SAND2013-5369C

Sandia National Laboratories

Critical detonation thickness in vapor-deposited hexanitroazobenzene (HNAB) films with different preparation conditions

Alexander S. Tappan, Robert Knepper,
Michael P. Marquez, and J. Patrick Ball

The Eighteenth Biennial International Conference of the APS Topical Group on Shock Compression of Condensed Matter (APS-SCCM),
Seattle, Washington,
July 7–12, 2013.

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND2013-xxxxP

Sandia National Laboratories

Introduction

- Detonation failure
  - Occurs when size (diameter or thickness) of explosive is decreased
  - When losses to confinement dominate behavior
- Data for small-scale behavior of high-density pure explosives are scarce
  - Difficult to prepare small-scale samples
  - Failure length scales are often sub-millimeter

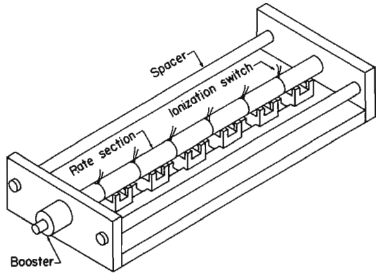
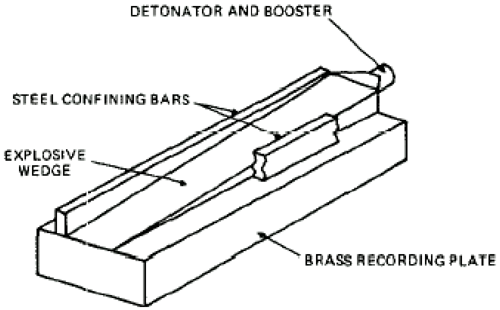
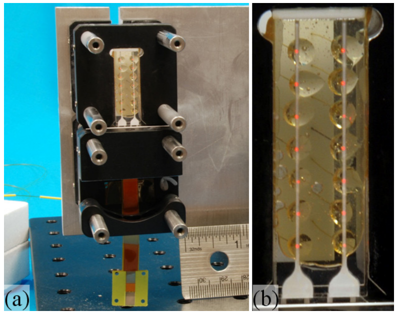


Fig. 1. Schematic of a typical rate-stick assembly.

Rate stick experiment.



Detonation failure experiment.



Critical thickness experiment.

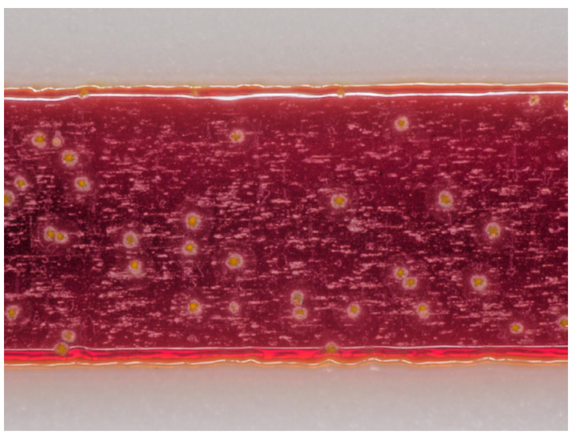
Campbell, A.W. and Engelke, R., "The Diameter Effect in High-Density Heterogeneous Explosives," 6th Symposium (International) on Detonation, Coronado, CA, August 24-27, 1976, pp. 642-652.

Gibbs, T.R. and Popolato, A., LASL Explosive Property Data, Detonation Failure Thickness, pp. 289-290. Berkeley, Los Angeles, London: University of California Press, 1980.

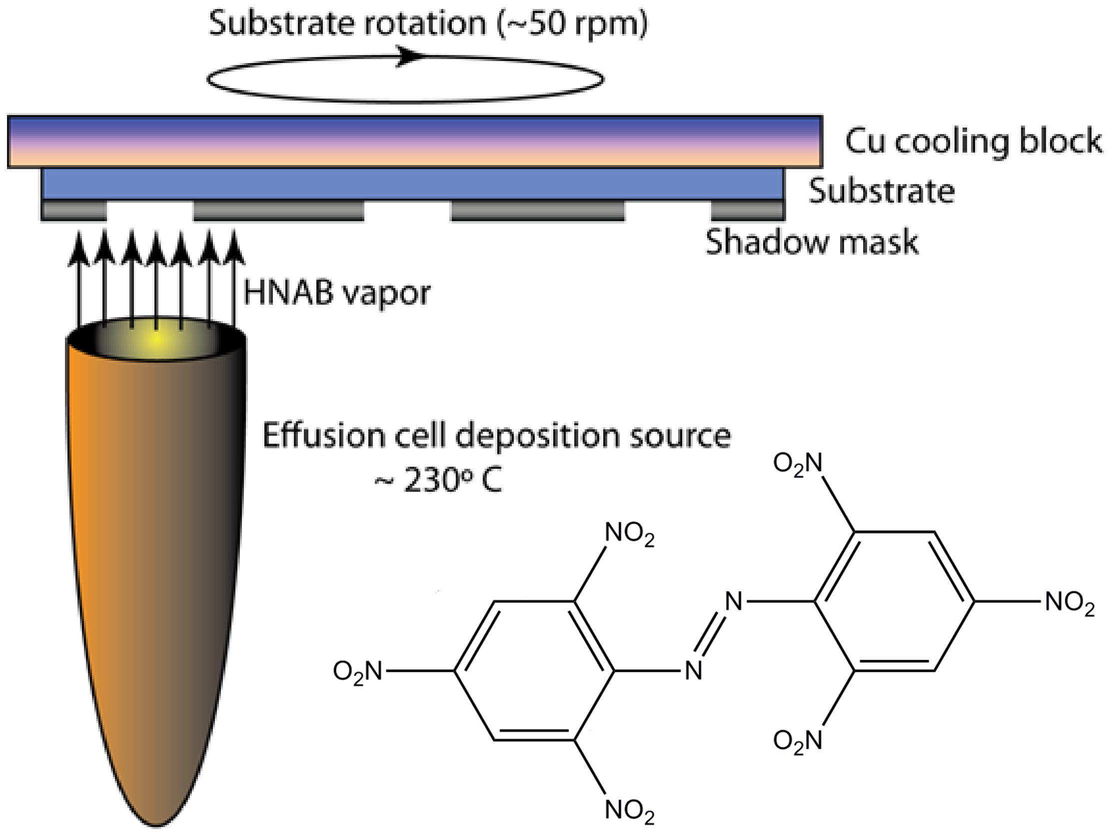
Tappan, A.S., Knepper, R., Wixom, R.R., Marquez, M.P., Miller, J.C., and Ball, J.P., "Critical Thickness Measurements in Vapor-Deposited Pentaerythritol Tetranitrate (PETN) Films," 14th International Detonation Symposium, Coeur d'Alene, ID, April 11-16, 2010.

