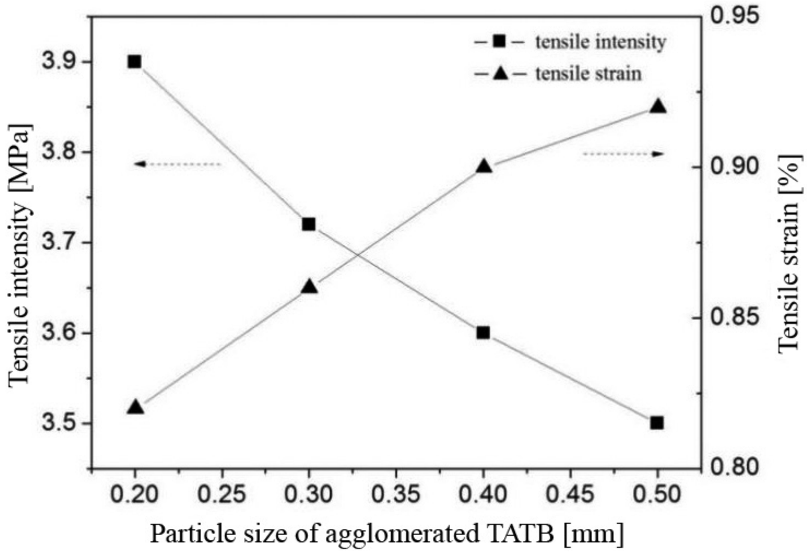

Figure 5. Tensile properties of PBX 2, PBX-5, PBX-6 and PBX-7 with different agglomerated TATB particle sizes

3.3 Results from compression tests

Figure 6 shows the compression stress-strain curves of the PBXs with different agglomerated TATB contents. Figures 7 and 8 show the compressive properties for formulations PBX-1 to PBX-4 with different content of agglomerated TATB, and PBX-2, PBX-5, PBX-6 and PBX-7 with different particle sizes of agglomerated TATB, respectively. In Figures 7 and 8 the values were at the maximum load. The uncertainty of the compression strength testing results was evaluated and the results showed that the expanded uncertainty of compression strength was 0.21 MPa when the confidence levels was 0.95 [21], the RSDs of the five samples were 2.4-3.2%. As can be seen from Figures 7 and 8, the modulus of elastic deformation gradually decreases with increasing content or particle size of agglomerated TATB in TATB-based PBXs. The compression stress and strain values of the PBX with plain TATB (no agglomeration) at the maximum load were 26.6 MPa and 1.6%, respectively. It can be seen that the compressive mechanical strength displays a decreasing trend with the addition of agglomerated TATB, which indicates, as expected, that the compressive mechanical strength depends to a greater extent on the filler strength in the PBXs since the mechanical strengths of the agglomerated TATB are weaker than those of TATB-crystals. The addition of agglomerated TATB also results in increases in strain at maximum stress, indicating that the PBXs are more ductile.

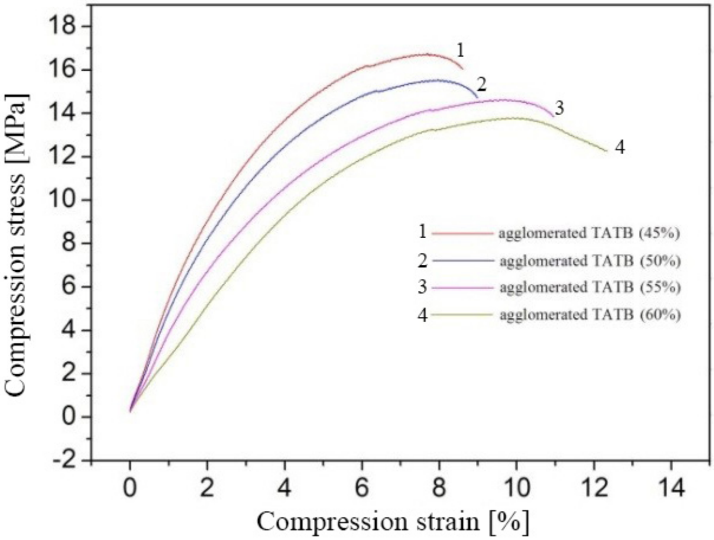

Figure 6. Compression stress-strain curves of PBX-1 to PBX-4 with different agglomerated TATB content

