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Micro-Sandwich Test for Equation of State Data of Vapor-Deposited Hexanitroazobenzene (HNAB)

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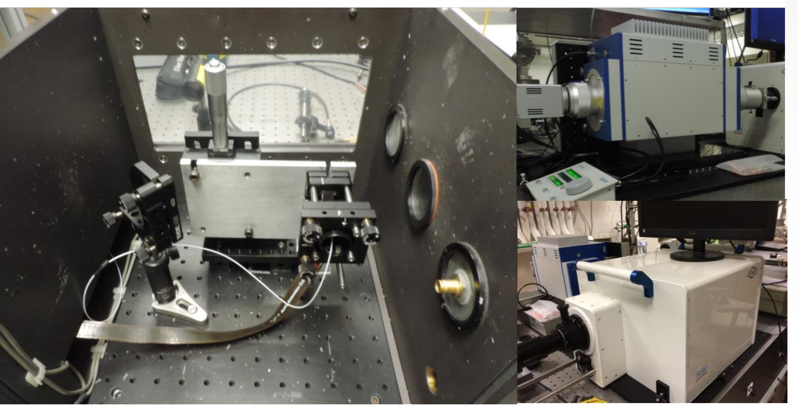
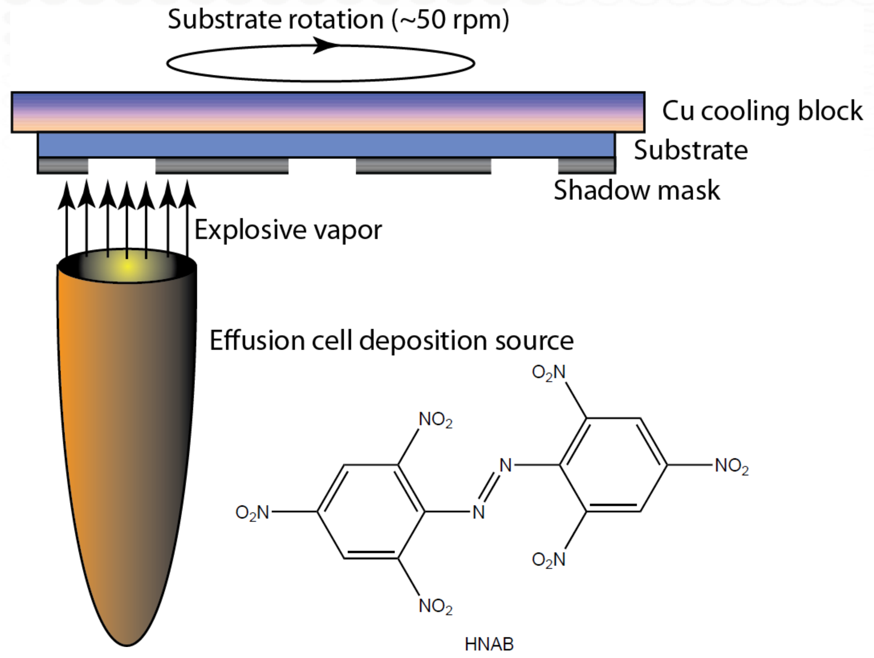


Exceptional service in the national interest

Sandwich Test on a Smaller Scale

- The goal is to provide reaction products expansion data for HNAB using a scaled down sandwich test.
- A sandwich test is the 2-dimensional version of the well-known 1-dimensional cylinder test.
  - ⇒ A cylinder test consists of a metal tube (usually copper) filled with explosive that is detonated at one end (1-D axisymmetric geometry).
  - ⇒ A sandwich test consists of slab geometry with a liner, generally metal, on either side of the explosive that is detonated at one end (2-D infinite slab geometry).
  - ⇒ The sandwich test is better suited for explosives that can be deposited by physical vapor deposition, whereas the cylinder test is better suited for explosives that are manipulated in the solid or liquid form
  - ⇒ Sandwich tests allow for thinner liner material, as it only needs to bend whereas in the cylinder test it needs to stretch and thin.
- Using a small thickness of HNAB (~100 µm per side), the micro-sandwich test is smaller than previous sandwich experiments
  - ⇒ Using tantalum for liner material in 50.8 µm, 76.2 µm, and 101.6 µm thicknesses
  - ⇒ Each substrate (or half-sandwich) was cut using a LPKF ProtoLaser U3 (355 nm) laser cutting tool into 10 mm × 30 mm and annealed.
  - ⇒ HNAB was deposited onto these substrates with a width of 6 mm, which is 30 times the assembled sandwich thickness