HNAB physical vapor deposition

- Polycarbonate substrates
- Amorphous HNAB films
- 100% dense

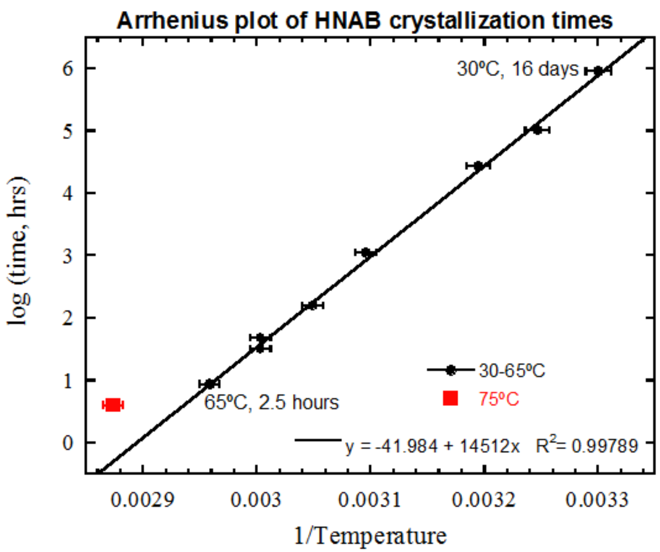


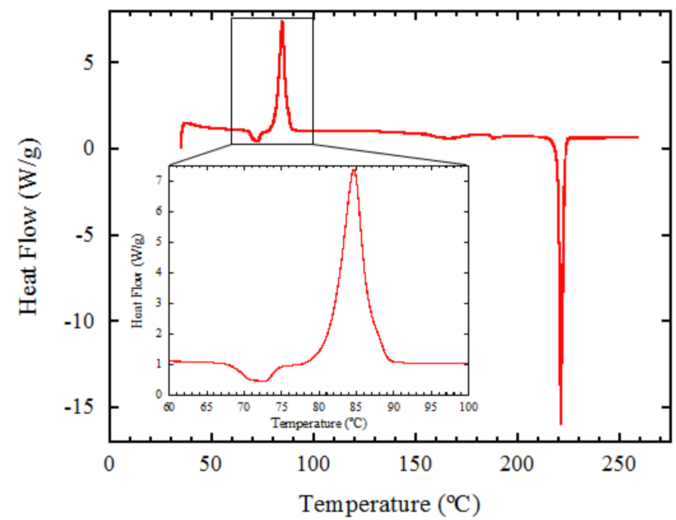
Optical micrograph of as-deposited HNAB.



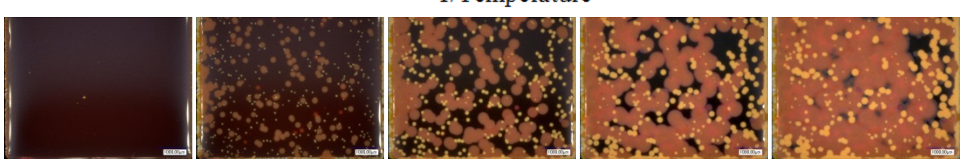
HNAB crystallization

- Amorphous HNAB films crystallize over time
- Pronounced difference in crystallization above glass transition temperature (~ 70–75° C)





DSC data from an amorphous HNAB film heated from 40–250°C at 5°C/min.

