MECHANICAL BEHAVIOR OF ENERGETIC MATERIALS DURING HIGH ACCELERATION

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The mechanical behavior of explosives subjected to high acceleration has been studied in an ultracentrifuge at -10^{o}C and 25^{o}C. Melt-cast TNAZ and pressed TNAZ, LX-14, Composition A3 Type II, PAX-2, and PAX-3 have been studied. Failure occurs when the shear or tensile strength of the explosive is exceeded. The fracture acceleration of melt-cast TNAZ is greater than the fracture acceleration of pressed TNAZ at -10^{o}C and 25^{o}C. The fracture acceleration of PAX-3 is greater than the fracture acceleration of Composition A3 Type II at -10^{o}C and 25^{o}C. The fracture acceleration of melt-cast TNAZ and pressed TNAZ at -10^{o}C is about 10% less than that at 25^{o}C. The fracture acceleration of PAX-3 at -10^{o}C is about 2.6 times that at 25^{o}C. The fracture acceleration of Composition A3 Type II at -10^{o}C is about 1.7 times that at 25^{o}C.

INTRODUCTION

We have introduced several new fields of research to study the mechanical behavior of energetic materials during high acceleration by using an ultracentrifuge.[1-11] Energetic materials are of significant interest for scientific and practical reasons in the extraction (mining) industry, structure demolition, space propulsion, and ordnance. In these applications the materials can be subjected to high, fluctuating, and/or sustained acceleration. The nature of the fracture

process of such materials under high acceleration is of particular interest, especially in ordnance and propulsion applications. For example, explosives in projectiles are subjected to setback forces as high as 50,000 *g* during the gun launch. These high setback forces can cause fracture and premature ignition of explosives.

Fundamental understanding of the behavior of energetic materials subjected to high acceleration is a key to better practical ordnance designs that solve the problems of abnormal propellant burning and premature ignition of explosives during gun launch. The pressure gradient that is experienced by the explosive during acceleration in the gun and under *g*-loading in the ultracentrifuge is unique and will produce different kinds of behavior and failure than under other material test conditions. The present work is particularly relevant to the future development of insensitive energetic materials to be used in devices with higher acceleration.

Previously, (1-11) we have used an ultracentrifuge to study the fracture behavior of TNT (trinitrotoluene), Composition B [59% cyclotrimethylenetrinitramine (RDX), 40% TNT, 1% wax], four types of Octol [70% cyclotetramethylenetetranitramine (HMX), 30% TNT; 75% HMX, 25% TNT; <75% HMX, 25% TNT, <1% HNS (hexanitrostilbene); and 83% HMX, 17% TNT]. In the present work, we studied the fracture behavior at high acceleration in an ultracentrifuge at -10^{o}C and 25^{o}C of melt-cast TNAZ (1,3,3-trinitroazetidine), pressed TNAZ, and pressed plastic bonded explosives LX-14 (95% HMX, 5% Estane), Composition A3 Type II (91% RDX, 9% polyethylene), and PAX-3 [75% (85% HMX, 9% BDNPF (bis-dinitropropyl acetal formal), 6% CAB (cellulose acetate butyrate)) /25% aluminum].

TECHNIQUE

A Beckman ultracentrifuge model L8-80 with swinging-bucket rotor model SW 60 Ti was used to rotate the samples up to 60,000 rpm (~ 500,000 *g*). The distance of the specimen from the axis of rotation ranged from 6 to 12 cm.

The samples were machined into the shape of the frustrum of a cone. The large diameter was typically 11 mm and the small diameter 9 mm. The angle between the base and the side was 80^{o}. Each sample was fitted into a 5-mm long, 11-mm o.d. aluminum cylinder. At one end the i.d. was 11 mm and at the other end 9 mm. The angle between the inner and outer sides of the sleeve was 10^{o}. The 9-mm diameter top of the sample faced away from the axis of rotation.

For an experiment the acceleration was increased up to a maximum and then held there until the total elapsed time reached 5 min. The sample was then decelerated smoothly. In a series of experiments on a material, the initial maximum acceleration was then increased systematically in each successive 5-min run. The sample fractured when the shear or tensile strength of the material was exceeded, causing particles to break loose from the exposed surface and transfer to the closed-end of the tube. A hemispherical fracture surface resulted.

RESULTS

Melt-cast TNAZ when subjected to high acceleration experiences brittle fracture at grain boundaries. This occurs when the shear or tensile strength of the melt-cast TNAZ is exceeded. The fracture acceleration of pressed TNAZ and the pressed plastic-bonded explosives LX-14, PAX-2A, PAX-3, and Composition A3 Type II also experience brittle fracture when the shear or tensile strength is exceeded.

