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Informal Report

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X-0298

A Rubber-Bonded PBX

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A RUBBER-BONDED PBX

by

T. M. Benziger, E. D. Loughran, and R. K. Davey

ABSTRACT

The properties of X-0298, a rubber-bonded HMX composition, are described. It is a high explosive of exceptional stability, an effect of its novel binder system (a styrene-ethylenebutylene-styrene block copolymer extended with a paraffinic oil). It appears particularly suited for applications that require extended service at elevated temperatures.

I. INTRODUCTION

This study is part of a continuous effort within the US Department of Energy (DOE) laboratories to improve plastic-bonded, high-energy explosives to meet the needs of modern ordnance. In such applications, the desired properties include maximum explosive performance, chemical stability to endure extended service at high temperatures, handling safety in production and use, and physical properties to withstand creep and thermal strain in structural applications.

In designing these explosive systems, the requirement for the maximum explosive performance necessarily restricts the binder level to a low value (4-8 vol%). Even with this limitation, the nature of the binder can have a significant effect on the properties of the composite. Accordingly, the X-0298[1] formulation was developed with particular regard to the physical and chemical features of its binder phase.

The thermoplastic rubber/oil binder that was chosen produced the desired effect, with the composition demonstrating, in a variety of tests, an overall balance of properties superior to standard high-energy PBX compositions.

II. BINDER STUDIES

Several desirable characteristics of polymeric binders for plastic-bonded, press-formed explosives can be identified. They include the following properties.

Chemical stability for compatibility with the explosive filler.

Resistance to oxidative, thermal and hydrolytic attack that promote chain scission of the polymer.

Solubility in the common organic solvents used in the slurry process for molding powder manufacture.

A critical surface tension lower than that of the filler to ensure wetting.

A softening range (90-120°C) that is suitable for press fabrication.

A reasonable strength at the maximum service temperature.

No exudation if a plasticizer is employed.

A low glass point, low modulus, and a high elasticity; properties reducing sensitivity to impact in manufacture, handling, and operational use.

A high elastic limit to accomodate thermal strain and creep in structural applications.

A thermoplastic rubber possessing these properties is used in the X-0298 formulation. It is Kraton G-1650, a styrene-ethylene-butylene-styrene block copolymer noted for its thermal and chemical stability. Kraton is an unusual polymer in that it acts as a cross-linked (vulcanized) rubber at temperatures below the glass point of styrene (100°C), through an association of the styrene blocks (domains). At higher temperatures these bonds are broken and the polymer may be treated as a thermoplastic in forming operations such as compression molding. It reverts, however, to its original, cross-linked structure upon cooling. Certain solvents also weaken these bonds and dissolve the polymer, thus allowing the use of the slurry process in PBX manufacture.

The properties of Kraton G-1650 may readily be varied by extending it with a paraffinic oil, which advantageously increases elasticity and reduces the tensile modulus. Such extension does not destroy the attractive cross-linking feature of the polymer that allows retention of the desired physical properties at normal service temperatures.

Studies were made on Kraton-oil blends using a pure paraffinic oil[a] having the following properties.

Specific gravity	0.873 (25°C)
Viscosity (cP)	138 (25°C)
Pour point (°C)	-16
Vapor pressure (μm)	7 (190°C)

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[a]Cenco Hyvac #93050-3, Central Scientific Co.

Data on the effect of oil addition on durometer values are illustrated in Fig. 1. The relaxation of cross-linking bonds in the region of the polystyrene glass point (100°C) is demonstrated in extrusion plastometer data in Fig. 2.

The properties of the binder system chosen for X-0298 are relatively constant over a wide temperature range with the material showing a remarkable elasticity.

Composition (wt%)	45/55 - Kraton/oil
Exudation (paper absorption - 75°C/64 h)	none
Elongation, elastic (%)	900
Elongation, break (%)	> 900
Shore durometer (A-2)	
+ 74°C	15
+ 24°C	21
- 23°C	30
Glass point, T_G (°C))	- 63

III. EXPLOSIVE PROPERTIES

The composition of X-0298 was established to equal the explosive performance of PBX 9404, using the computational method of Urizar.[2] As shown in Table I, this objective was met in detonation velocity, plate dent P_{CJ}, and cylinder test comparison.

