Quantification of thermal and mechanical damage in PBX's

TNO | Knowledge for business

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Outline

- Introduction
- Quantification of Damage
- Inducing damage
  - Mechanical damage and sensitivity
    - Compression
    - Gas gun
    - Shock initiation by flyer impact
  - Thermal damage and sensitivity
    - GDM
    - Shock initiation by flyer impact
    - Shock initiation by bullet/fragment impact
- Conclusions
- Acknowledgements

Introduction

- Development of IM-related (laboratory scale) tests to understand mechanism of the response of an explosive
- Cook-off, Bullet/Fragment Impact and Shaped charges impact, etc
- Friability test, BIC etc, flyer impact
- IM / Sensitivity Research at TNO Defense Security and Safety
  - Understand initiation of explosives
  - Determine the parameters that have a major influence on the sensitivity
  - To understand the mechanisms that leads to a particular response

Introduction 2

- Development of theoretical as well as computer models for these processes
- For all type of responses, material properties, mechanical properties and damage play a major role in the process that lead to:
- First the initiation of the explosive material and
- secondly response eg. detonation (type I and II) or a less violent reactions (III, IV or V)
- SDT, DDT and XDT <----> less violent reactions

Overview Damage research

- Induce Damage
  - Thermal
  - Mechanical

- Quantify Damage
  - Closed bomb test
  - dP/dt and Burning area
  - Area under loads in subsequent cycles

- Optical / Microscopical analysis (SEM, microscopy)
- Determine mechanical properties (Tensile strength test or GDM**)**

- Laboratory testing
  - Shock Initiation (Flyer Impact)
  - Fragment Impact testing
  - Bam Friction and Fall hammer

- Find a relation between sensitivity and amount of damage

- Computer simulation

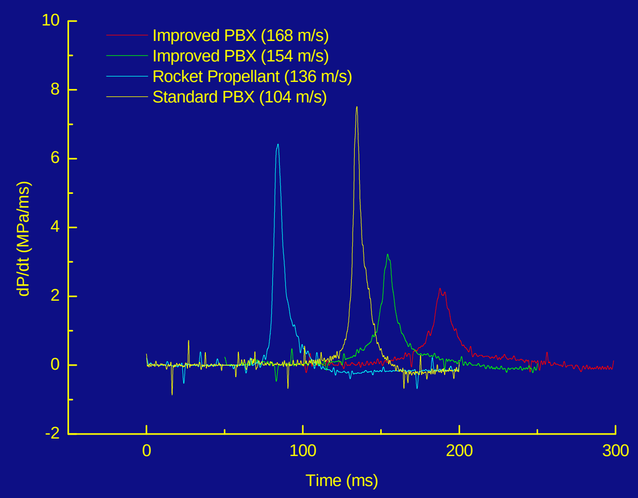
Quantification of Damage (1)

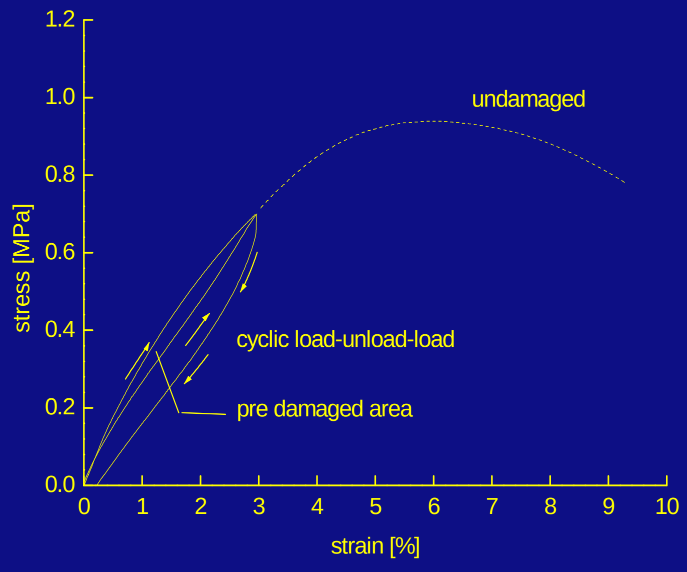
- Damage can be induced by thermal threat (cook-off), mechanical threat (bullet impact) or a combination of both (hot fragment impact)