Physical Vapor Deposition Of Explosives



Schematic of the deposition system used to fabricate explosive films

- Deposition conducted in a vacuum chamber evacuated to ~ 10^{-6} Torr
- Fast deposition rate (~ 200 µm/hr) for HNAB
- Shadow masks used to define deposition geometry
- MP = 221ºC
- Chemically stable as melt to ~ 300ºC
- ρ ~ 1.744 g/cm^3 and ~99.5% dense after crystallization
- Small critical thickness for detonation (< 100 µm)

Crystallization and Adhesion Layers

- HNAB forms a dense (non-porous) amorphous structure with a very low surface roughness (~ 20 nm), independent of film thickness
- HNAB films will crystallize over time to a structure with very little porosity, a sub-micron grain size, and smooth surface (~ 50 nm roughness). This microstructure is reproducible and leads to films that can detonate at very small thicknesses (less than 100 µm) with a very consistent detonation velocity
  - ⇒ The films will crystallize into a mixture of two different polymorphs, the orange HNAB-II structure and a yellowish structure which has yet to be identified
  - ⇒ The two crystal structures appear to have significantly different detonation properties – the unknown structure will not detonate at thicknesses where HNAB-II readily supports detonation
  - ⇒ Both substrate material and ambient conditions (temperature and humidity) have been observed to have a significant impact on both the rate of crystallization and in determining which polymorph forms
- Deposition of HNAB (~100 µm) directly onto tantalum proved ineffective. Other materials were explored as adhesion promoters, including chromium (~50 nm) and Parylene C (~1-2 µm). All of the films were crystallized in an oven at 35°C.

Image	Base Layer	Adhesion Layer	Explosive Deposition	Capping Layer
a	Tantalum	Chromium	HNAB amorphous	
b	Tantalum	Chromium	HNAB amorphous	Parylene C
c	Tantalum	Parylene C	HNAB amorphous	
d	Tantalum		HNAB amorphous	Parylene C
e	Tantalum	Parylene C	HNAB amorphous	Parylene C

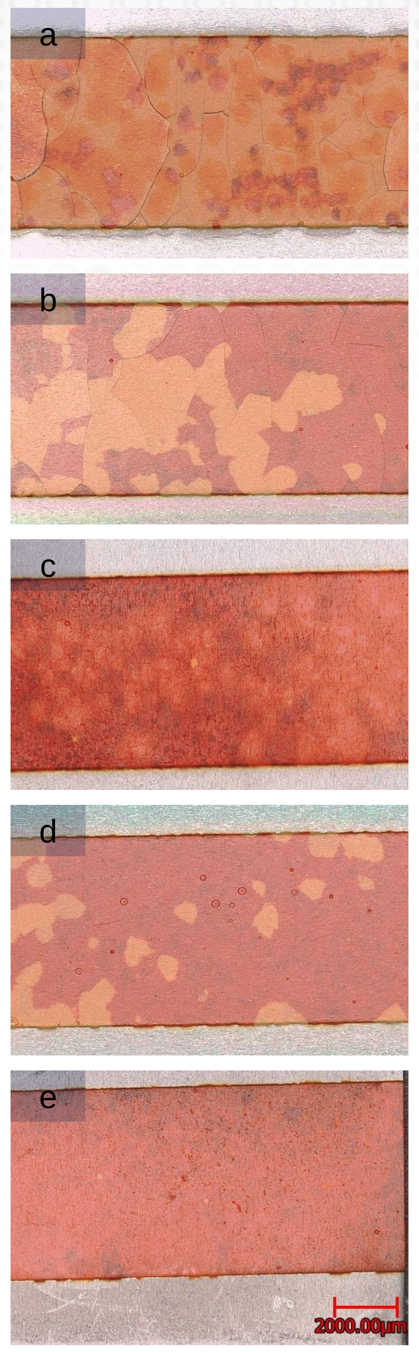


Table describes adhesion layers and correlates them to plan-view images of HNAB crystallized at 35° C (all images are to the same scale).