It is significantly less sensitive than PBX 9404 in the standard sensitivity tests. This is particularly true in the skid test (handling safety) with a 50% drop height of 4.2 m (13.8 ft); PBX 9404 in this test has a value of about 1.0 m. The low response of X-0298 in this test is attributed to its compliant binder, an effect noted in other systems containing binders of a similar nature.

The sensitivity of X-0298 in the Susan test (a measure of susceptibility to crushing impact) is shown in Fig. 3. It has a quite low reactivity in terms of threshold velocity and energy release when compared with other high-energy PBX compositions, such as PBX 9404 or PBX 9501. Its threshold velocity appears to be in excess of 65 m/s (212 ft/s).

IV. STRENGTH PROPERTIES

The strength properties of X-0298 given in Table II are generally similar to those of other high-energy explosives such as PBX 9404 and PBX 9501. In tension, however, it differs in having an unusually large strain-to-failure and a low modulus. These features (illustrated in Figs. 4 and 5) reflect the soft, elastic nature of the binder. Such properties, particularly at low temperatures, are desirable in structural applications of explosives that involve a large thermal strain.

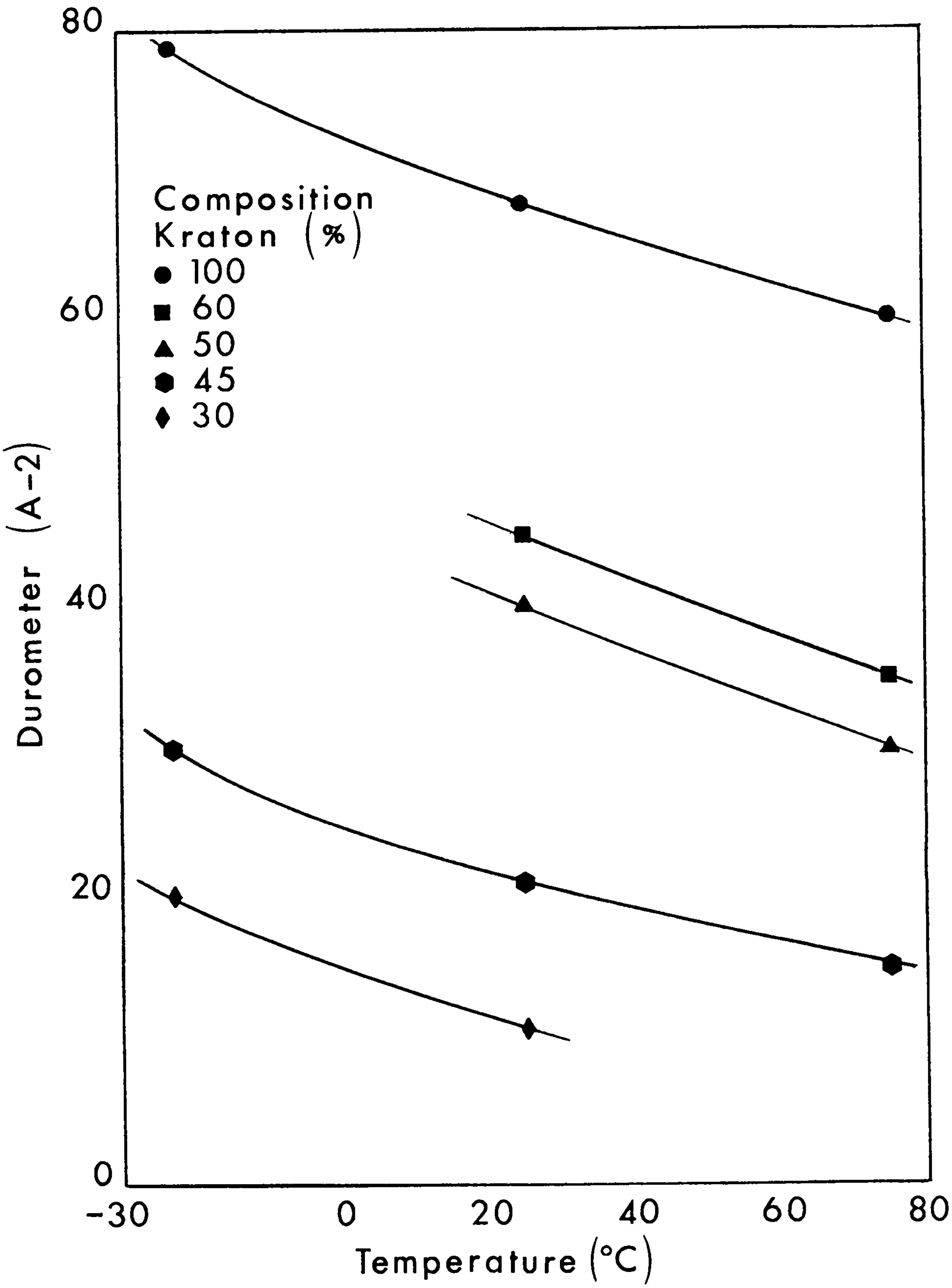

Fig. 1. Kraton/oil properties.

