



# High-Strain Rate Mechanical Response of Green Insensitive Munitions Gun Propellants

by Michael G. Leadore

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## High-Strain Rate Mechanical Response of Green Insensitive Munitions Gun Propellants

Michael G. Leadore

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## Abstract

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Four lots of green insensitive munitions gun propellants were tested in uniaxial compression. A production lot of M14 that is currently used in the M865 training round was also tested for comparison purposes. The materials were tested while conditioned at 21°, 63°, and -32 °C. The materials were taken to ~60% strain using a deformation rate of 1.3 m/s. The stress at failure, strain at failure, compressive modulus, failure modulus, incremental energy density, and the fracture assessment values were recorded for each test.

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## 1. Introduction

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The subject of this report is the material test systems servo-hydraulic tester high-rate mechanical response of Alliant Tech Systems M865 gun propellants (Figure 1). Four lots were designed as RPD-441, RPD-442, RPD-443A, and RPD-443B. The Radford manufactured materials were a part of the Green Insensitive Munitions Program (test sets 21-31, FY 02). For comparative purposes, a production lot of M14, lot no. HCL95C025003, was also tested using similar test conditions.

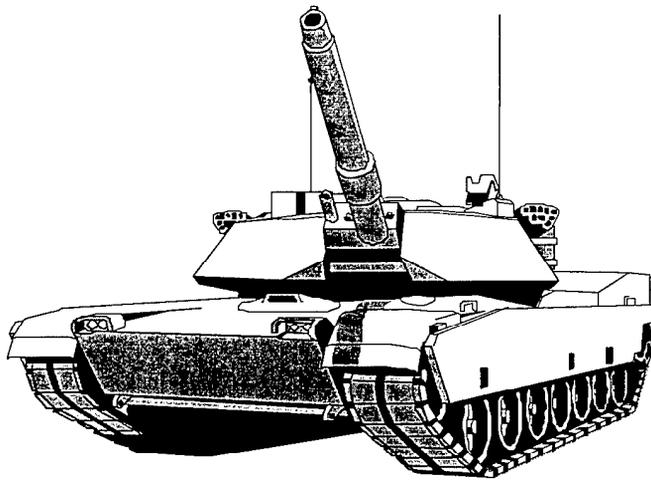


Figure 1. M1 Abrams with 120-mm cannon.

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## 2. Background

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Four lots of Radford manufactured gun propellants (Figure 2) were received from Alliant Tech Systems of the Radford Army Ammunition Plant. Note the rough and somewhat deformed grain surfaces from lot RPD-443A. Lots RPD-441 and RPD-442 were solventless formulations, and lots RPD-443A and RPD-443B were manufactured using solvent. The high-energy propellants were manufactured in a mixer and extruded thermally into a granular configuration. The granular material had a diameter of ~6.3 mm. Several grains from each lot of experimental gun propellants were shipped to Dr. Robert Lieb of the U.S. Army Research Laboratory, Aberdeen Proving Ground (APG), MD. Also, a production lot of Radford manufactured M14 granular propellant was procured from APG for comparison testing. All of these materials were tested during December 2001 for high-rate uniaxial compression mechanical response evaluation.

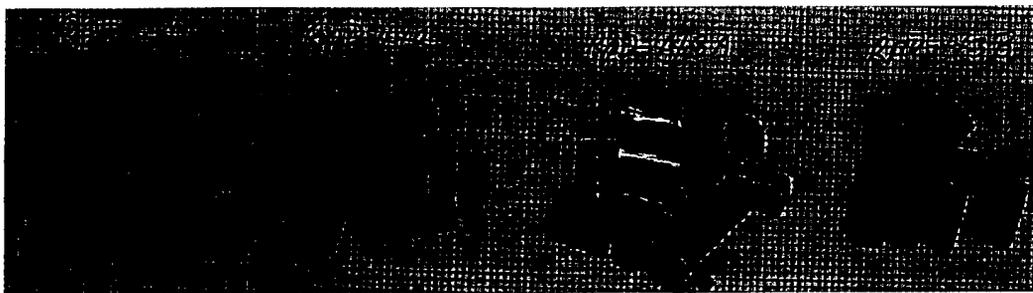


Figure 2. Green insensitive munitions propellant lots of gun as received. (Note rough surfaces and irregular shaped grains for lot RPD-443A.)