Sandwich Fixture

- The experiment takes place in a chamber rated for small-scale explosives testing.
  - ⇒ The internal volume of the chamber is ~0.0283 m^3 (1 ft^3), which must contain the entire micro-sandwich fixture system and allow for clear viewing of the micro-sandwich by the measurement equipment.
  - ⇒ A fixture was developed for testing allowing for the side of the sandwich to be viewed by the framing and streak cameras as well as allowing for photonic Doppler velocimetry (PDV) probes to measure the face of the sandwich

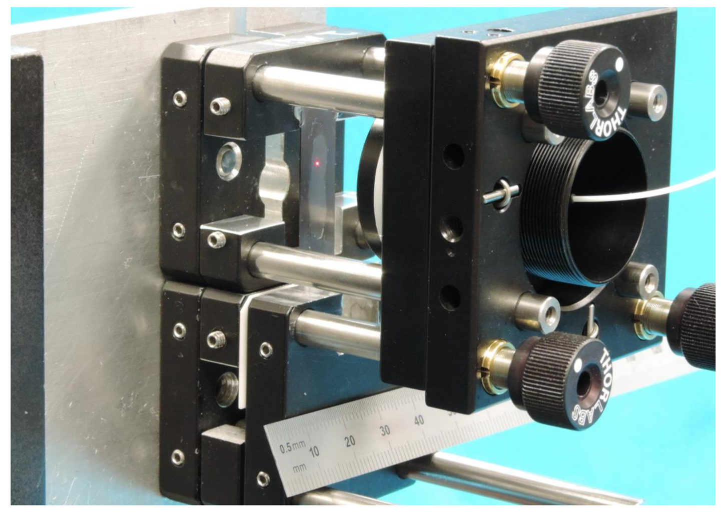
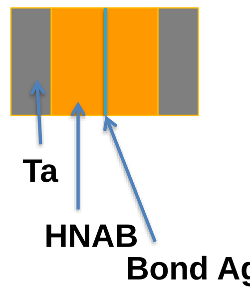


Image of the sandwich assembly fixture with the PDV probe using a red alignment laser to show where the PDV probe laser will be located during the experiment.

Cartoon of sandwich cross-section.



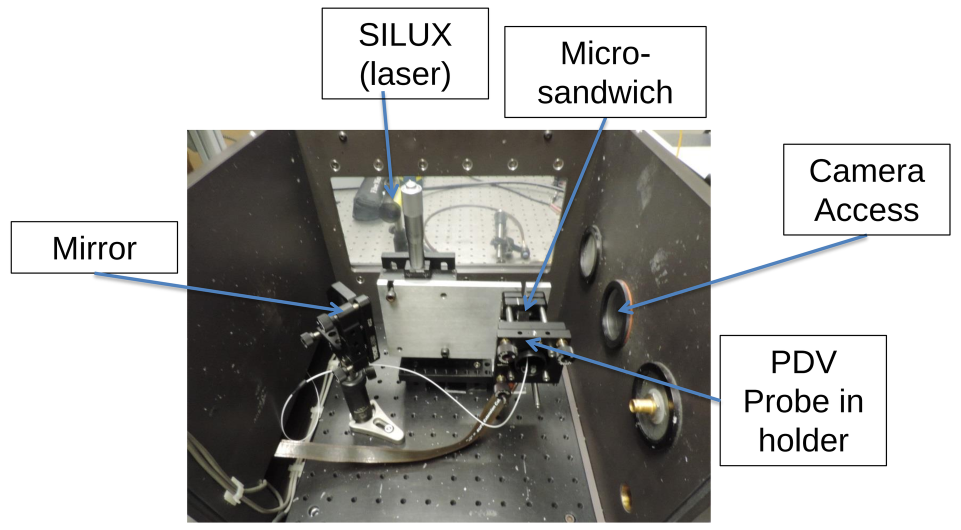
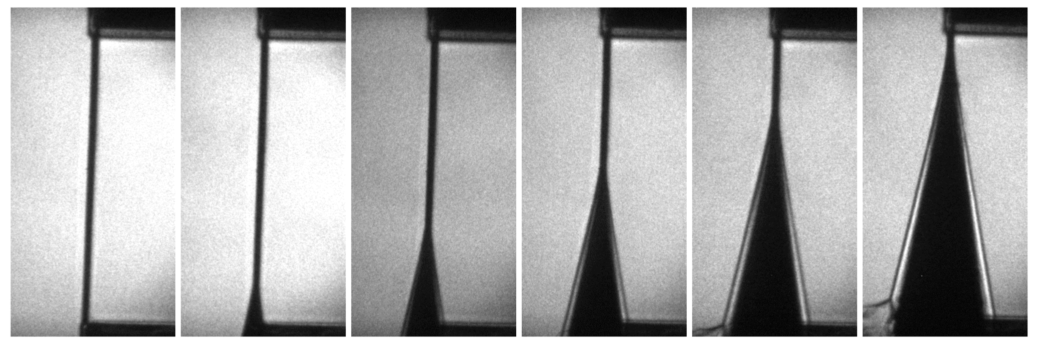
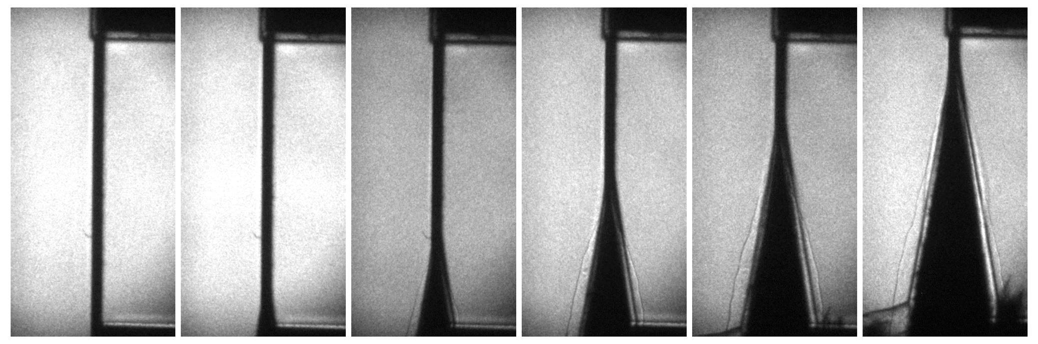