- What is damage?
  - Induced porosity, change of binder properties, deformation of binder, debonding of binder from crystal, crystal cracks, phase change of crystal material (HMX β->δ transition), oxidation of binder etc……

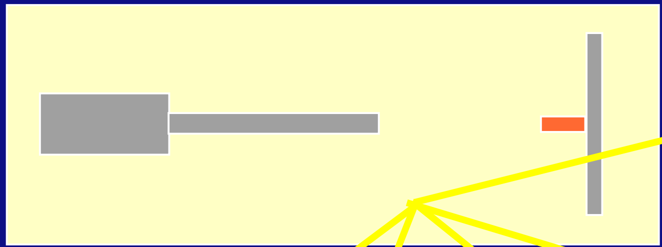
Quantification of Damage (2)

- Quantification of damage by means of macroscopic parameter:
  - Thermal damage: Several hours at elevated temperature: Closed Combustion Bomb
  - Mechanical damage: Load-Unload-Load cycle: Area under 1st and 2nd load cycle





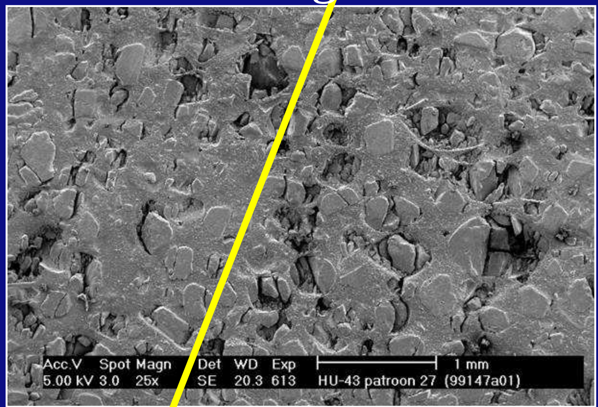
Damage research in the past

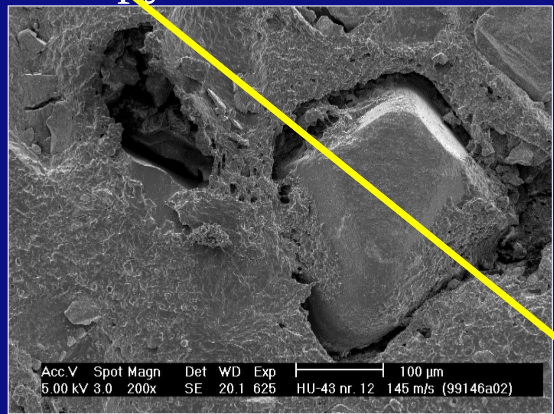


Mechanical Damage

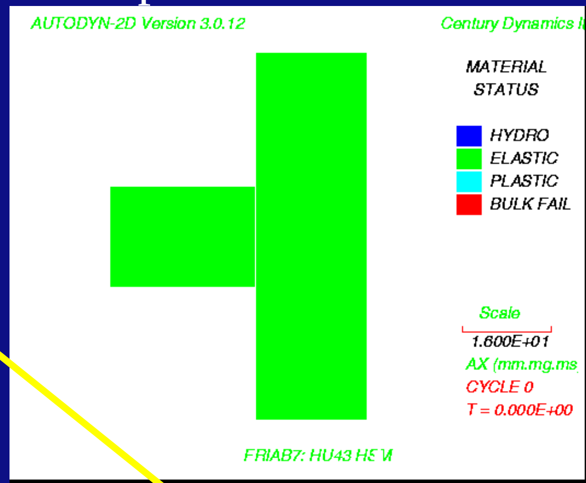
Visual observation