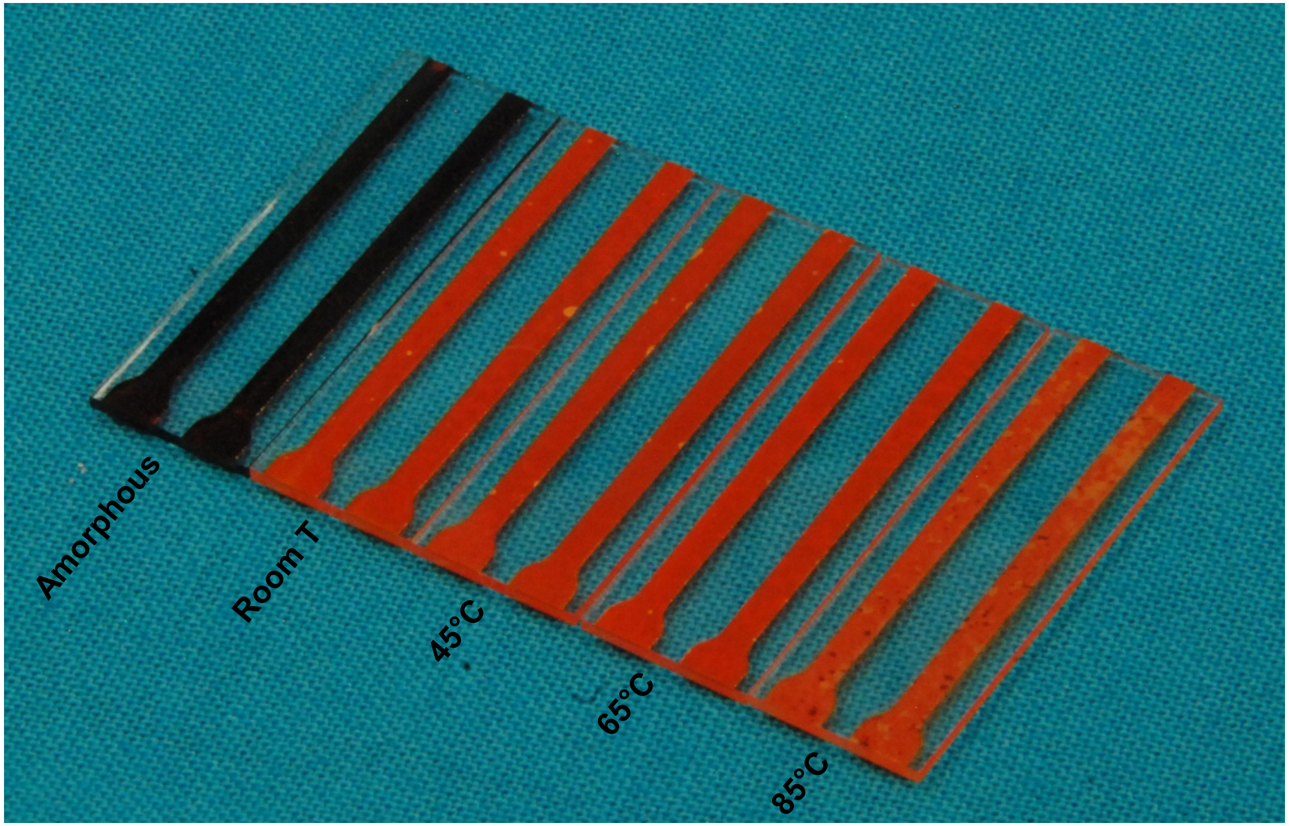


Time-lapse HNAB crystallization, 65°C, 24 min./image.

Knepper, R., Browning, K., Wixom, R.R., Tappan, A.S., Rodriguez, M.A., and Alam, M.K., "Microstructure Evolution during Crystallization of Vapor-Deposited Hexanitroazobenzene Films," *Propellants, Explosives, Pyrotechnics,* vol. 37, pp. 459 – 467, 2012.

HNAB samples

- Polycarbonate substrates
- Four crystallization conditions
  - Amorphous
  - Room temperature
  - 65° C
  - 85° C
- 45° C condition not tested

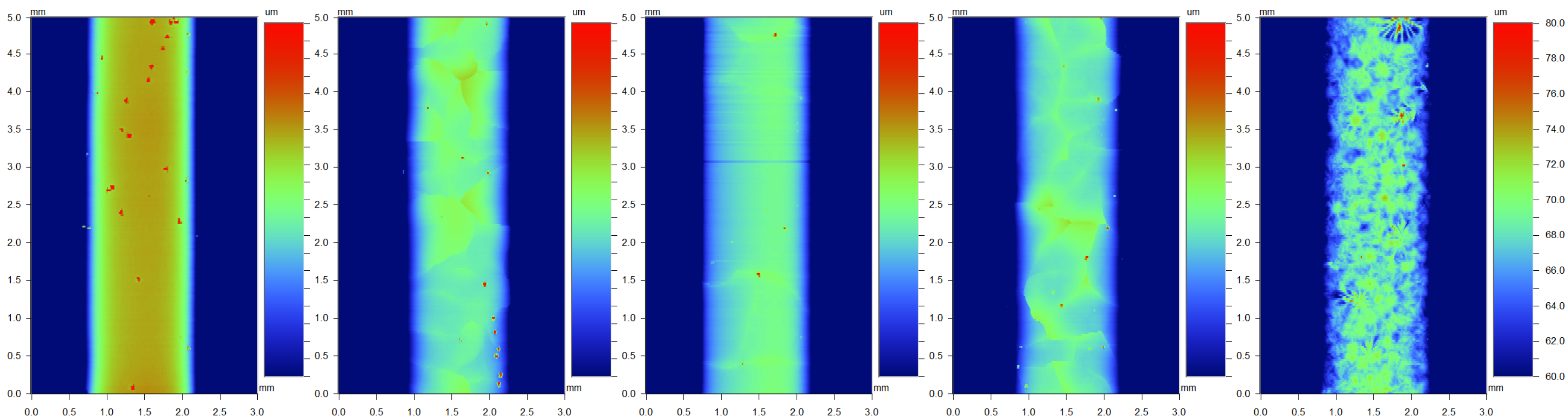


Photograph of five HNAB films on polycarbonate. Amorphous film on left and increasing crystallization temperature to right.

