Development of Cure Cast IHE's with High Loading of HMX

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Abstract

An improved family of cure cast explosives with high loading of HMX was developed. 88-91.5 wt.% loading of HMX were introduced to a HTPB based explosive. This high solids content was achieved by introducing of new self-developed wetting agents to the explosive, and improving the mixing procedure.

The developed explosives have a low end-of-mix viscosity (0.7 to 6.5 kPs) and no residual shear stress. The mechanical properties are excellent: (σ_m=5-7 kg/cm^2, ε_m=10-45%, E_0=40-90 kg/cm^2).

The small-scale safety properties of the explosives are also very good: impact sensitivity of more than 31 N*m, friction sensitivity of 165-250 N, decomposition temperature of around 250^{o}C.

The detonation velocities range from 8380 m/s for the 88% HMX composition to 8510 m/s for the 91% HMX composition.

The densities of the explosives are almost equal to TMD: 1.68 g/cm3 for the 88% HMX composition to 1.73 g/cm3 for the 91% HMX composition.

1. Introduction

Development of Insensitive Munitions (IM) technology was a significant step in energetic materials area in the last decades. PBX's (polymer bonded explosives) can serve as a good example of energetic materials which combine relatively high performance with good safety characteristics. Typical cast-cure PBX formulation consists of explosive powder (e.g., nitramines RDX, HMX) incorporated in rubbery polymer matrix. As a rule, filler particles of different sizes used in these formulations to enable maximal solids content (bi- or trimodal packing).

PX-80 is an improved Israeli equivalent explosive to PBXN-110. It consists of 88% HMX in two fractions and 12% HTPB based binder.

The typical end-of-mix viscosity of PX-80 is 0.7 kP and the explosion and mechanical properties are very good.

The improvement in the rheological and mechanical properties was achieved by adding a new self-developed wetting and bonding agent to the explosive.

The low end-of-mix viscosity enables an increase of HMX loading in the explosive.

The main objective of this study were:

One. Increasing the HMX loading in the explosive to the maximum that allows good and void free casting, and getting explosives that are insensitive with good mechanical properties and improved explosion properties.

Two. Improving the safety properties by using smaller HMX particles.

2. Experimental

2.1. Formulations

All PBX formulations prepared in this study were compared with the reference PX-80 explosive. The composition of studied PBX formulations is shown in Table 1.

Table 1. Composition of Studied Formulations (weight %)

Ingredient	PX-80 (88% HMX)	PX-19 (89% HMX)	PX-90 (90% HMX)	PX-91 (91% HMX)	PX-733	PX-755	PX-738
coarse HMX (300µ)	61.6	62.3	63.0	63.7	-	-	29.9
HMX (15µ, wide span)	-	-	-	-	-	88.0	-
ground HMX (5µ)	26.4	26.7	27.0	23.7	86.0	-	58.1
HTPB based binder	12.0	11.0	10.0	9.0	14.0	12.0	12.0

2.2 Preparation of PBX formulations

In general, preparation procedures of cast-cure explosives are well known and proven in the industry of explosives. Mixing of the ingredients was performed by 1 gallon Baker-Perkins planetary mixer. Uncured explosives were cast under vacuum into moulds to produce explosive blocks of any desired shape. Curing of the explosive was at 65 ^{o}C in a designated explosive oven.

2.3. Characterization of Compositions

Rheological characteristics. The viscosity and residual shear stress of the uncured explosive were measured by a Brookfield viscometer, HAT model, with T-C spindle, at rotation speed of 2.5 RPM. The measurement took place at constant temperature bath at 65 ^{o}C. The measured viscosity values are end-of-mix viscosity (η_0) and initial viscosity one hour after introduction of curing agent (η_1). Pot life was determined according the time in which the viscosity reaches 15 kPs.

Mechanical properties were measured by Instron testing machine at uniaxial tensile mode according to JANNAF standard. The PBX specimens tested at ambient temperature, at the tensile rate of 5 cm/min. The measured parameters are initial elasticity modulus, maximal engineering and real stresses and strain at maximal stress.

Impact Sensitivity Tests were performed according to the BAM (*Bundsanstalt fur Material Prefung*) procedure by “Julius Peters” falling hammer device. The tests were performed according to Bruceton method. 25 tests were conducted to evaluate the height of 50% probability for explosive reaction.

