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# High-Strain Rate Uniaxial Compression of Future Combat Systems (FCS) Generation One High-Energy Gun Propellants

by Michael G. Leadore

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Weapons and Materials Research Directorate, ARL

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## Abstract

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Six lots of Thiokol-manufactured Future Combat Systems (FCS) Generation One experimental high-energy gun propellants were tested in uniaxial compression. The materials were taken to ~60% strain at a strain rate of 100 per second, while conditioned at 21 °C, 63 °C, and -32 °C. The stress at yield, strain at yield, Young's modulus, failure modulus, incremental energy density, and fracture assessment values were recorded for each test. The average values achieved are reported.

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## 1. Introduction

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The following is the U.S. Army Research Laboratory's (ARL's) Material Test Systems (MTS) servo-hydraulic tester (SHT) high-rate mechanical response report of Generation One Future Combat System (FCS) Next Generation Experimental Gun Propellants. The six lots were manufactured by the Thiokol Corporation, at Brigham City, Utah Division (Test Sets 63-80, Fiscal 01). The lots are candidate propellants for the M1A2 Abrams with 120-mm cannon (Figure 1).

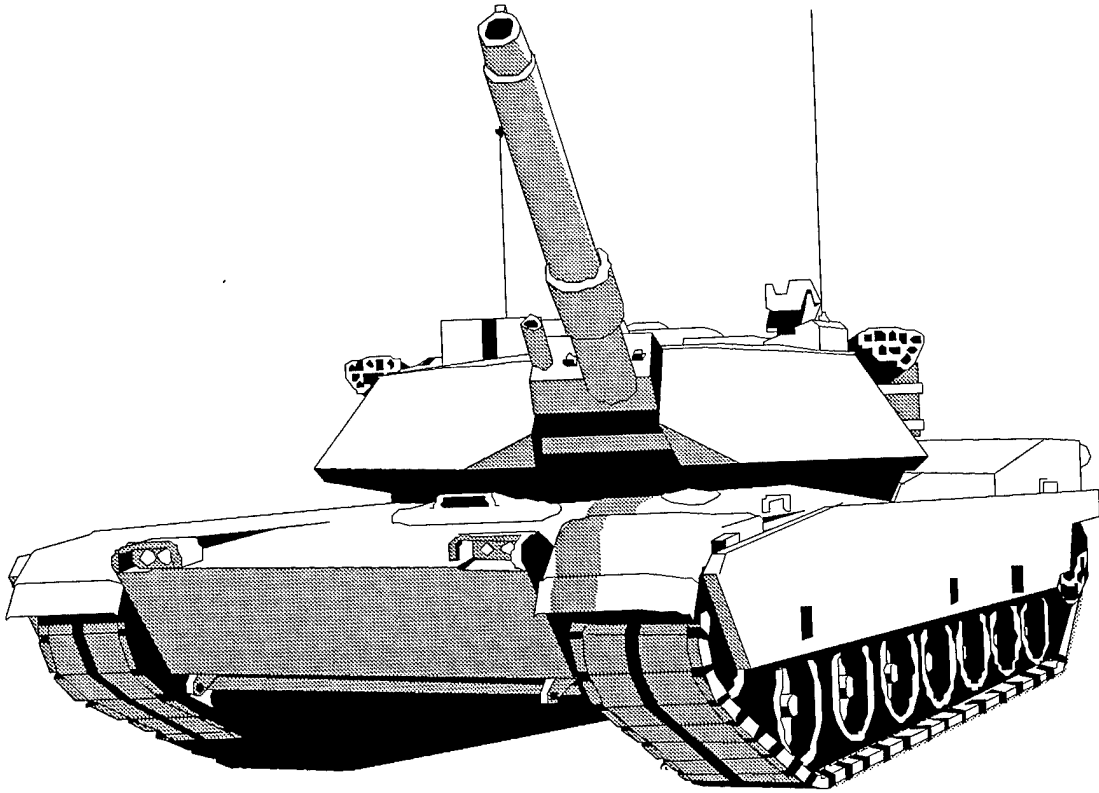


Figure 1. M1A2 Abrams with 120-mm cannon.