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### 3. Approach and Results

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The RPD-441, RPD-442, RPD-443A, and RPD-443B propellant lots were received in granular form. The lots were cut into test specimens having a length-to-diameter ratio of 1.06. Specimen preparation was accomplished using an Isomet low-speed diamond bladed saw. Sample ends were machined so that the surfaces were flat, parallel to each other, and perpendicular to the extruded axis. The M14 lot was also granular, with a diameter of 6.60 mm, and was also cut using an Isomet diamond saw.

Material test systems servo hydraulic tester mechanical properties tests [1-7] (Figure 3) were conducted on several specimens under each test condition. Strain rates of  $130.0 \text{ s}^{-1}$  were achieved. The specimens were taken to failure at ambient pressure to ~50% end strain while conditioned at  $21^\circ$ ,  $63^\circ$ , and  $-32^\circ \text{ C}$ . The stress at failure, strain at failure, the modulus, failure modulus, the incremental energy density, and the fracture assessment value were recorded for each test, and the average values are listed in Table 1.



Figure 3. Preparing to test energetic material using high-rate load frame.

Table 1. Mechanical properties of Radford manufactured green insensitive munitions propellant lots at 21°, 63°, and -32 °C.

| Lot                       | Stress at Failure (MPa) | Strain at Failure (%) | Modulus (GPa) | Failure Modulus <sup>a</sup> (GPa) | IED <sup>b</sup> (MPa) | FAV <sup>c</sup> (MPa) |
|---------------------------|-------------------------|-----------------------|---------------|------------------------------------|------------------------|------------------------|
| at 21 °C                  |                         |                       |               |                                    |                        |                        |
| RPD-441<br>Lot 01K071870  | 14.10                   | 4.30                  | 0.611         | 0.110                              | 10.10                  | 1AB                    |
| RPD-442<br>Lot 01K071867  | 16.12                   | 6.15                  | 0.402         | 0.131                              | 5.62                   | 1AB                    |
| RPD-443A<br>Lot 01K071868 | 97.08                   | 10.01                 | 1.21          | -0.0691                            | 18.72                  | 4AS                    |
| RPD-443B<br>Lot 01K071869 | 91.17                   | 8.36                  | 1.54          | -0.0950                            | 18.90                  | 4AS                    |
| M14<br>Lot 95C025003      | 104.80                  | 4.16                  | 2.94          | -0.0833                            | 17.47                  | 3AS                    |
| at 63 °C                  |                         |                       |               |                                    |                        |                        |
| RPD-441<br>Lot 01K071870  | 11.21                   | 6.30                  | 0.182         | 0.059                              | 3.54                   | 1AB                    |
| RPD-442<br>Lot 01K071867  | 12.02                   | 6.55                  | 0.762         | 0.056                              | 3.35                   | 1AB                    |
| RPD-443A<br>Lot 01K071868 | 64.74                   | 9.22                  | 0.901         | -0.032                             | 13.23                  | 2AS                    |
| RPD-443B<br>Lot 01K071869 | 63.07                   | 9.64                  | 1.27          | -0.086                             | 12.37                  | 2AS                    |
| M14<br>Lot 95C025003      | 76.58                   | 3.72                  | 2.40          | -0.081                             | 16.17                  | 3AS                    |
| at -32 °C                 |                         |                       |               |                                    |                        |                        |
| RPD-441<br>Lot 01K071870  | 52.36                   | 7.25                  | 1.37          | 0.088                              | 14.20                  | 3A                     |
| RPD-442<br>Lot 01K071867  | 64.20                   | 5.50                  | 1.36          | 0.271                              | 19.44                  | 3A                     |
| RPD-443A<br>Lot 01K071868 | 92.04                   | 8.60                  | 1.26          | -2.48                              | 6.20                   | 8AS                    |
| RPD-443B<br>Lot 01K071869 | 99.29                   | 8.54                  | 1.50          | -3.26                              | 7.67                   | 8AS                    |
| M14<br>Lot 95C025003      | 154.20                  | 4.33                  | 3.63          | -0.491                             | 6.78                   | 6AS                    |

<sup>a</sup>The failure modulus (slope of the curve after failure) has been added. Generally, the lower the value, the worse the material (i.e., a negative value indicates that the material is unable to sustain load). A positive value indicates a positive failure slope (i.e., the material is better able to support load after failure).