Friction Sensitivity Tests were performed according to the BAM procedure by “Julius Peters” friction apparatus. The reported value of load refers to the largest load on the pistil in which the material does not react for 10 successive tests (10 N.F.).

Decomposition (Ignition) Temperature Tests were performed by a TGA (Thermogravimetric Analyzer). The used TGA machine is Mettler, model TA3000. The tests were performed under air flowing at a rate of 200 ml/min and a heating rate was 10 ^{o}C/min.

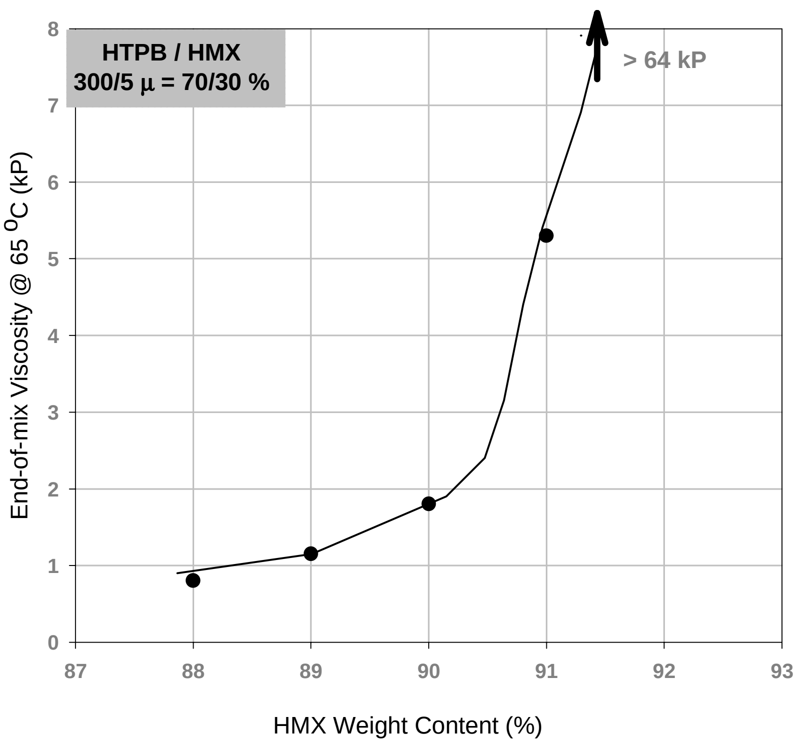
3. Results and Discussion

3.1. Formulations with increased HMX loading

At this stage of the study the formulations with higher HMX loading (up to 91 wt.%) were developed and characterized. All formulations make use of bimodal HMX packing (300μ/5μ=70/30).

Figure 1 represents the end-of-mix viscosities at 65 ^oC of the aforementioned formulations as a function of solids loading.

Figure 1. The values of end-of-mix viscosity at 65 ^oC as a function of HMX loading



All formulations up to 90% of HMX are characterized by very good rheological properties (low end-of-mix viscosity values and no residual shear stress) due to the use of self-developed wetting agent. It seems that a weight loading of 91% HMX is a practical upper limit for these systems, taking into account processability considerations. The end-of-mix viscosity of the formulation with 91.5% solid loading is out of the measuring scale (i.e., more than 64 kP).

The results of rheology investigation were compared with Farris model[1] of viscosity – concentration behavior of the multimodal suspensions. According to this model, the relative viscosity (η_r) of multimodal suspension can be described in terms of the volume filler content as follows:

$$\eta_r \geq (1 - \phi_T)^{-K} \qquad (1)$$

When ϕ_T is a total filler volume concentration.

For the bimodal system the filler concentration can be expressed as

$$\phi_T(\mathrm{bimodal}) = \phi_1 + \phi_2 - \phi_1\phi_2 \qquad (2)$$

When ϕ_1 and ϕ_2 are the volume concentrations of each fraction in apparent binder.

Figure 2 represents the viscosity – concentration behavior of HMX/HTPB systems based on experimental data. It is seen that the correlation between relative viscosity value and $1/(1-\phi_t)$ is linear.

According to the Farris model, the best fit between theoretical behavior and experimental data is obtained when K = 3. For studied systems, the calculated exponent K value is 6.7 in the weight content range of 88 – 91 wt.%. Farris[1] claims that K must be a function of mainly particle shape, so the distinction between calculated and theoretical values of K may be explained by deviation of HMX particles (both coarse and grounded) from spherical shape. Moreover, the initial assumptions of the Farris model (e.g., Newtonian fluid) may not be fully appropriate for the studied suspensions.