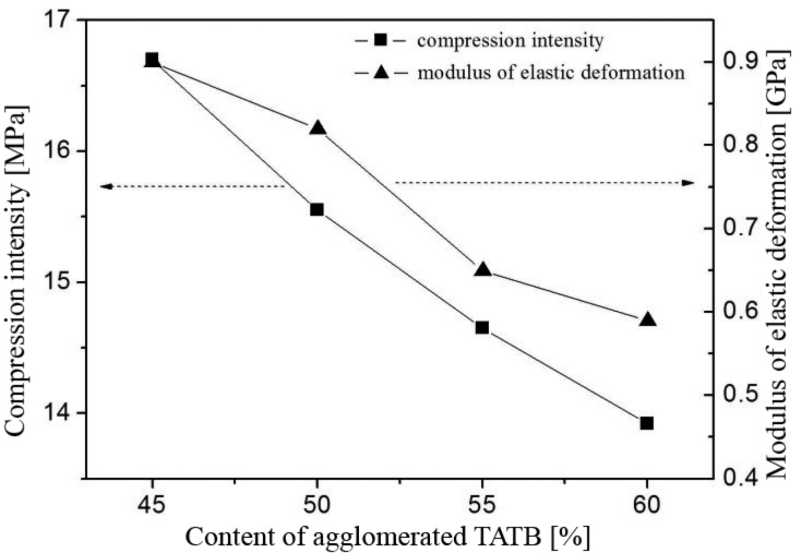

Figure 7. Compression properties of PBX-1 to PBX-4 with different agglomerated TATB content

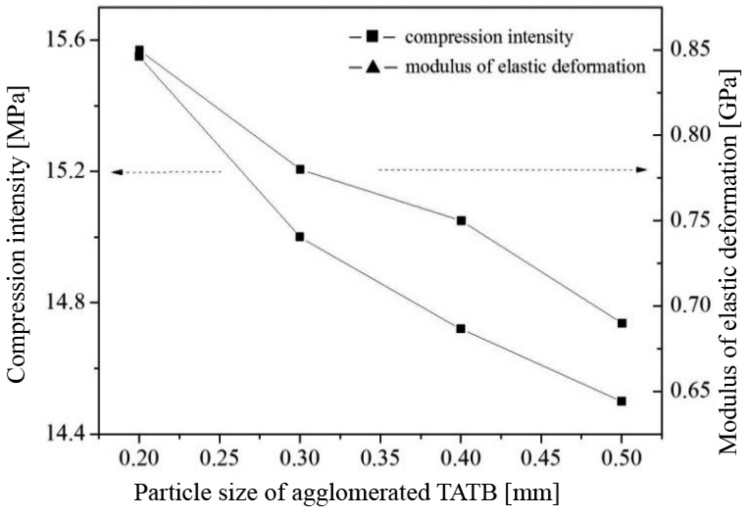

Figure 8. Compression properties of PBX-2, PBX-5, PBX-6 and PBX-7 with different agglomerated TATB particle size

The elongation and ductile values are critical for explosives in munitions. During transportation or use, the explosives are exposed to mechanical stresses or shocks, and cracks may occur in the explosives if the strength and toughness of the explosives are low [22]. The binder used for the PBXs we investigated was acrolein-pentaerythritol resin, which is a low ductility polymer [23]. Furthermore, it is necessary to increase the elongation and ductile values of the PBXs using acrolein-pentaerythritol resin as the binder. In view of the quasi-static tensile and compression results, the mechanical properties of TATB-based PBXs can be adjusted by introducing agglomerated TATB.

The T_g values of the explosives were calculated from the first derivative of elongation versus temperature graph in dilatometry. The $_g$ values for PBX-1 to PBX-7 were all –56.5 ±0.5 °C and the influence of the agglomerated TATB on T_g was negligible. Moreover, the T_g values indicated that –57 °C is the minimum temperature at which these explosives could be used or stored.

3.4 Results from sensitivity tests

The mechanical sensitivities for TATB-based PBXs were tested and the results are listed in Table 2. It was found that no chemical reaction (including explosion, sound, smell or colour *etc.*) was observed from all of the samples subjected to friction sensitivity testing even when the largest force (360 N) was loaded. The impact sensitivity results in Table 2 show that the samples were also insensitive to impact stimuli, and that samples with a higher content of agglomerated TATB are less sensitive to impact stimuli. One explanation for this observation might be that the agglomerated TATB provides a shock absorber or diverter under the mechanical impact stimuli, contributing to a reduction in the probability to form "hot-spots". Therefore the impact insensitivity can be improved by introducing agglomerated TATB for TATB-based PBXs.

Table 2. The impact sensitivity for TATB-based PBXs

Formulation	Impact sensitivity [J]	Confidence interval [J]	Confidence level
PBX-1	24.2	23.3-25.1	0.95
PBX-2	27.8	26.8-28.7	0.95
PBX-3	32.5	31.5-33.5	0.95
PBX-4	36.7	35.7-37.7	0.95

4 Conclusions

In this work, cast PBXs containing agglomerated TATB were tested. The effects of agglomerated TATB on the mechanical and impact sensitivity properties of TATB-based cast PBXs were investigated. The major findings can be summarized as follows:

- ♦ The tensile and compressive mechanical strength both display a decreasing trend with increasing agglomerated TATB content in the PBXs.
- ♦ The tensile strain at the max stress displays an increasing trend with increasing agglomerated TATB content in the PBXs.
- ♦ The modulus of elastic deformation decreases with increasing content or particle size of agglomerated TATB in TATB-based-PBXs.
- ♦ The impact sensitivity can be improved by introducing agglomerated TATB for TATB-based PBXs.
- ♦ According to these results, the mechanical properties of TATB-based cast PBXs can be adjusted by using agglomerated TATB.

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