<sup>b</sup>The incremental energy density (IED) value reported is the amount of energy per unit volume absorbed at 25% strain; this includes a portion of the area located beneath the stress/strain curve.

<sup>c</sup>The tested specimens were assigned a fracture assessment value (FAV). The values range from 0 (no observed fracturing) through 9 (severe fracturing observed). The type of fracture was also characterized using the following methodology: A = axial fracture, S = shear fracture, B = barreling/deformation, and R = radial splitting (i.e., 8AS indicates the tested specimens showed a severe amount of axial fracture).

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## 4. Conclusions

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Four lots of Radford manufactured high-energy gun propellants (Figure 2) and a production lot of M14 were tested for mechanical response evaluation at ambient pressure while conditioned at 21°, 63°, and -32 °C. The materials were tested in uniaxial compression to ~50% end strain using a deformation rate of 1.33 m/s.

At 21 °C, RPD-441, RPD-442, RPD-443A, RPD-443B, and the M14 lots all showed good response to uniaxial compression. The positive failure modulus values achieved indicated the lots' abilities to sustain load beyond ~50% strain. Note that the stress vs. strain plot (Figure 4) shows RPD-441 and RPD-442 lots work hardening beyond 40% strain. The tested specimens (Figure 5) suffered permanent deformation with very minimal fracturing.

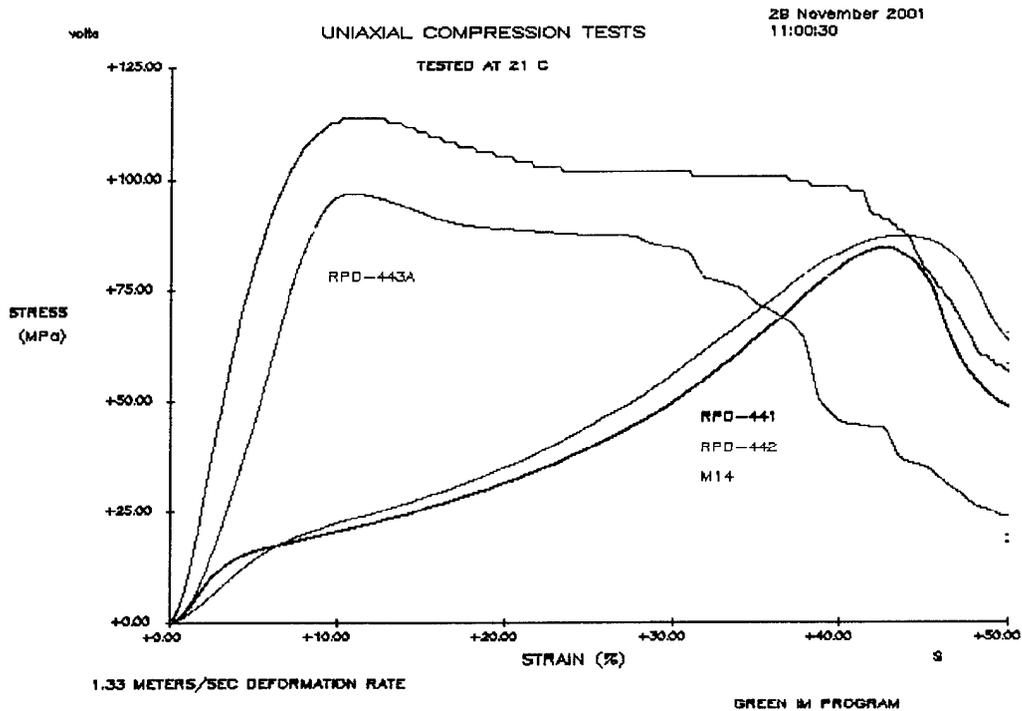


Figure 4. Stress vs. strain plot of green insensitive munitions propellant lots tested at 21 °C.