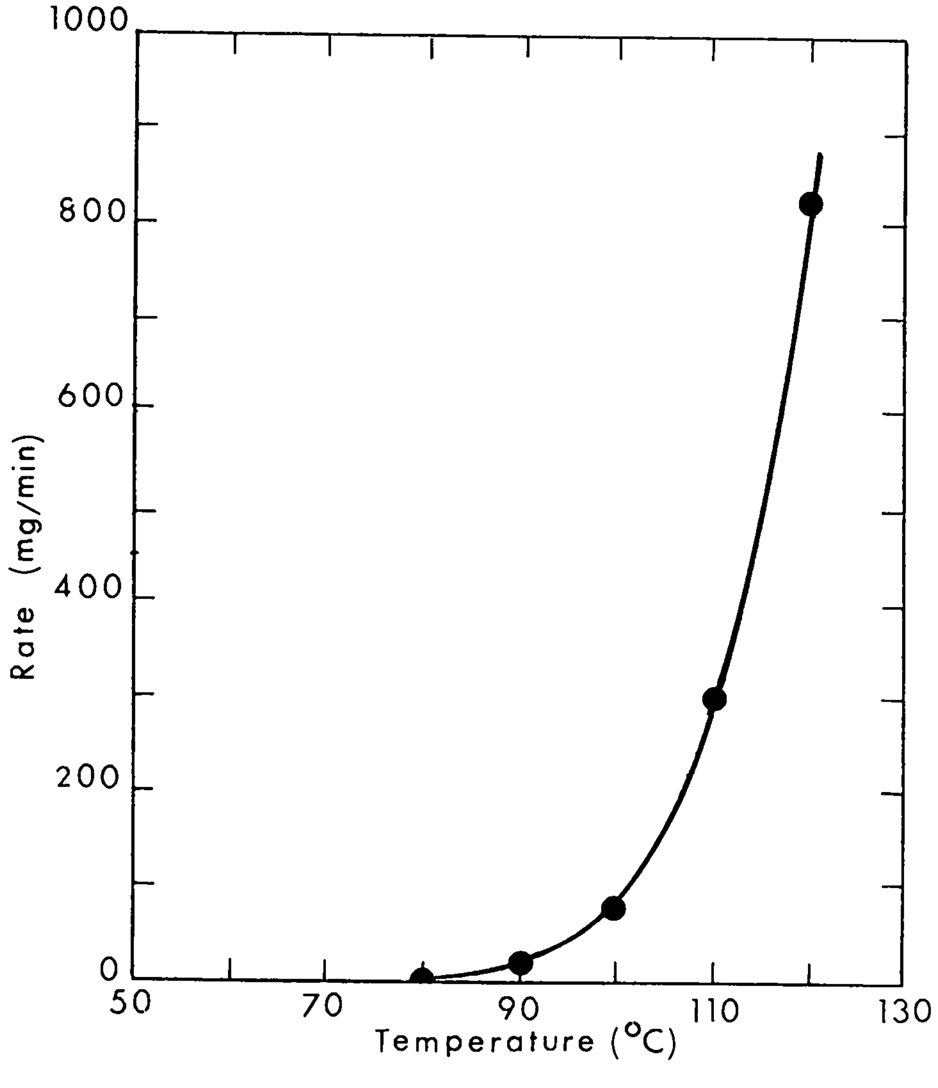

Fig. 2. Extrusion plastometer data on 45/55 - Kraton/oil.