Scanning Electron Microscopy





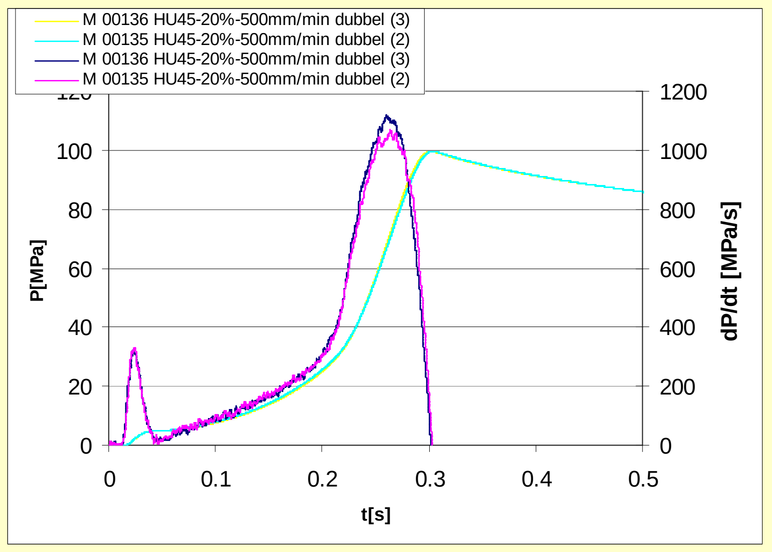
Computer simulation



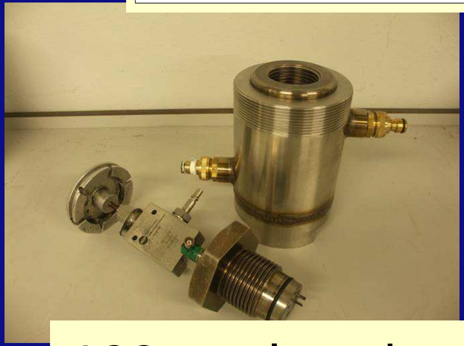
High-speed Camera

Shock Initiation

Burning area increase

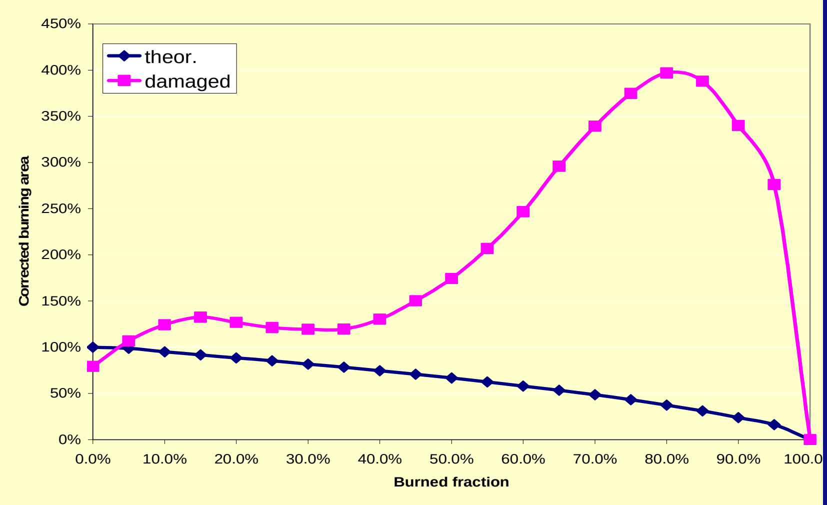


Reproducible results by tailored closed vessel



100 cc closed vessel bomb

Increased burning area as measure of damage



Performed tests mechanical damage

- HU44 (80% solid load, 20% binder + chain extender)
  - Compression testing: 10, 30 and 60% strain of 9 grams samples at 1, 50 and 500 mm/min and pristine material, also few samples with cycle
  - Gas gun damage (55-85 m/s)
  - CV testing→ dP/dt and vivacity and burning area
  - Flyer impact testing (shock sensitivity)