It is evident from this study that the rheological behavior of the HTPB/HMX suspensions is very sensitive to filler concentration (even more than it can be expected from the theoretical models).

Figure 2. Viscosity – Concentration Behavior of HTPB/HMX suspensions at 65 ^{o}C

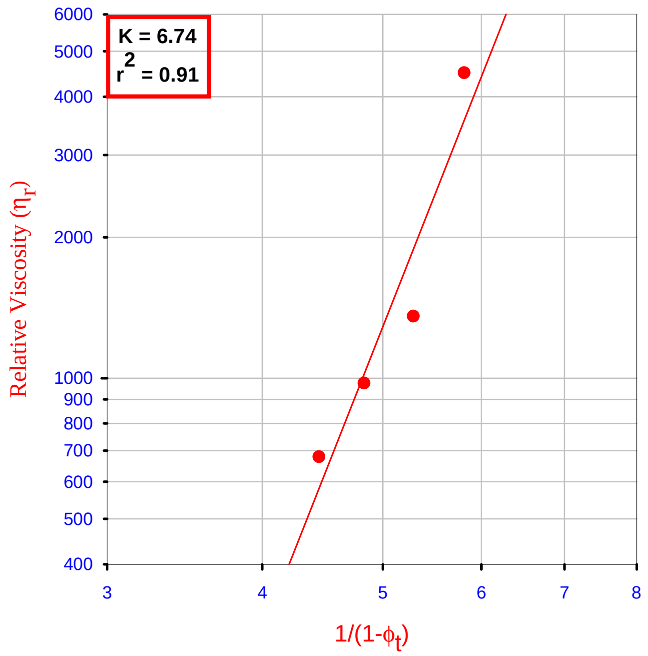
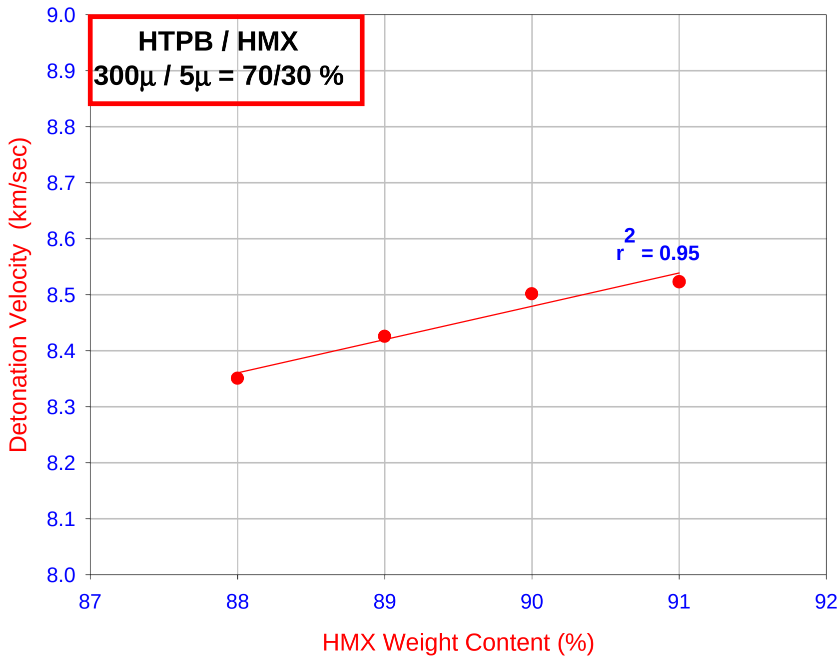


Figure 3 represents the detonation velocity of the developed explosives as a function of HMX loading.