TABLE I

X-0298 EXPLOSIVE PROPERTIES

Composition (wt%)	97.5/1.12/1.38 - HMX/Kraton/oil
(vol%)	94.8/2.27/2.92 - HMX/Kraton/oil
Theoretical density (g/cm^3)	1.847
Pressed density (g/cm^3)	1.813-1.825 (98.2-98.8% TMD)
Powder bulk density (g/cm^3)	0.98
<u>Performance</u>	
Detonation velocity (m/s)	8833 (1.817 g/cm^3)
Calculated P_{CJ} (kb)	366 (1.817 g/cm^3)
Plate dent P_{CJ} (kb)	363 (1.817 g/cm^3)
Cylinder test (PBX 9404 = 100)	100.4 (19 mm) (1.820 g/cm^3) 99.6 (6 mm)
<u>Sensitivity</u>	
Drop-weight impact, 12/12B (cm)	47/54
Skid test, 45° (m)	4.2 (13.8 ft) low partials
Gap test, small scale (mm)	1.65, brass (1.818 g/cm^3)
Gap test, standard (mm)	52.76, aluminum (1.815 g/cm^3)
Minimum priming (g Extex)	0.026
Spark (J)	0.5 (0.08 mm foil), 3.9 (0.25 mm foil)
Friction	no reaction, 45° at 100 cm drop
Machining	satisfactory
Wedge failure (mm)	0.47
Explosive ballistic limit (m/s)	916 (9404-820)

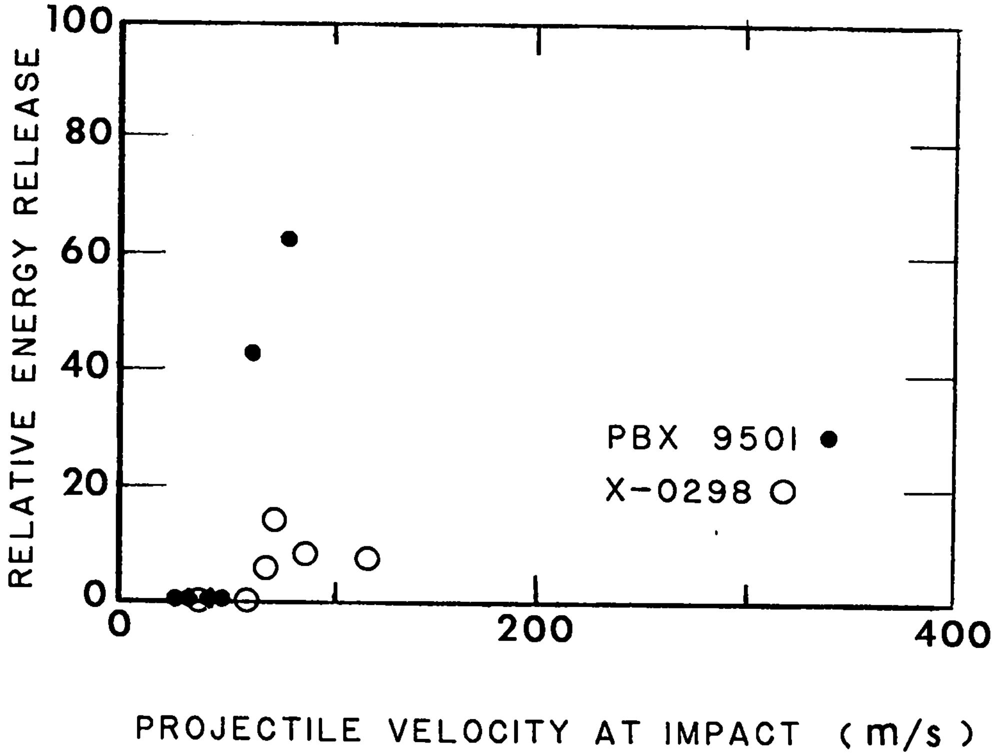

Fig. 3. Susan test: X-0298 in comparison with PBX 9501.

TABLE II

STRENGTH PROPERTIES OF X-0298

Tensile	Prop Limit MPa	Prop Limit (psi)	Ultimate MPa	Ultimate (psi)	Modulus GPa	Modulus (10^5 psi)	Elongation %
+74 C	0.12	(18.0)	0.35	(51.0)	0.23	(0.33)	0.27
+24	0.22	(32.0)	1.48	(215.0)	0.75	(1.09)	0.69
-54	1.57	(228.0)	4.71	(683.0)	6.14	(8.91)	0.17
Compression							
+74	2.70	(391.0)	3.08	(447.0)	0.28	(0.41)	
+24	10.47	(1518.0)	14.26	(2068.0)	1.05	(1.53)	
-54	17.41	(2525.0)	27.99	(4059.0)	2.00	(2.90)	
Shear							
+74	2.42	(351.0)	2.88	(418.0)			
+24	5.71	(828.0)	6.41	(930.0)			
-54	11.07	(1605.0)	12.95	(1878.0)			