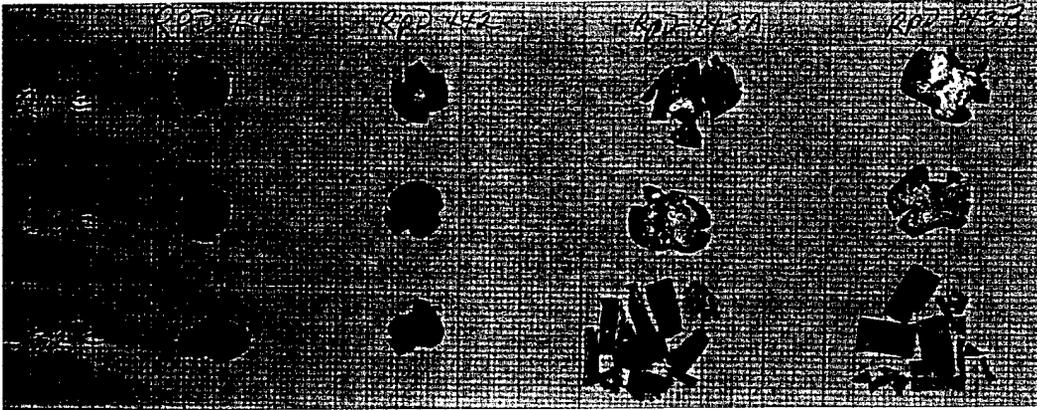


Figure 5. Remains of specimens tested at 21°, 63°, and -32 °C.

At 63 °C, again, the mechanical response of all the lots was quite good. The Young's modulus values showed some "softening" as a result of the higher testing temperature; this would be expected. The stress/strain plot (Figure 6) shows that all the lots were capable of sustaining load. The tested specimens (Figure 5) again showed minimal axial fracture and deformation.

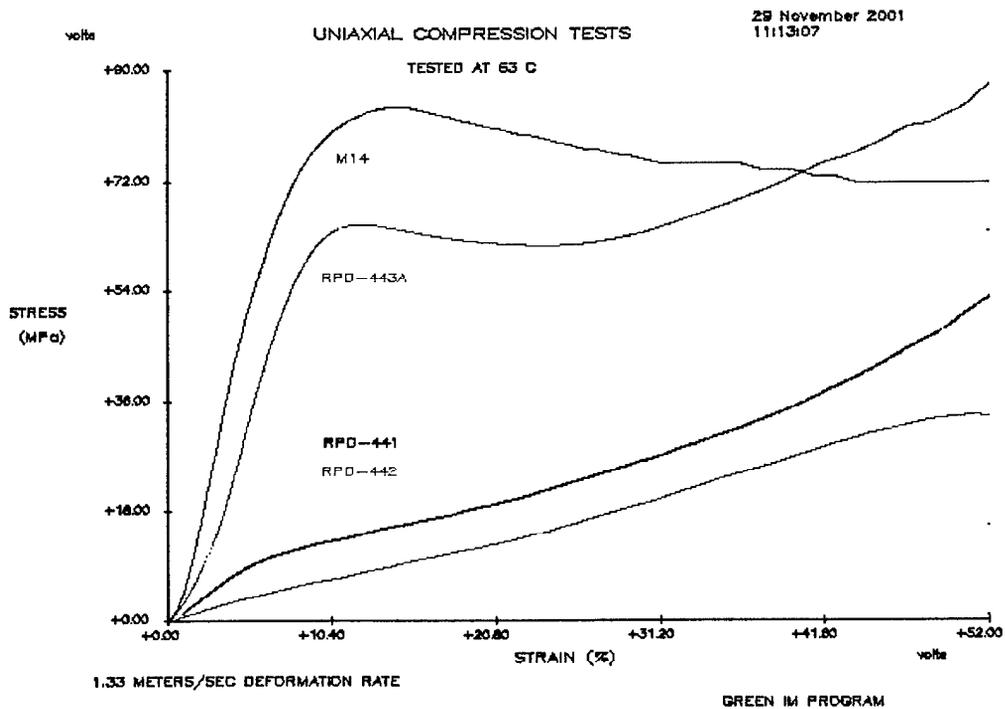


Figure 6. Stress vs. strain plot of green insensitive munitions propellant lots tested at 63 °C.