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## 2. Background

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Six lots of Generation One FCS propellants, identified as lots TGD013, TGD014, TGD015, TGD016, TGD017, and TGD018, were received from Thiokol-Utah (Figure 2). The next generation high-energy propellants were manufactured in a

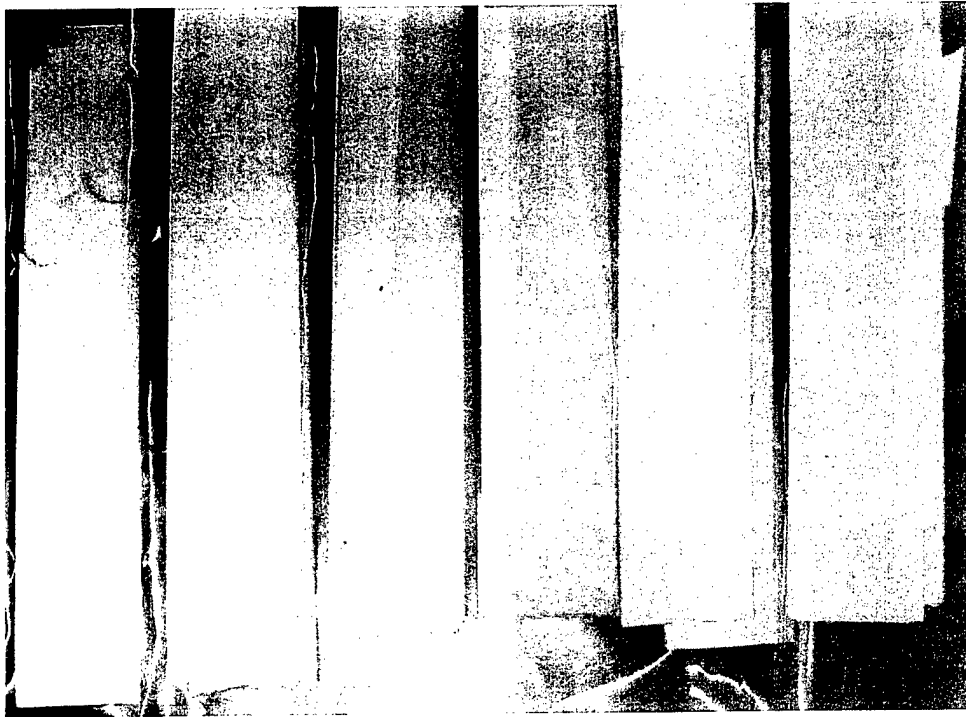


Figure 2. Thiokol lots TGD013, TGD014, TGD015, TGD016, TGD017, and TGD018 as received.

mixer and extruded thermally into sheets. The sheet materials had a thickness of ~2.0 mm. The sheets were cut into 25-mm × 500-mm sheets, and several pieces from each lot of the experimental gun propellants were shipped to Mr. Charles Leveritt of ARL. They were recently tested for high-rate uniaxial compression mechanical response evaluation. The matrix summary and constituents with particle size (microns) as designated by Thiokol-Utah are shown in Table 1.

Table 1. Matrix summary and constituents with particle size.

Lot No.	%BAMOAMMO	%CL-20	%RDX
TGD013	22	78 (2 $\mu$ m)	0
TGD014	30	70 (2 $\mu$ m)	0
TGD015	22	78 (7 $\mu$ m)	0
TGD016	24	0	76 (2 $\mu$ m)
TGD017	30	0	70 (2 $\mu$ m)
TGD018	24	0	76 (7 $\mu$ m)

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### 3. Approach and Results

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The Thiokol-Utah propellant lots were received in solid sheet form and were without perforations. The lots were cut into samples and stacked resulting in a length to diameter (L/D) ratio of 0.93. Sample preparation was accomplished using a 12.68-mm stainless steel hole punch. Sample ends were machined so that the surfaces were flat, parallel to each other, and perpendicular to the extruded axis.

MTS SHT mechanical properties tests [1-7] were conducted on several specimens under each test condition (Figure 3). Strain rates of  $128.0 \text{ s}^{-1}$  were achieved. The specimens were taken to failure at ambient pressure to ~60% end strain while conditioned at temperatures of 21 °C, 63 °C, and -32 °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. The average values are listed in Table 2.