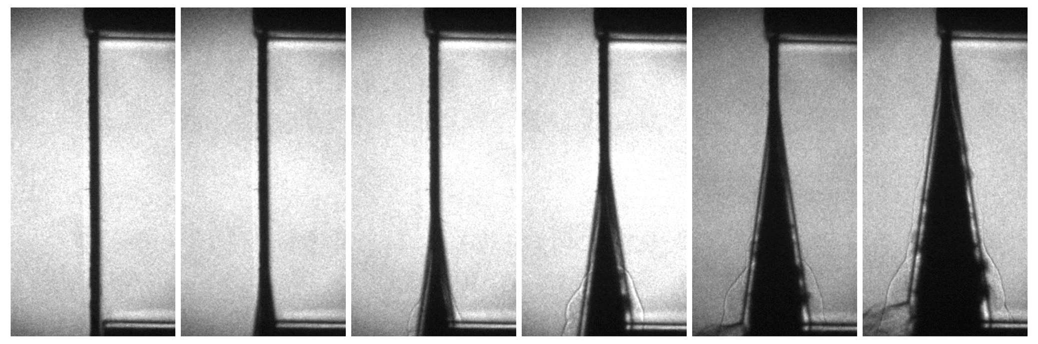
Image of the experimental setup inside the explosive chamber



50.8 µm tantalum experiment on HNAB micro-sandwich test. 5 ns exposure, 2.4 MHz (1/417 ns).



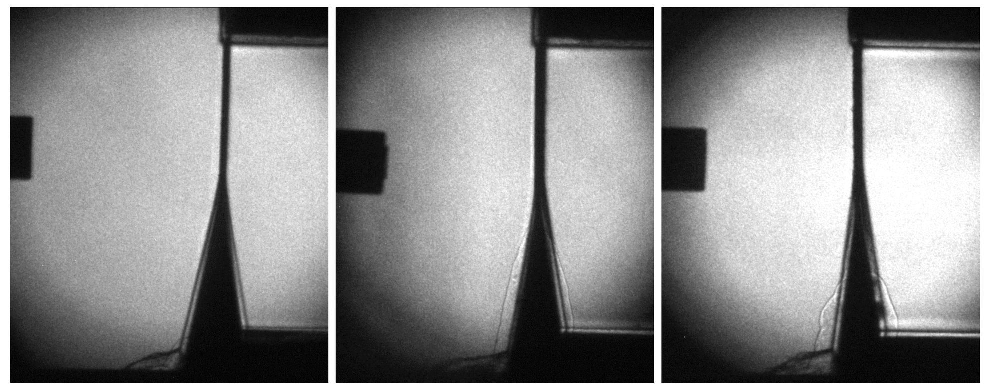
76.2µm tantalum experiment on HNAB micro-sandwich test. 5 ns exposure, 2.4 MHz (1/417 ns).