TNAZ

The fracture acceleration of melt-cast TNAZ and pressed TNAZ at 25°C is given in Table 1. Melt-cast TNAZ was made with 70% liquid TNAZ and 30% 40 micron maximum size TNAZ particles. Polycrystalline melt-cast TNAZ has been found to fracture at grain boundaries at ~ 105 kg at 25°C. This melt-cast TNAZ was 97.4% of its theoretical maximum density (TMD) of 1.84 g/cc. Pressed TNAZ has been found to fracture at ~ 62 kg at 25°C. This pressed TNAZ was 97.0% of its TMD.

The fracture acceleration of melt-cast TNAZ and pressed TNAZ at –10°C is given in Table 2. Polycrystalline melt-cast TNAZ has been found to fracture at grain boundaries at ~ 93 kg at –10°C. This melt-cast TNAZ was 97.3% of its TMD. Pressed TNAZ fractured at ~ 55 kg at –10°C. This pressed TNAZ was 98.4% of its TMD.

PRESSED PLASTIC-BONDED EXPLOSIVES

The fracture acceleration of melt-cast TNAZ and pressed TNAZ at 25°C is compared with the fracture acceleration of LX-14, PAX-2A, PAX-3, and Composition A3 Type II at 25°C in Table 1. LX-14 has been found to fracture at ~ 84 kg at 25°C. This LX-14 was pressed at 96.9% of its TMD of 1.849 g/cc. PAX-2A has been found to fracture at ~ 81 kg at 25°C. This PAX-2A was pressed at 99.3% of its TMD of 1.79 g/cc. PAX-3 has been found to fracture at ~ 43 kg at 25°C. This PAX-3 was pressed at 97.9% of its TMD of 1.955 g/cc. Composition A3 Type II has been found to fracture at ~ 33 kg at 25°C. This Composition A3 Type II was pressed at 96.8% of its TMD of 1.662 g/cc.

TABLE 1. FRACTURE ACCELERATION OF PRESSED EXPLOSIVES IN AN ULTRACENTRIFUGE AT 25°C.

Explosive	Fracture Acceleration (kg)	Density (%TMD)
TNAZ(cast)	105	97.4
LX-14	84	96.9
PAX-2A	81	99.3
TNAZ	62	97.0
PAX-3	48	97.9
CompA3TII	33	96.8

The fracture acceleration of melt-cast TNAZ and pressed TNAZ at –10°C is compared with the fracture acceleration of LX-14, PAX-2A, PAX-3, and Composition A3 Type II –10°C in Table 2. LX-14 at –10°C did not fracture at the largest acceleration employed in these experiments, 140 kg. This LX-14 was pressed at 95.9% of its TMD. Similar to the LX-14 result PAX-2A at –10°C did not fracture at the 140 kg experimental limit. This PAX-2A was pressed at 99.4% of its TMD. PAX-3 has been found to fracture at ~ 123 kg at –10°C. This PAX-3 was pressed at 97.4% of its TMD. Composition A3 Type II fractured at ~ 55

kg at –10°C. This Composition A3 Type II was pressed at 98.1% of its TMD.

DISCUSSION

The fracture acceleration of cast TNAZ is greater than that of pressed TNAZ at –10°C and 25°C. Since the fracture acceleration of cast explosives is inversely related to the grain size,[1] the high fracture acceleration of this melt-cast TNAZ may therefore be due to its very small grain size (<0.1 mm). The fracture acceleration of melt-cast TNAZ and pressed TNAZ at –10°C was about 10% less than at 25°C.

TABLE 2. FRACTURE ACCELERATION OF PRESSED EXPLOSIVES IN AN ULTRACENTRIFUGE AT –10°C.

Explosive	Fracture Acceleration (kg)	Density (%TMD)
LX-14	none	95.9
PAX-2A	none	99.4
PAX-3	123	97.4
TNAZ(cast)	93	97.3
CompA3TII	55	98.1
TNAZ	55	98.4

The fracture acceleration of PAX-3 is greater than that of Composition A3 Type II at –10°C and 25°C. LX-14 and PAX-2A did not fracture at –10°C in these experiments. The fracture acceleration of PAX-3 at –10°C is about 2.6 times that at 25°C. The fracture acceleration of Composition A3 Type II at –10°C is about 1.7 times that at 25°C.

Stronger explosives with higher fracture acceleration are less likely to fail. The relationship between sensitivity and strength is not known.

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