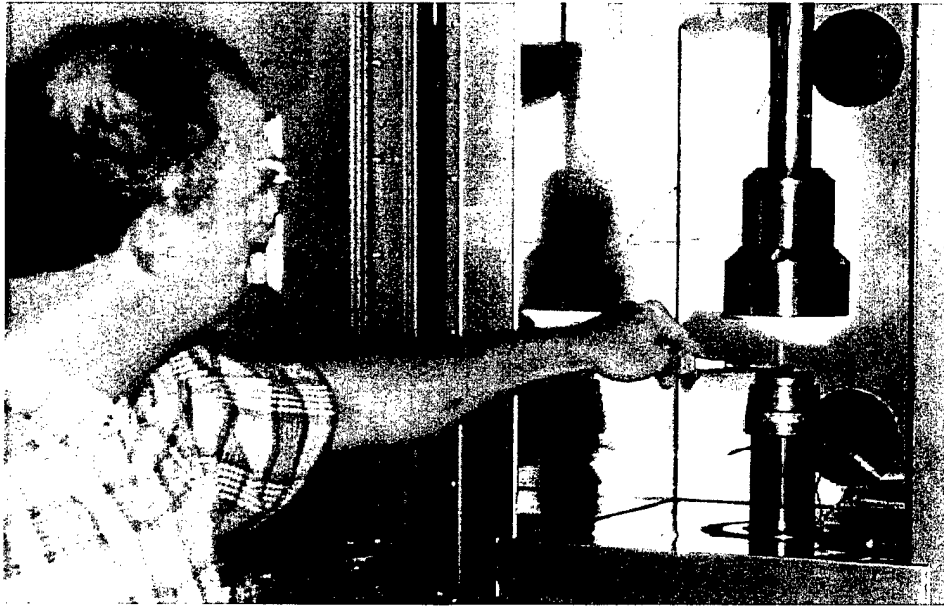


Figure 3. Energetic material being loaded for a high-rate test.

Table 2. Mechanical properties of Thiokol lots.

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						
TGD013	56.20	10.10	0.801	0.009	7.36	1AB
TGD014	39.23	13.34	0.391	0.125	6.81	1AB
TGD015	33.46	7.70	0.576	0.086	7.68	1AB
TGD016	39.03	12.05	0.416	0.072	8.31	1AB
TGD017	34.22	19.27	0.193	0.059	6.37	0B
TGD018	40.58	11.77	0.440	0.009	8.77	1AB
at 63 °C						
TGD013	21.58	12.57	0.211	0.021	4.60	0B
TGD014	12.79	13.50	0.074	0.054	2.76	0B
TGD015	15.82	12.75	0.133	0.037	3.38	0B
TGD016	8.98	13.05	0.126	0.016	3.72	1AB
TGD017	9.65	16.68	0.041	0.042	1.94	0B
TGD018	8.73	12.39	0.166	0.038	4.08	1AB
at -32 °C						
TGD013	93.86	5.23	2.75	-0.290	16.70	7AS
TGD014	85.67	6.05	2.01	-0.058	20.20	3AS
TGD015	91.78	5.15	2.42	-0.680	12.88	7AS
TGD016	76.03	9.36	1.14	-0.064	15.90	4AS
TGD017	62.67	12.38	0.765	-0.018	12.74	2AS
TGD018	81.86	6.60	1.72	-0.101	17.40	4AS

<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., negative value indicates 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 IED (incremental energy density) 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, R = radial splitting (i.e., 9A indicates the tested specimens showed a severe amount of axial fracture).

## 4. Conclusions

A matrix of Thiokol-manufactured lots designated as TGD013, TGD014, TGD015, TGD016, TGD017, and TGD018 next generation experimental FCS gun propellants were tested for mechanical response evaluation at ambient pressure

while conditioned at 21 °C, 63 °C, and -32 °C. The materials were tested in uniaxial compression to ~60% end strain using a deformation rate of 1.31 m/s.

At 21 °C, the TGD lots provided good mechanical response at high-strain rate. It was noted when comparing the Young's modulus that lots TGD014 and TGD017 were a bit "softer" than the remaining lots. This was expected as these lots contained additional plasticizer. The failure modulus values were all positive values indicating the lots did well at sustaining load. The tested specimens showed minimal (Figure 4) axial fracture and barreling.