Sandia National Laboratories

Surface profiler measurements

- Root mean squared surface roughness (Rq)
  - Amorphous films are smooth with a low Rq
  - Films crystallized below glass transition temperature (~ 70–75° C) have crack networks and slightly higher Rq
  - Film crystallized above Tg higher Rq

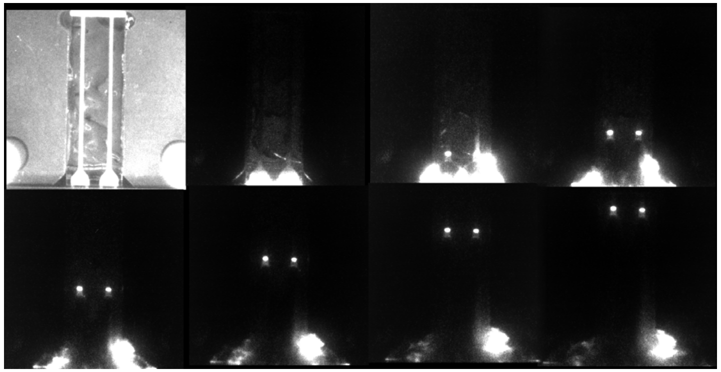


Amorphous	Room T	45°C	65°C	85°C
Rq = 0.17 µm	Rq = 0.34 µm	Rq = 0.18 µm	Rq = 0.37 µm	Rq = 0.86 µm
0.22%	0.48%	0.31%	0.54%	1.32%

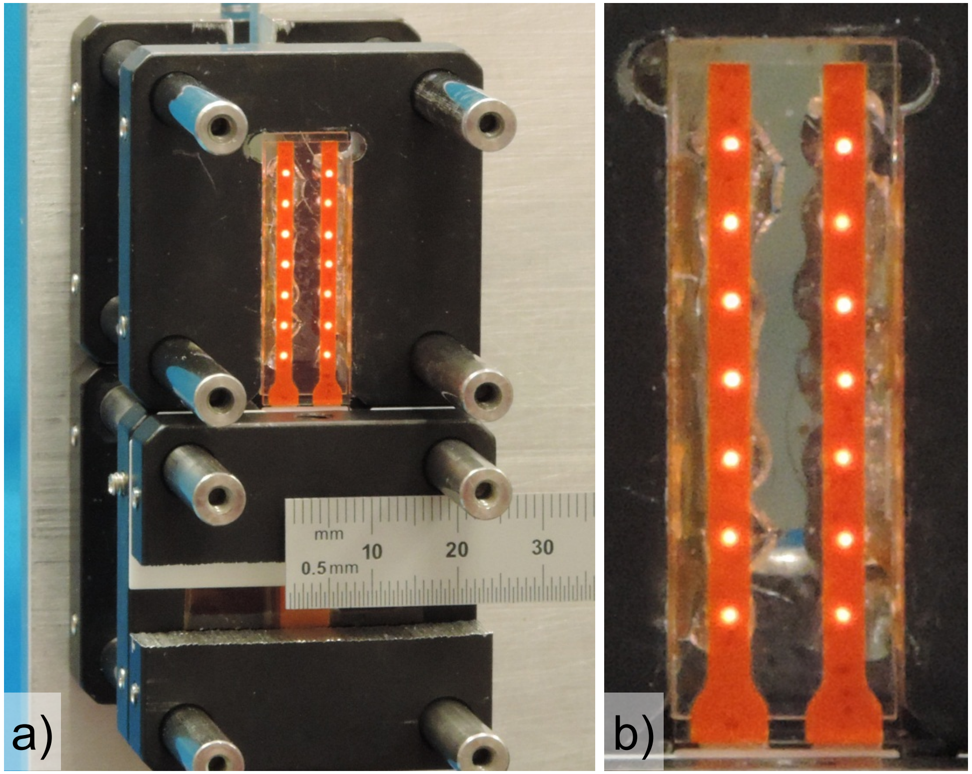
Critical detonation thickness experiment

Sandia National Laboratories

- Two experiments (HNAB lines) each shot
- Optical fibers deliver detonation light to photodetector