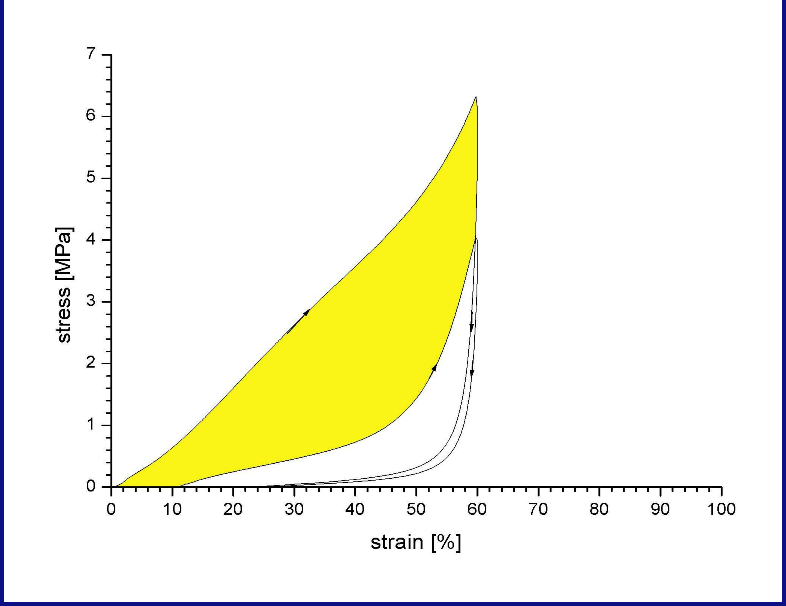
- HU45 (85% solid load, 15% binder)
  - Compression testing: 10 and 20% strain of 9 grams samples at 500 mm/min and pristine material, single and double cycle
  - CV testing→ dP/dt and vivacity and burning area

Performed tests thermal damage

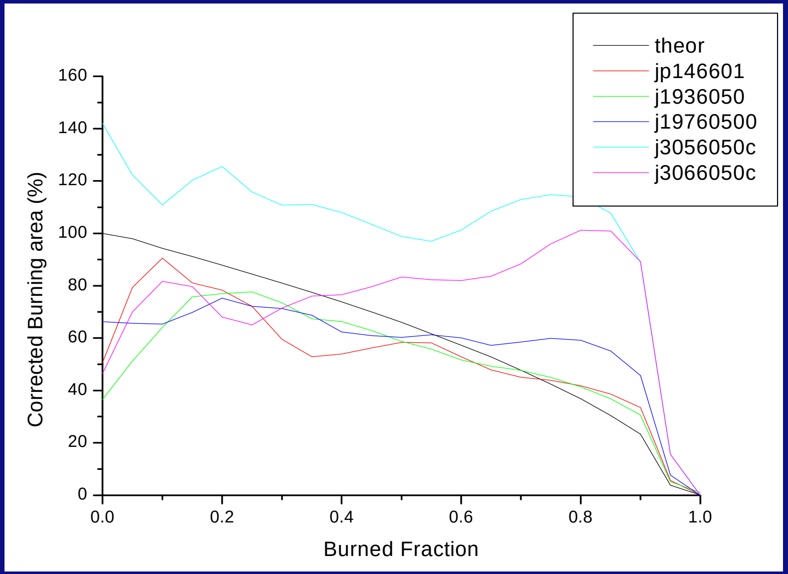
- Thermal damage with HU45 (85% sl, 15% binder), 165°C, 170℃, 175℃ for 5 hours and pristine material
  - CV testing→ dP/dt and vivacity and burning area
  - Flyer impact testing (shock sensitivity)
  - Gas dilatometry testing
  - Bullet/fragment impact testing (shock sensitivity)