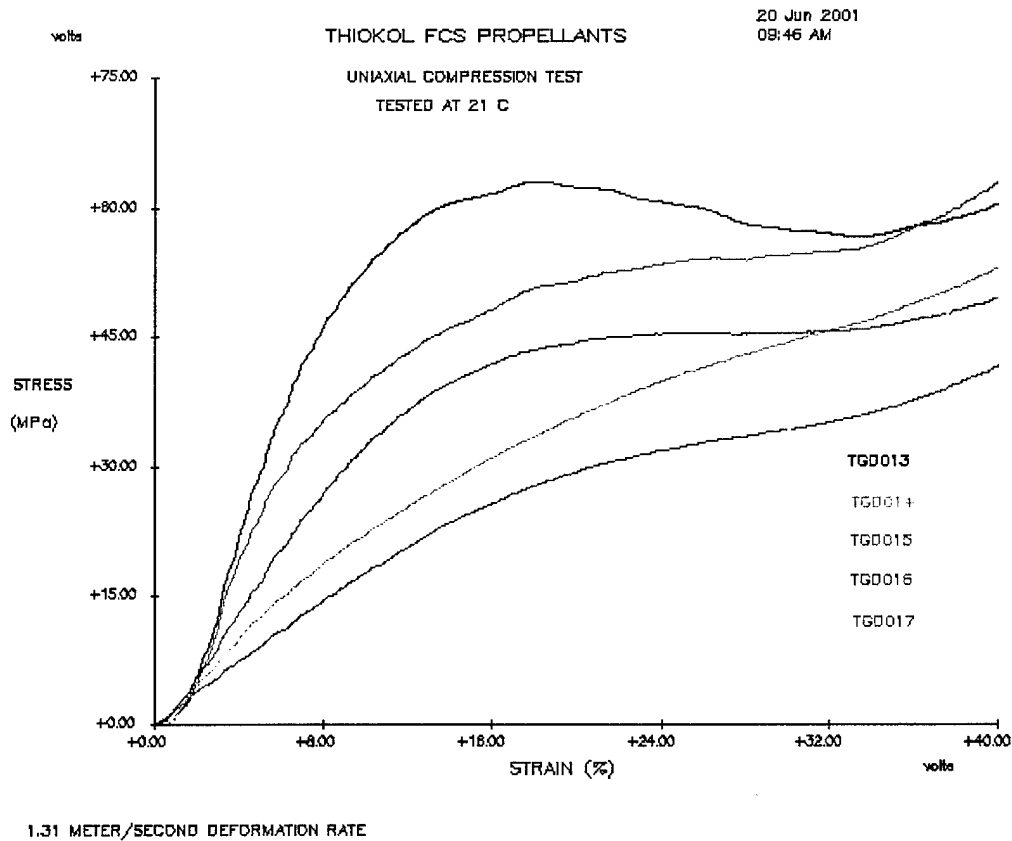


Figure 4. Stress vs. strain plot of Thiokol propellants at 21 °C.

At 63 °C, "softening" of the six lots was noted as a result of the higher testing temperature. The tested specimens showed minimal permanent deformation and barreling. Due to the thermal softening, the stress/strain plots showed lots TGD014 and TGD017 loading with non-definitive stress at yield (Figure 5), then continuing to workharden to ~40% strain. When comparing the Young's modulus at 63 °C and 21 °C for lots TGD014 and TGD017, a factor of five decrease was noted. This would indicate thermal softening and, thus, increasing