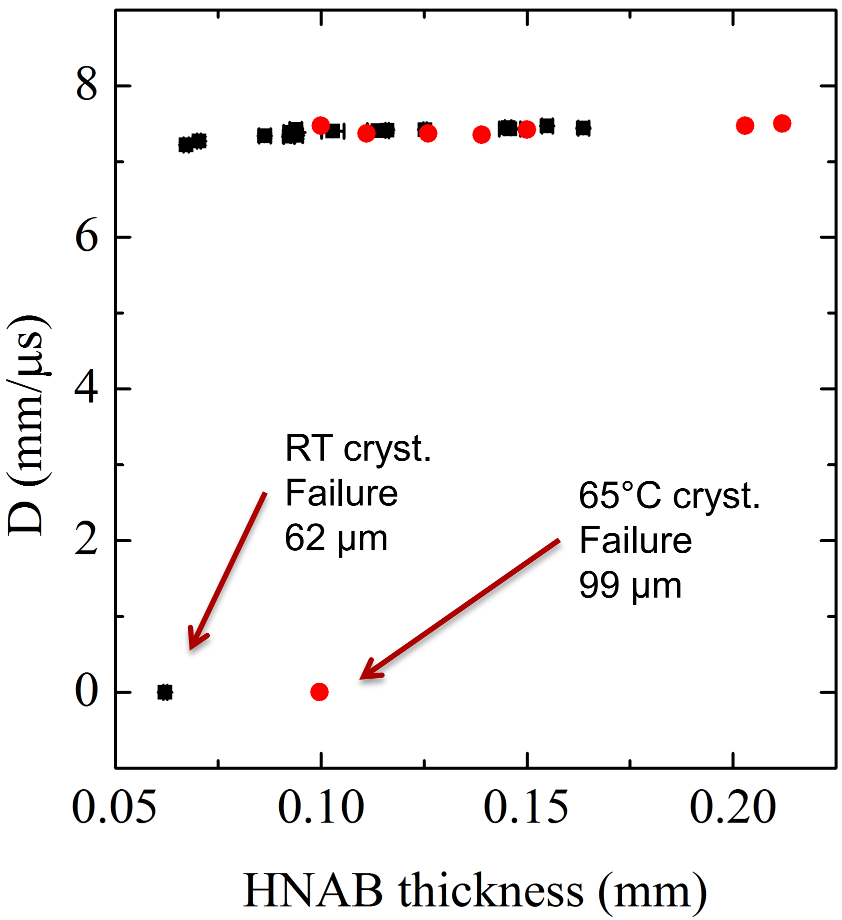
Framing camera images of critical thickness experiment (PETN). 1.67 Mfps (1/600 ns), 20 ns exposure time.



Photographs of critical detonation thickness experiment. Optical fibers illuminated to highlight position.

Critical detonation thickness for room temperature and 65° C crystallized HNAB

- Detonation velocity relatively consistent up to failure
- Room temperature crystallized HNAB fails at a thickness of about 62 µm
- 65° C crystallized HNAB fails at a thickness of about 99 µm



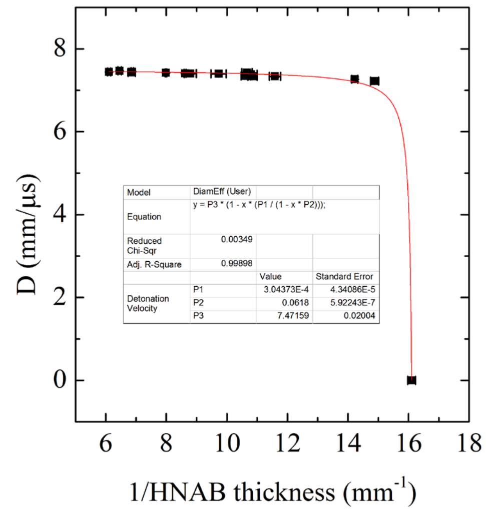
Detonation velocity versus thickness. One failure point is included.

Critical detonation thickness for room temperature and 65° C crystallized HNAB

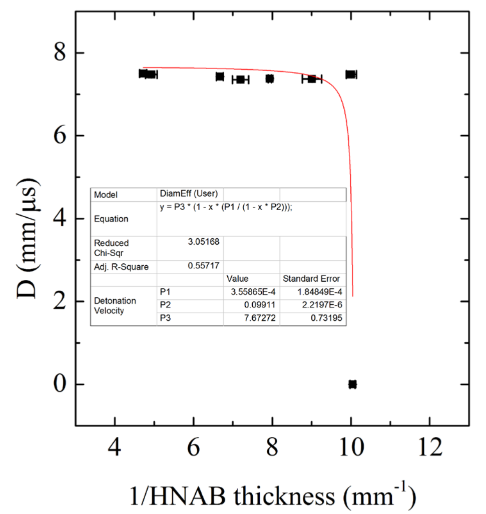
- Analysis of critical thickness data is performed in an analogous fashion to Campbell and Engelke (1976)

$$D(t) = D(\infty)\left[1 - A/(t - t_c)\right]$$

Condition	Detonation Velocity at Infinite Thickness, $D(\infty)$	Critical Thickness, t_c	Length Parameter, A
	mm/μs	mm	mm
Room T	7.47 ± 0.02	0.062 ± 0.000	0.0003 ± 0.00004
65° C	7.67 ± 0.73	0.099 ± 0.000	0.0004 ± 0.0002