Mechanical damage HU44

HU44, 60% strain, 50 mm/min

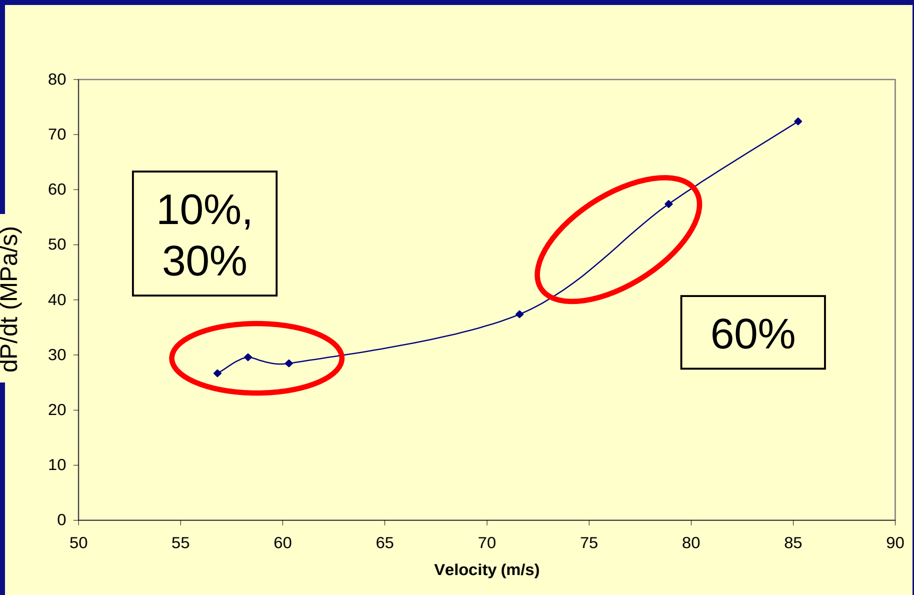


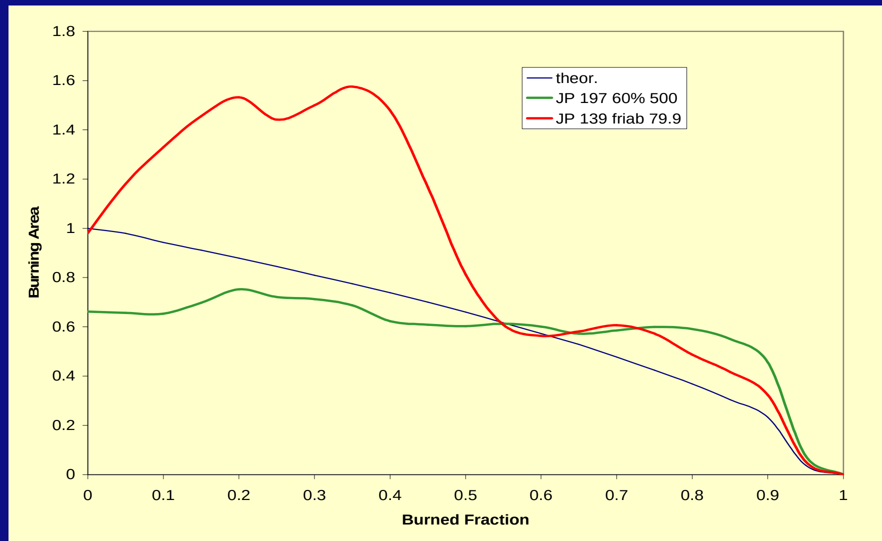
Energy between two cycles: 1.14 MJ/m3