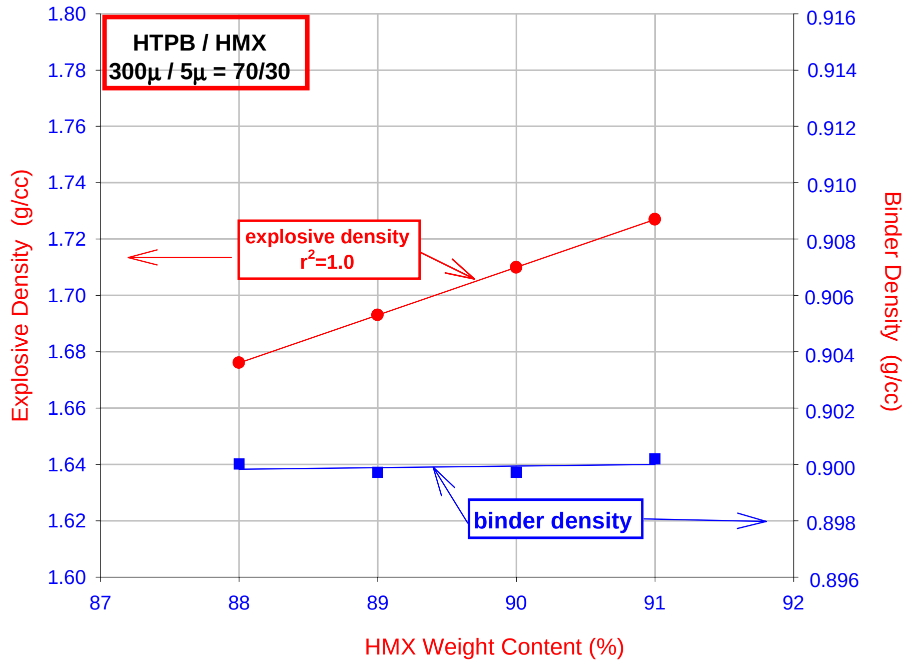
Figure 3. Detonation Velocity of HTPB/HMX based PBX's as a Function of HMX Loading



As it was expected, the detonation velocity increases with higher HMX loading. In the HMX content range studied this increase is quite close to linear. The value of detonation velocity approaches 8520 m/s at 91% HMX loading.

Obviously, the explosive density increases linearly with filler content loading, as can be seen at Figure 4.

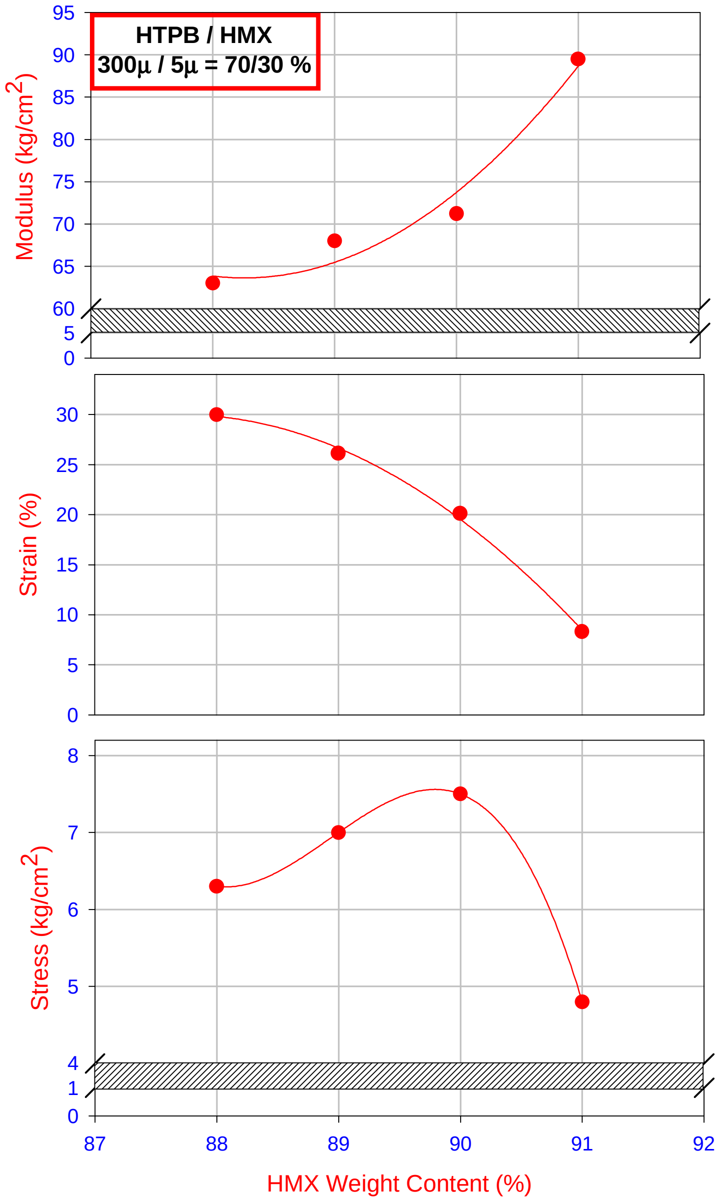
Figure 4. Density of HTPB/HMX based Explosives as a Function of HMX Loading



Actually, the measured explosive density values are equal to the TMD (Theoretic Maximal Density) values. It proves that even at the very high HMX content (relatively to conventional cure-cast PBX) the explosive is void free.