Room T

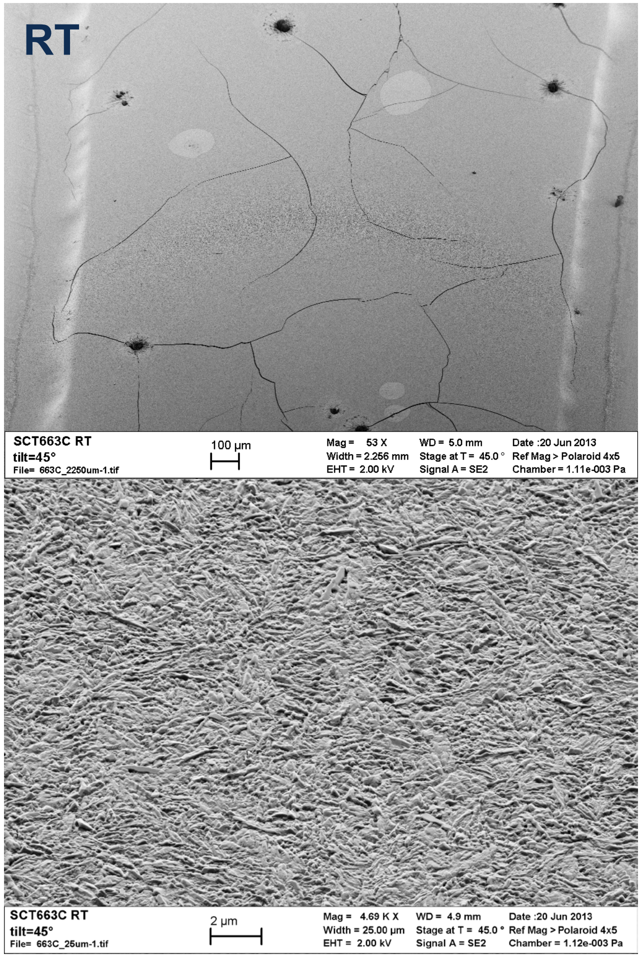


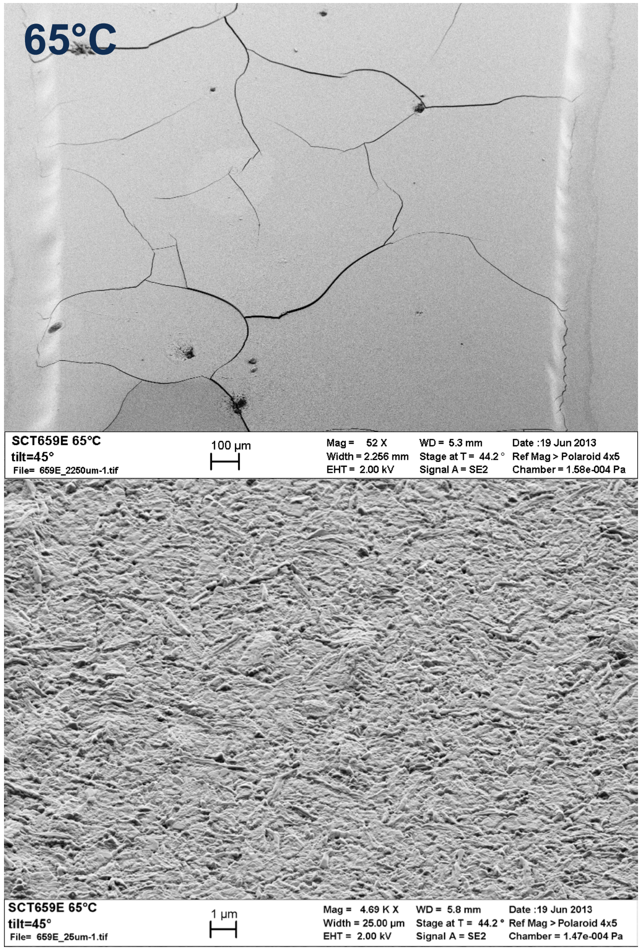
65°C

Campbell, A.W. and Engelke, R., "The Diameter Effect in High-Density Heterogeneous Explosives," 6th Symposium (International) on Detonation, Coronado, CA, August 24-27, 1976, pp. 642-652.