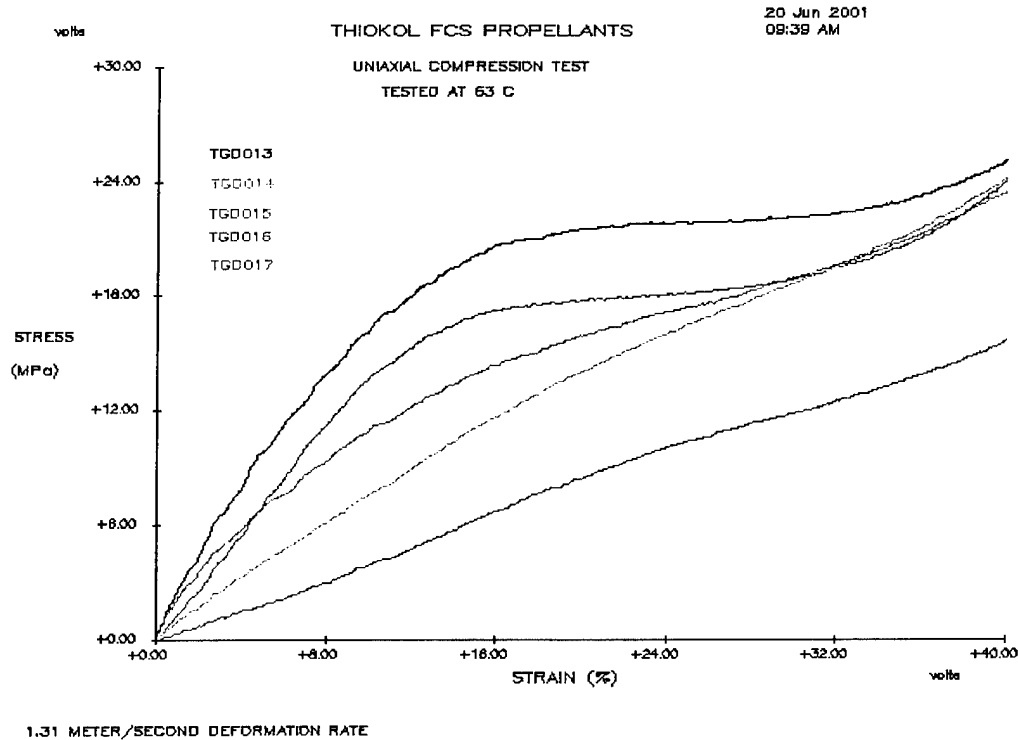


Figure 5. Stress vs. strain plot of Thiokol propellants at 63 °C.

the probability of material agglomeration at temperatures at or around 63 °C. The thermal softening of lots TGD014 and TGD017 could cause incomplete combustion of the materials in a ballistic environment. The tested specimens (Figure 6) showed permanent deformation and barreling.

At -32 °C, the tested specimens from lots TGD013 and TGD015 suffered moderate to severe amounts of axial and shear fracture, likely causing an increase in available surface area and thus, increasing the burn rate of the material. The stress/strain plot (Figure 6) for the lots also correlates well with the physical damage observed in the tested specimens. Lots TGD014, TGD016, and TGD017 showed the better failure modulus values, which indicated these lots sustained load much better and also suffered less physical damage than the remaining lots. When comparing the Young's modulus values for lots TGD013 and TGD015 at 21 °C and -32 °C, a factor of four increase was noted, indicating these two lots had likely made a glass transition. The failure modulus values achieved at -32 °C also supports this observation.

Overall, the 21 °C and 63 °C test results were quite good. However, lots TGD014 and TGD017 suffered much softening at 63 °C. At -32 °C, lots TGD014, TGD016, TGD017, and TGD018 showed the better mechanical response (Figure 7). Lots TGD013 and TGD015 were much too "brittle" and suffered prolific fracture.