Comparison Compression vs Friability

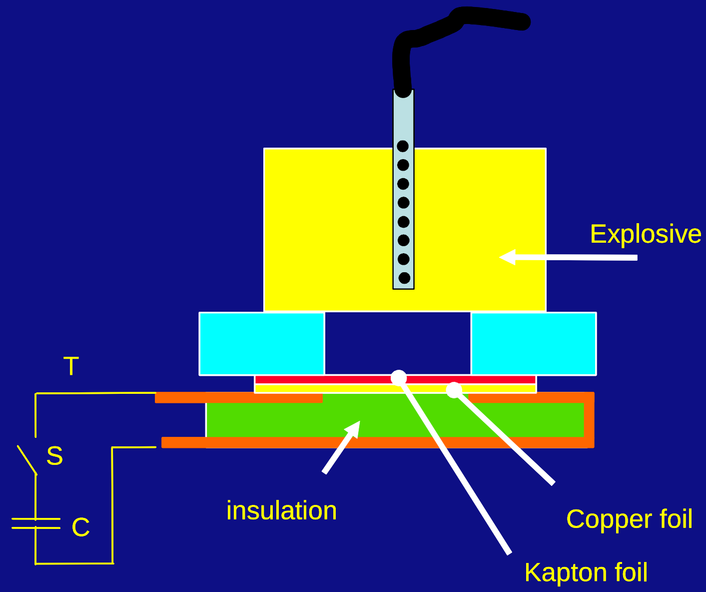
velocities ~ 56-85 m/s

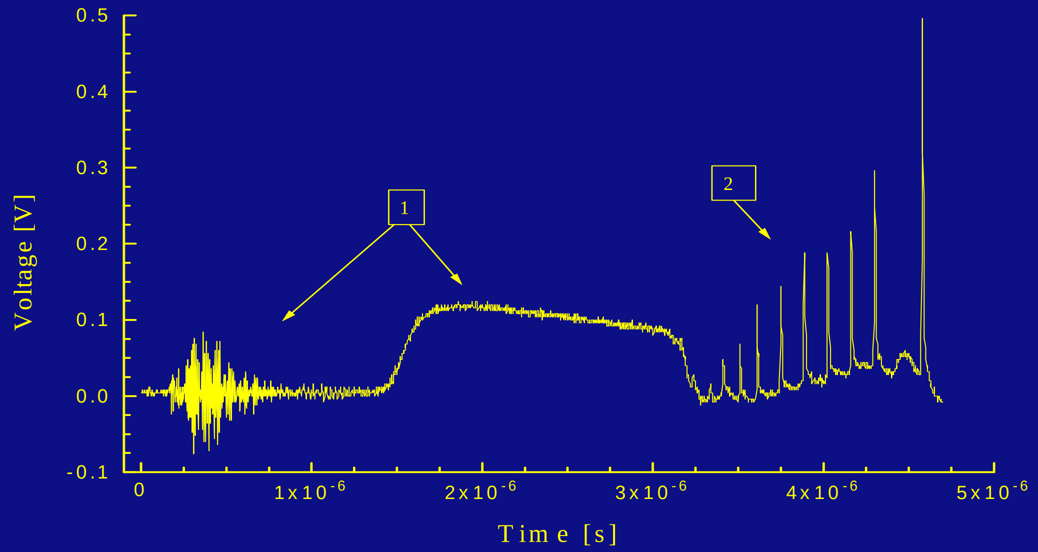


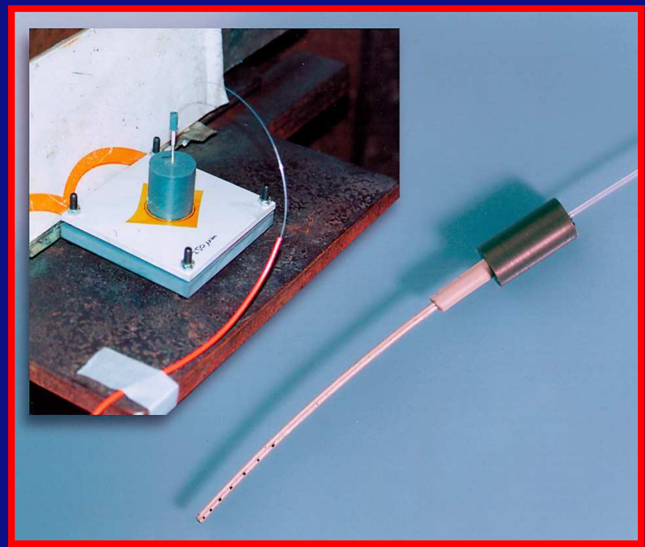


Fibre Optic Probe (FOP)