Figure 5 shows the main mechanical characteristics (elasticity modulus, engineering stress, real strain) of the examined explosives as a function of the HMX content.

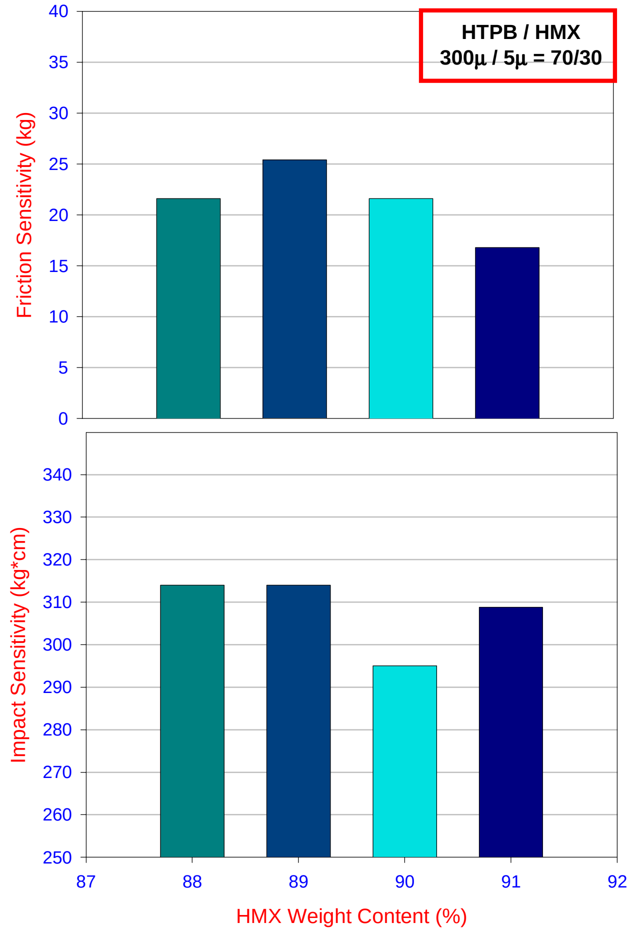
Figure 5. Mechanical Characteristics of HTPB/HMX PBX's as a Function of HMX Loading



There is clear tendency of explosive's hardening with increase of solids loading. The increase of elasticity modulus and the decrease of real strain express this tendency. The mechanical properties are quite good up to 90% solids loading (engineering stress of 7.5 kg/cm^2, real strain of 20%, origin modulus of 72 kg/cm^2). Additional increase of HMX content up to 91% causes to deterioration of explosive's mechanical properties.

The small-scale safety characteristics (impact and friction sensitivities) are represented on Figure 6.

Figure 6. Impact and Friction Sensitivities of HTPB/HMX PBX's as a Function of HMX Loading



Generally speaking, the impact and friction sensitivity values of the developed formulations are quite good. It can be concluded that the influence of the solid loading (in the examined range of the HMX concentrations) on the small-scale safety characteristics is negligible.

3.2. Formulations with monomodal filler packing

At this stage of the study formulations with only ground fine filler particles were developed. One formulation includes 86% HMX filled PBX (PX-G-733). The mean particle's size of nitramine fraction was 5 µ. Likewise, formulations with 88% HMX (15µ) (PX-G-755, 757) in wide monomodal particle size distribution were prepared and characterized. All formulations make use of fine HMX ground by fluid energy mill.

The values of end-of-mix viscosity of the above formulations are compared in Figure 7.