At -32 °C, the solventless produced lots RPD-441 and RPD-442 showed a far superior response to uniaxial compression than the other lots tested. The tested specimens (Figure 5) suffered only minimal amounts of axial and shear fracture, and the core area of the tested specimens remained mostly whole. Note that the stress/strain plot at -32 °C (Figure 7) shows that lots RPD-441 and RPD-442 are capable of sustaining load and work hardening beyond 40% strain and, thus, were the only lots yielding positive failure modulus values. Lots RPD-443A and RPD-443B showed very poor responses to mechanical testing at -32 °C. The failure modulus values for RPD-443A and RPD-443B at -32 °C were particularly disturbing and indicated these materials lacked any mechanical integrity. The tested remains from these lots showed much axial and shear fracture. This amount and type of fracturing observed would likely increase the surface area of these materials significantly and, thus, increase the burn rate of the material.

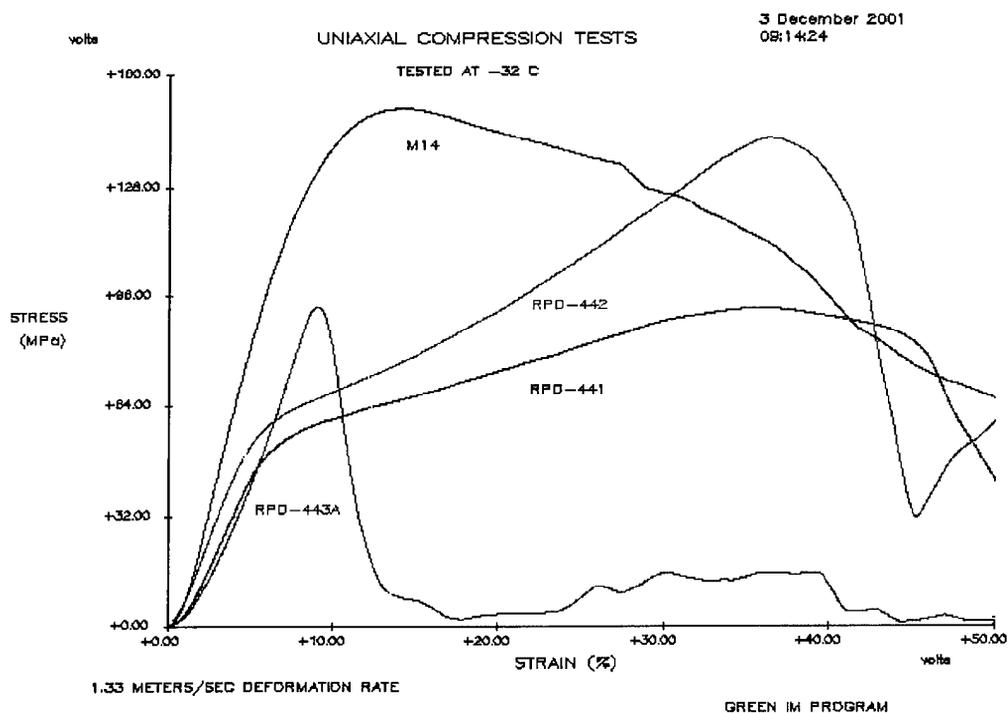


Figure 7. Stress vs. strain plot of green insensitive munitions propellant lots tested at -32 °C.

Overall, all the materials' mechanical responses at 21° and 63 °C were quite good. At -32 °C, the RPD-441 and RPD-442 lots were clearly the better materials, followed by the M14 lot, and finally the solvent produced lots RPD-443A and RPD-443B, which suffered prolific fracture at -32 °C.

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