Creep

Deflection, 0.69 MPa (100 psi), 60°C, 24 h (%) 0.30

Thermal Expansion

C.T.E., -54 to +74°C ($°C^{-1}$) 48.4×10^{-6}

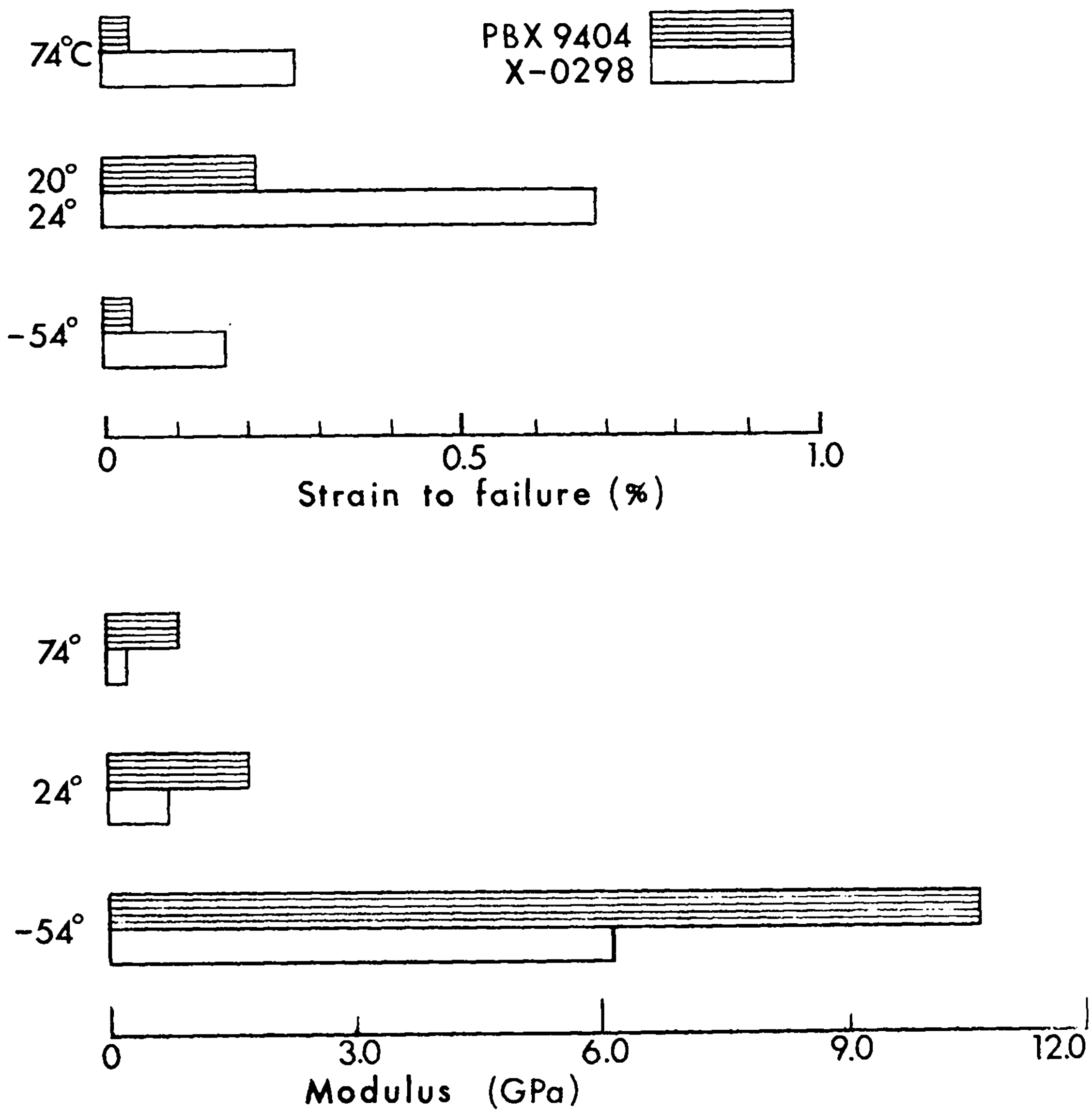

Fig. 4. Tensile properties.