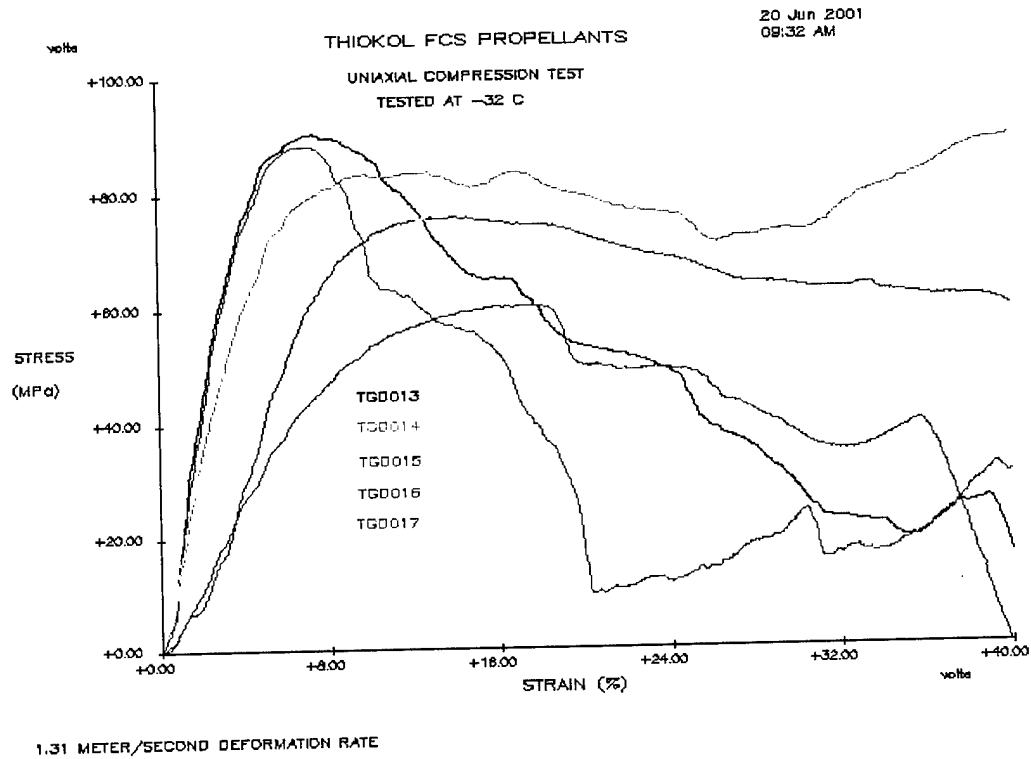


Figure 6. Stress vs. strain plot of Thiokol propellants at -32 °C.

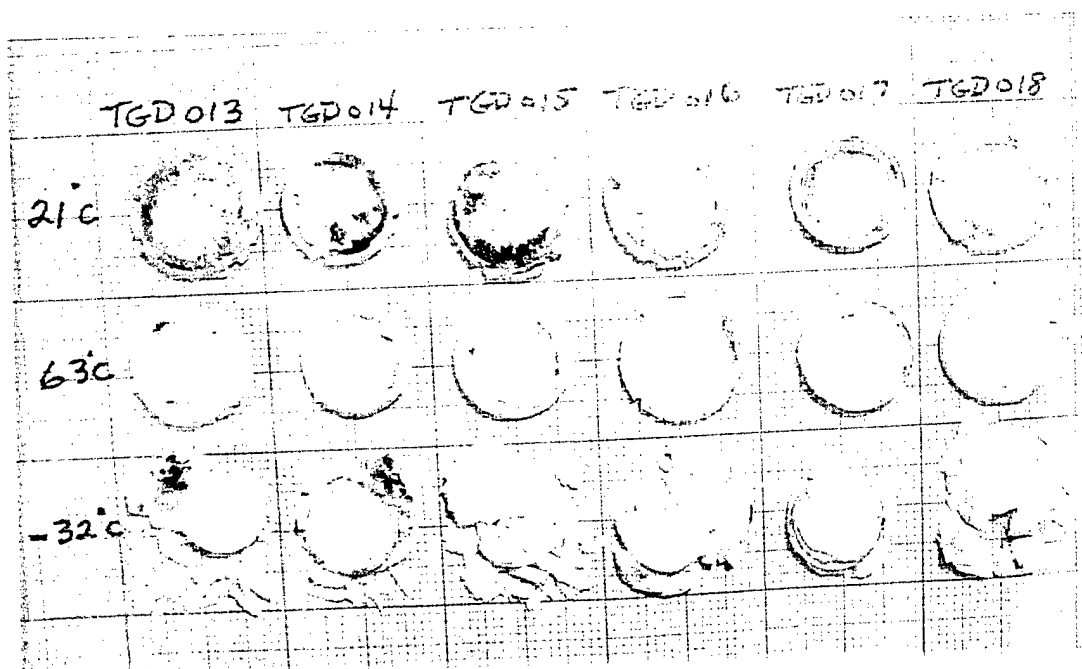


Figure 7. Tested specimens from Thiokol lots at 21 °C, 63 °C, and -32 °C.

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