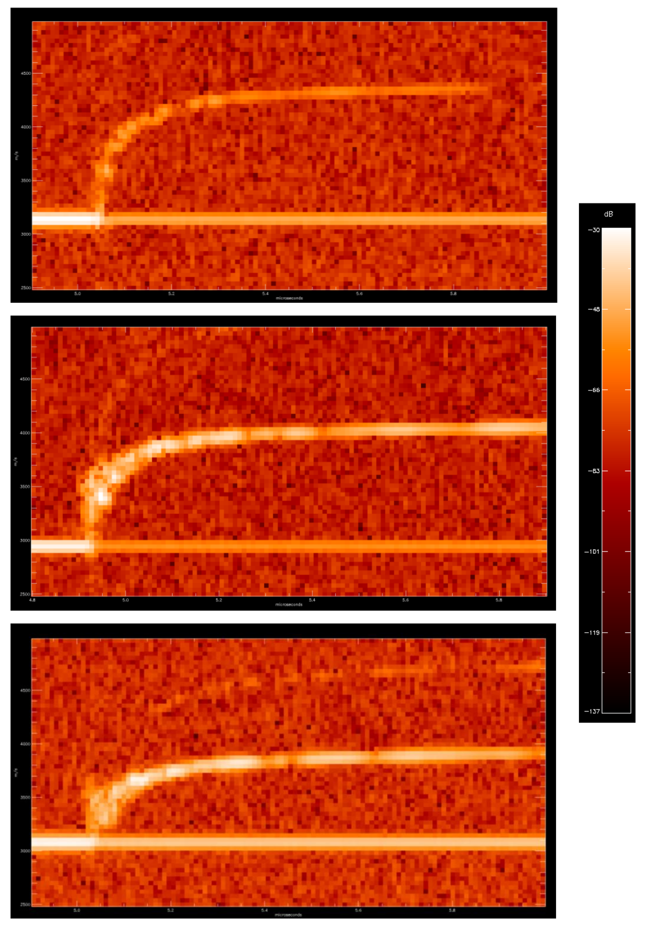
101.6 µm tantalum experiment on HNAB micro-sandwich test. 5 ns exposure, 2.4 MHz (1/417 ns).

Detonation Experiments

- The experimental data showed slight variation in liner angle than increased as liner thickness decreased.
  - ⇒ The 50.8 µm thick experiment had an angle of 11.1° ± 0.1°
  - ⇒ The 76.2 µm thick experiment had an angle of 9.1° ± 0.1°
  - ⇒ The 101.6 µm thick experiment had an angle of 7.3° ± 0.1°
- The Photonic Doppler Velocimetry (PDV) data from the experiment found that the velocity of the liner is increased as the liner thickness decreased among the three different thicknesses.
  - ⇒ The 50.8 µm thick experiment had a velocity of 1300 m/s ± 20 m/s
  - ⇒ The 76.2 µm thick experiment had a velocity of 1150 m/s ± 50 m/s
  - ⇒ The 101.6 µm thick experiment had a velocity of 900 m/s ± 5 m/s



50.8, 76.2, and 101.6 µm (left to right respectively) tantalum experiment on HNAB micro-sandwich test. 5 ns exposure, 2.4 MHz (1/417 ns).



Spectrograms of the PDV Data for 50.8, 76.2, and 101.6 µm experiments (top to bottom respectively).

Conclusions

- Vapor-deposited HNAB is a useful model material for studying detonation behavior at small scales due to its uniform microstructure and low surface roughness.
- Different thicknesses of tantalum yielded liner angles and velocities that increase with decreasing liner thickness.
- Future work will focus on modeling reaction product expansion data to derive an equation of state

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