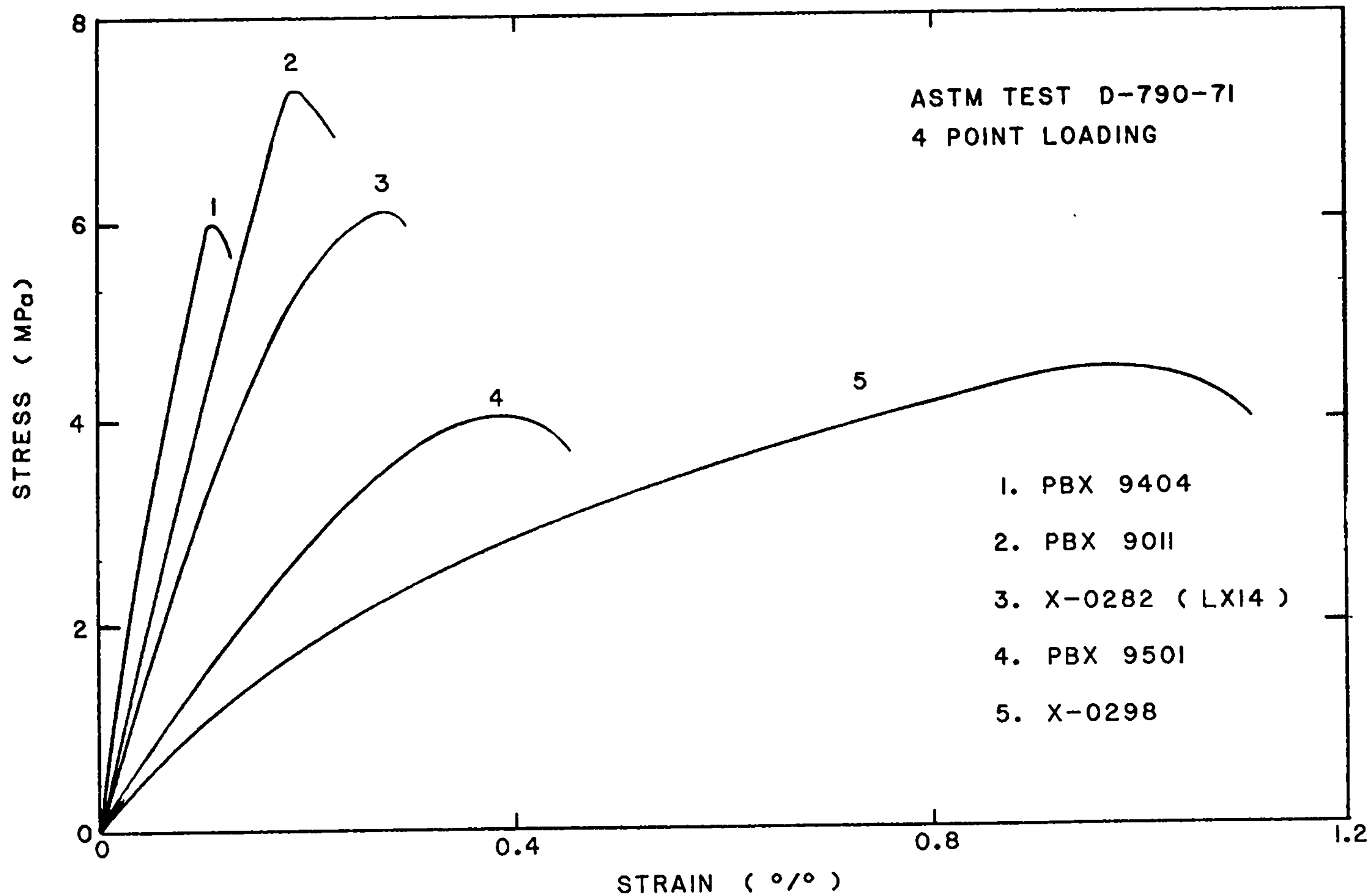

Fig. 5. PBX flexural properties.

V. STABILITY

The X-0298 system demonstrates excellent stability in extended, high-temperature tests. This is an effect of the resistance of the Kraton/oil binder to oxidative degradation and its compatibility with the HMX filler.