Top surface microscopy of room temperature and 65°C crystallized HNAB

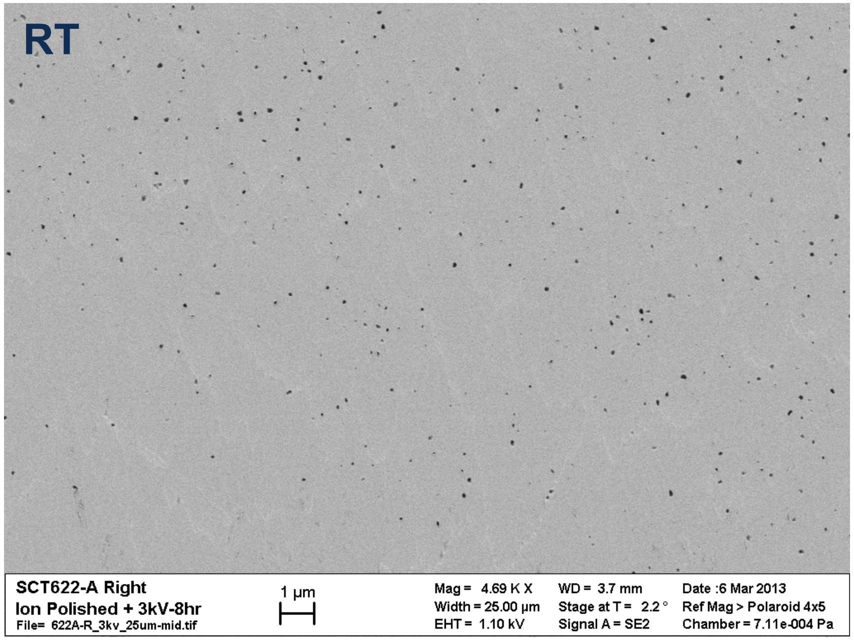
- Similar top surface appearance



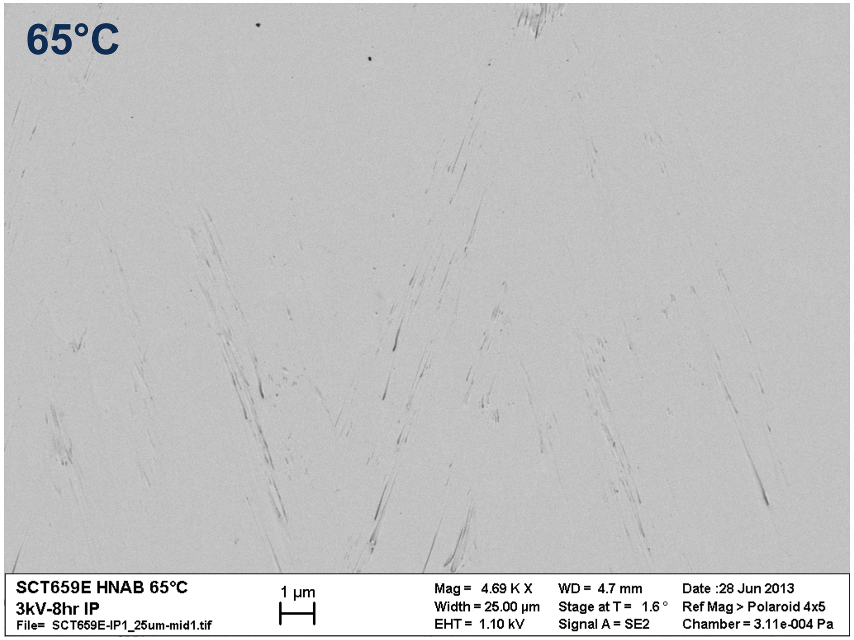


Ion-polished cross-sections of room temperature and 65° C crystallized HNAB

- Pores (~ 100 nm) are distributed throughout room temperature crystallized HNAB, but not in 65° C crystallized HNAB



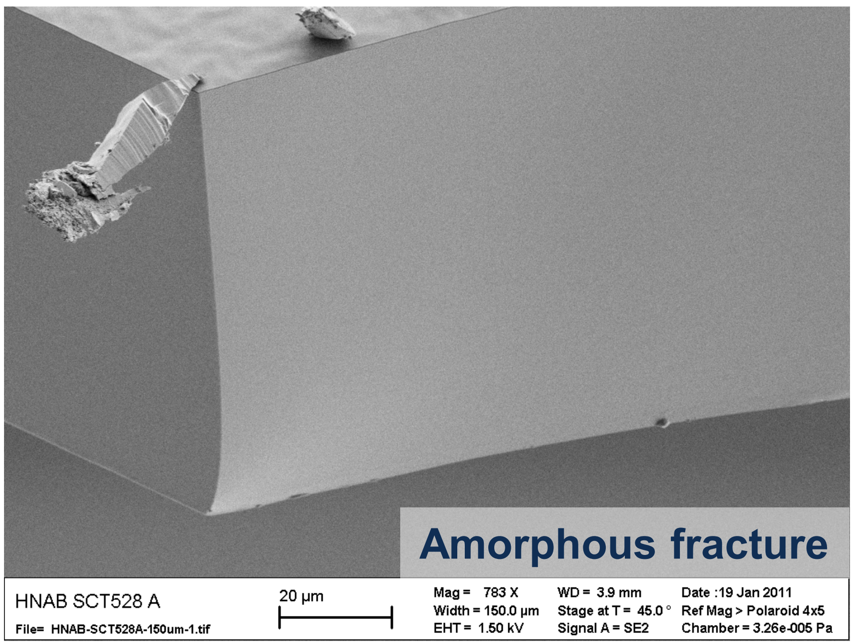
Scanning electron micrograph of ion polished room temperature crystallized HNAB. Image width 25.00 µm.