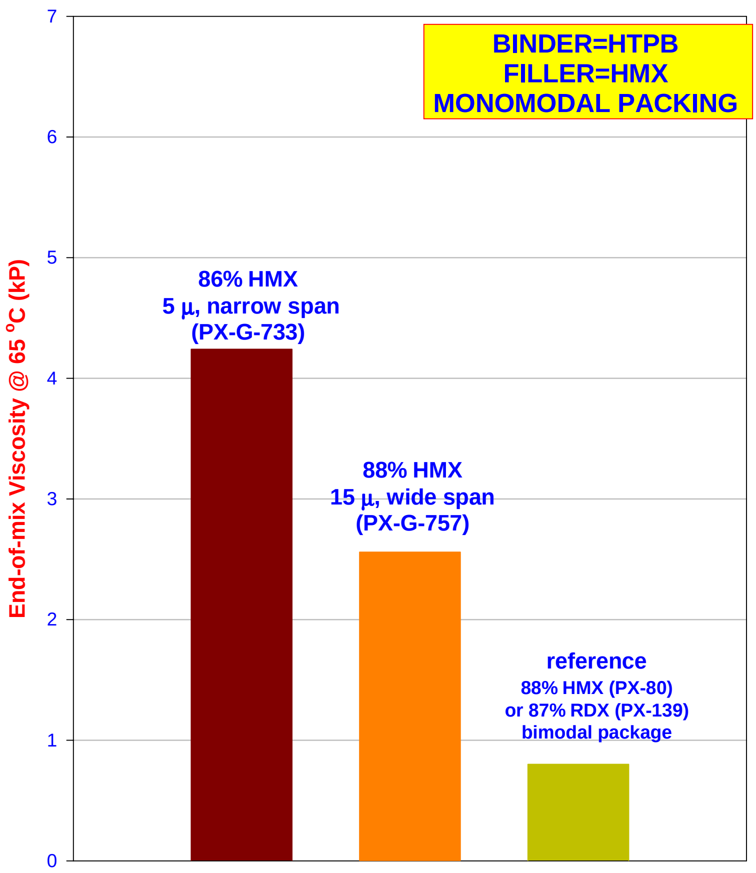


Figure 7. Comparison of End-of-Mix Formulations

Generally speaking, all formulations showed good or acceptable end-of-mix viscosity values, and were easily mixed and readily cast into molds. As it was expected, widening of particle size distribution enabled to increase total solids loading and to decrease end-of-mix viscosity.

Table 2 represents main safety characteristics of the monomodal explosives.

Table 2. Safety Characteristics of Monomodal and Bi-modal Formulations

88% HMX		Characteristic
PX-80 (bimodal)	PX-755 (monomodal)	
300	421	**Impact Sensitivity (kg*cm)**
21.6	28.8	**Friction Sensitivity (kg)**
244.3	247	**Decomposition Temperature (^{o}C)**

There is a significant improvement in impact sensitivity of PBX when all coarse particles replaced by fine ones. The improvement in friction sensitivity is more moderate. The obtained correlation is expected because it has been shown that the smaller the particle's size, the higher the crystal quality and the lower sensitivity of the explosive. There is no evidence that the decomposition temperature is affected by the nitramine particle's size.

The mechanical properties of the studied formulations in comparison with the references are shown in Table 3.

Table 3. Mechanical Properties of Monomodal and Bi-modal Formulations

88% HMX		Characteristic
PX-80 (bimodal)	PX-G-757 (monomodal)	
8.6	**15.0**	**Maximal Real Stress, σ^R (kg/cm^2)**
25.0	**31.7**	**Maximal Real Strain, ε^R (%)**
55	**63**	**Initial Elasticity Modulus, E_0 (kg/cm^2)**

The mechanical properties of developed "monomodal" formulation are much better than of the reference bi-modal composition due to improved wetting of the filler particles by polymeric matrix.

3.3 Formulations with "inverse" filler packing

At this part of the research the formulation with 34/66 coarse-to-fine fraction ratio was developed and characterized. Rheological, mechanical and safety properties were tested and compared to reference explosives with 70/30 ratio, as represented on Figure 8 and Tables 4-5.