As the following data show, X-0298 is quite stable in the conventional short-term tests.

DTA exotherm (°C)	260
Vacuum stability (cm^3/g, 120°, 48 h)	0.1-0.3
Henkin test	acts as pure HMX

The excellent stability of the composition was more fully demonstrated in storage-stability tests made at elevated temperatures. In one set of experiments, small cylinders of X-0298 were stored for eight months at 90°C in sealed ampoules containing an air atmosphere. Gas evolution for this period amounted to only 0.5 cm^3/g. In a 60°C, 16-month test, the total gas evolution was only 0.04 cm^3/g. Analysis of the evolved gases (N_2O, CO_2, CO and H_2O) indicated that essentially all decomposition was that of HMX, with the binder remaining unchanged. The inert nature of the binder was also shown by GPC measurements in which the molecular weight of both the Kraton and the oil binder fractions showed no significant change over the 8-month, 90°C test period.

In another test, tensile measurements were made on specimens that had been stored in sealed containers under air for a period of 34 months at a temperature of 60°C. Properties such as modulus, elongation, and strength were relatively unaffected by this exposure. There was, however, a slight decrease in the molecular weight of the Kraton.

VI. STABILIZER STUDIES

The Kraton rubber, as received from the manufacturer, contains approximately 0.1% Irganox 1010[b] as an antioxidant. This corresponds to about 12 ppm in the PBX composition examined in the high-temperature storage tests.

Thin-film studies were performed to assess the efficacy of this stabilizer in the Kraton/oil binder system. Binder films, containing Irganox concentrations ranging from 0 to 1.2%, were cast on NaCl plates and stored in air at 60, 74, and 98°C. Periodic examinations of the films by infrared (for oxidation products) and GPC analysis (for molecular weight changes) determined the onset and degree of oxidative degradation of the polymer and/or oil. This study demonstrated a general proportionality between Irganox content and storage lifetime (onset of oxidation) at each test temperature.

Based on this study an Irganox content of 1.2% in the binder was established for X-0298. This corresponds to a content of 300 ppm in the composition. This stabilizer level, much larger than

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[b]Ciba-Geigy Co.

used in storage tests, will greatly extend the ability of X-0298 to endure extended high-temperature service.

VII. MANUFACTURE

A. Formulation

Kraton as a binder is quite effective in many compositions. It readily wets explosive fillers, a property related to its low critical surface tension (26 dynes/cm). When compounded with various oils and resins, its common use is as an adhesive.

These properties are reflected in the X-0298 molding powder as produced by the slurry process described below. The granules are well coated and are of uniform size and high-bulk density.

1. A slurry of 10.24 kg of Class A HMX (coarse) and 3.41 kg of Class B HMX (fine) in 50 liters of water is prepared in an agitated, heated vessel.

2. A lacquer consisting of 157 g of Kraton G-1650, 193 g of paraffinic oil (Hyvac 93050-3), 4.2 g of Irganox 1010, and 1.20 liters of n-butyl acetate is added slowly to the HMX slurry, which is at 75°C and under strong agitation. Residual lacquer is washed into the vessel with 200 ml of the lacquer solvent.

3. After the granules have formed, the agitation is reduced to a low level, and heat is applied to remove the solvent by azeotropic distillation. The suspension is then cooled and the product recovered by filtration.

B. Pressing

The pressing procedure is generally that used with other PBX compositions of similar binder level. The pressing temperature, however, must exceed the glass point of polystyrene to bring the Kraton polymer into a thermoplastic state.

Pressure	137 MPa (20,000 psig), 3 intensifications
Vacuum	<1 mm Hg
Temperature	115-120°C
Typical pressed density	1.82 g/cm^3

VIII. SUMMARY

Considering the service requirements in modern applications of high-performance explosives, X-0298 has a quite desirable balance of properties.

Explosive performance of PBX 9404.

Relative insensitivity to impact (Skid and Susan tests).

High thermal stability in extended service.

A compliant, elastic nature to accommodate thermal strain in structural applications.

With these attributes, X-0298 offers a design flexibility not common in the usual, high-performance, plastic-bonded explosive.

ACKNOWLEDGMENTS

Measurements of small-scale explosive properties were made by M. J. Urizar. M. L. Matuszak performed the binder film studies. Assistance was also given in various property evaluations by WX and M Division personnel.

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