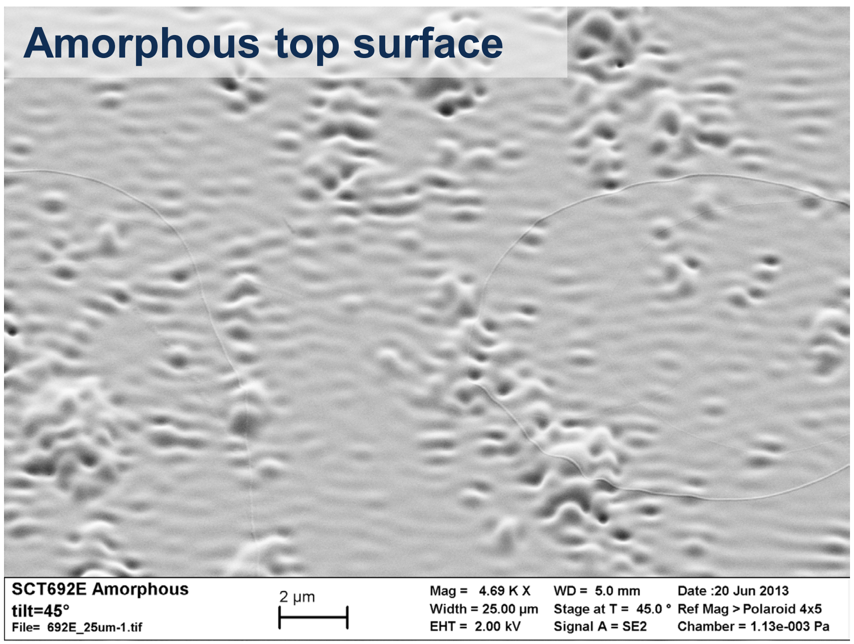


Scanning electron micrograph of ion polished 65°C crystallized HNAB. Image width 25.00 µm.

No detonation observed in amorphous HNAB or 85° C crystallized HNAB

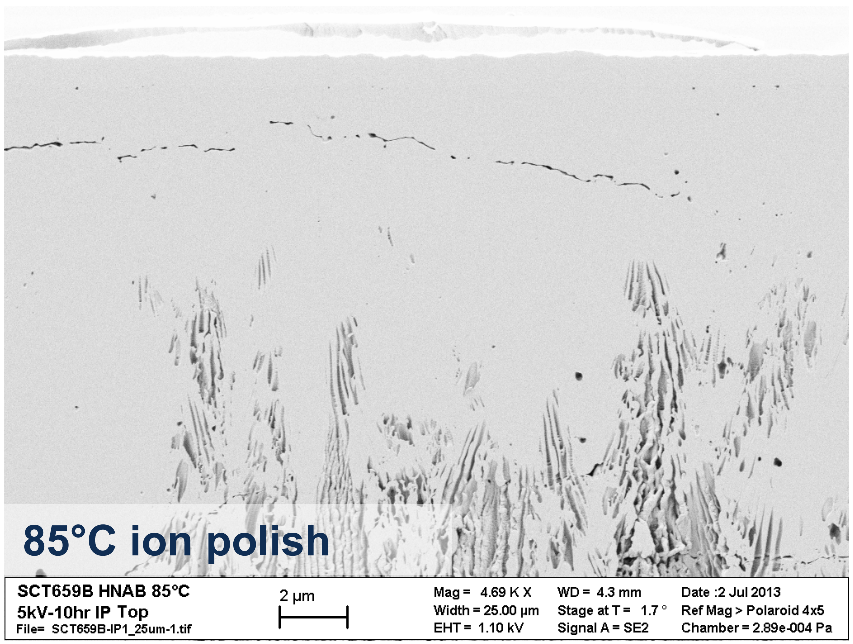
- In films up to ~ 200 µm thick
- No porosity in amorphous films

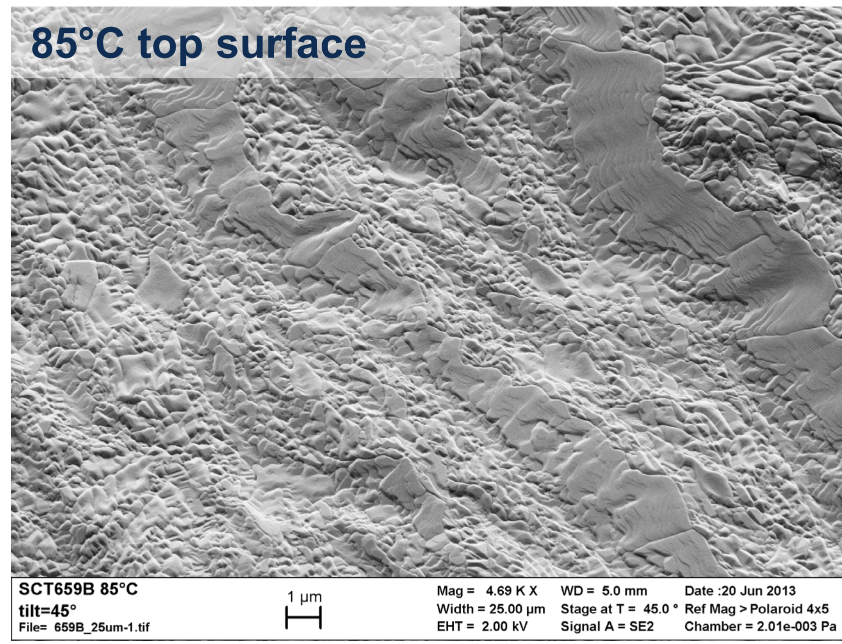




No detonation observed in amorphous HNAB or 85° C crystallized HNAB

- In films up to ~ 200 µm thick
- Crystallization at 85° C is above glass transition temperature





Conclusions

- Detonation in HNAB films depends on crystallization conditions
  - Similar detonation velocities for films crystallized at room temperature and 65° C
  - Different critical thickness for films crystallized at room temperature and 65° C
  - Amorphous films lack porosity and do not detonate up to ~ 200 µm thick
  - Films crystallized at 85° C (above Tg) do not detonate up to ~ 200 µm thick
- Acknowledgements

  - M. Barry Ritchey, Ryan R. Wixom
  - Jill C. Miller, Bob Patton
  - The Joint Department of Defense/Department of Energy Munitions Technology Development Program