Figure 8. Viscosity Test Results of "Inverse" Formulation in Comparison with PX-80

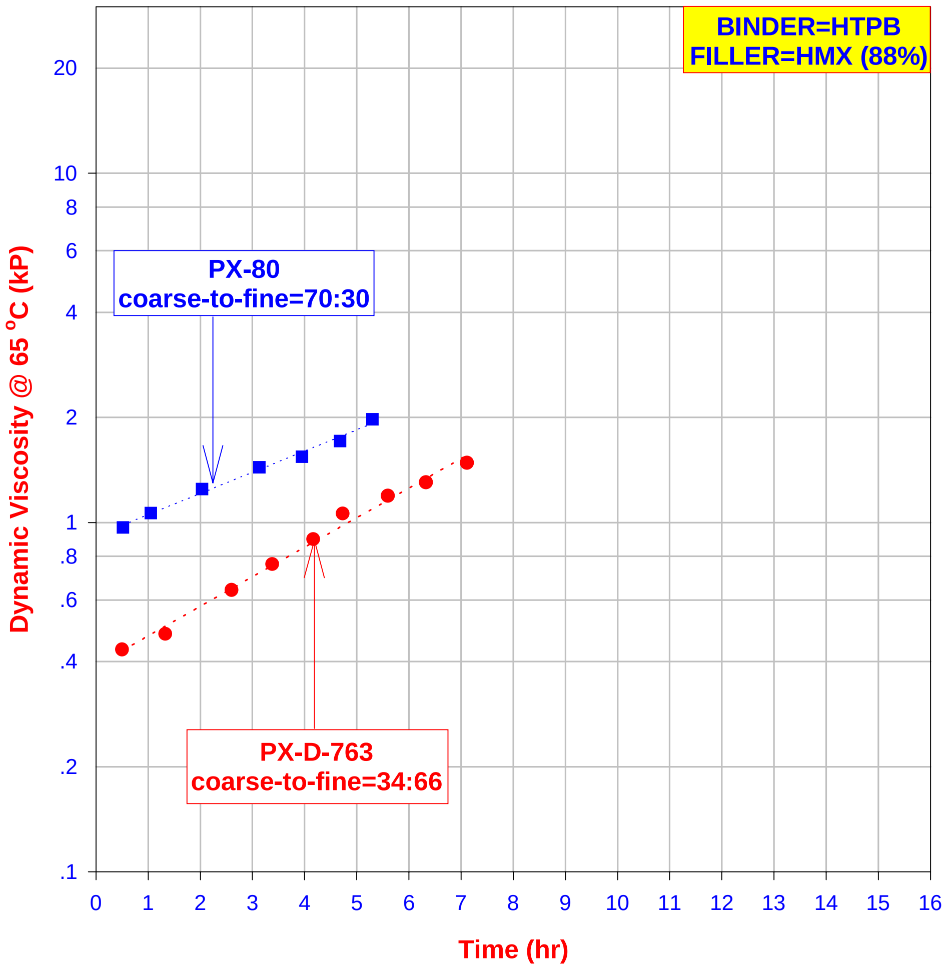


Table 4. Safety Characteristics of PBX with "Inverse" Particle Packing

PX-80 (300µ:5µ=70:30)	PX-G-738 (300µ:5µ=34:66)	Characteristic
300	374.9	Impact Sensitivity (kg*cm)
21.6	28.8	Friction Sensitivity (kg)
247	243.7	Decomposition Temperature (^oC)

Table 5. Mechanical Properties of PBX with Inverse Particle Packing

PX-80 (300µ:5µ=70:30)	PX-D-763 (300µ:5µ=34:66)	Characteristic
8.6	9.3	Maximal Real Stress, σ^R (kg/cm^2)
25.0	26.3	Maximal Real Strain, ε^R (%)
55.0	45.2	Elasticity Modulus, E_0 (kg/cm^2) Initial

The formulations with inverse coarse-to-fine particle ratio are characterized by improved rheological characteristics, namely very low end-of-mix viscosity making possible increase of total solids loading.

The expected improvements in safety and mechanical characteristics are more moderate than in monomodal compositions with only fine nitramine particles.

5. Conclusions

HTPB based processable formulations with 88-91% HMX loading were developed and characterized. These explosives have improved performance characteristics (detonation Velocity, and density) and very good mechanical and rheological properties. There is no significant reduction in friction / impact sensitivities as a result of the increase of HMX loading.

The HTPB/HMX based formulations with only fine particles (monomodal packing) or "inverse" loading show improved small-scale safety properties and better mechanical characteristics (in comparison with "classical" bimodal formulations).

5. References

1. R.J. Farris, *Transactions of the Society of Rheology*, 12:2, 281-301 (1968).