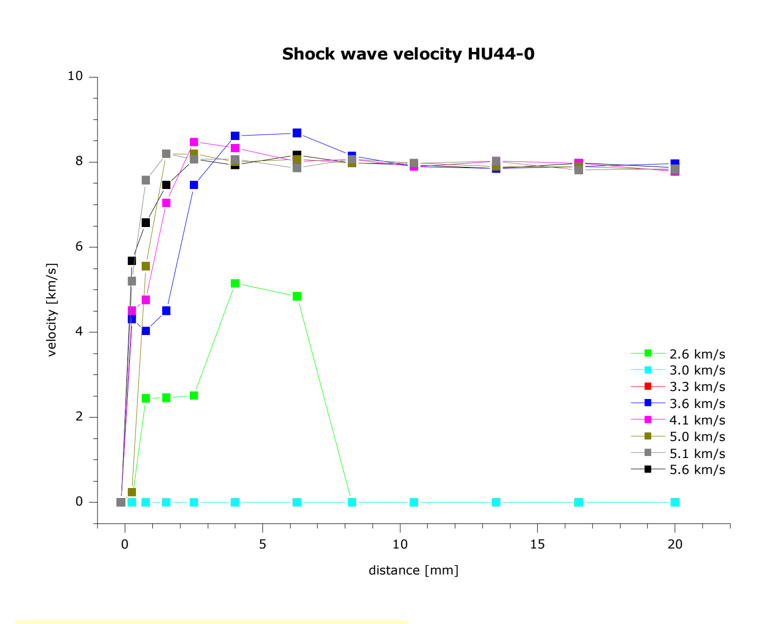
Material characterisation: shock initiation with 10-15mm Ø samples



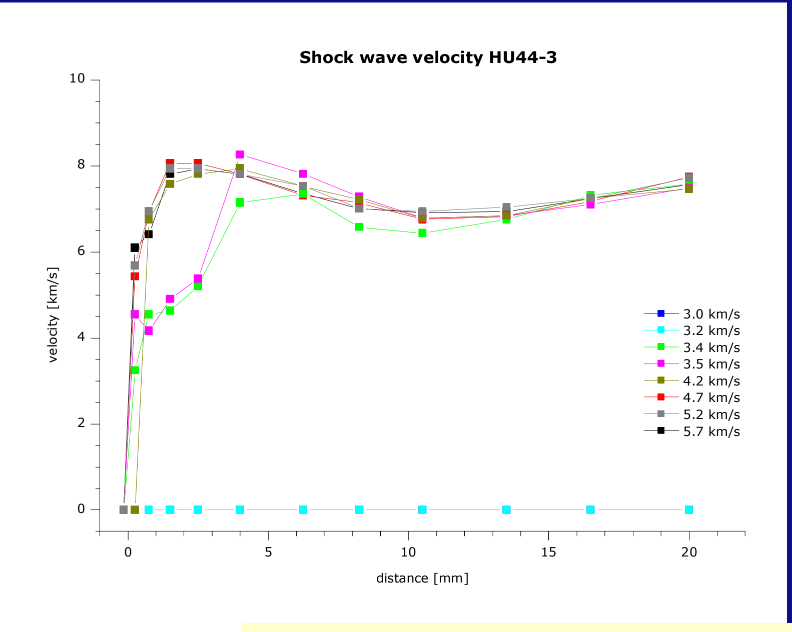




Shock sensitivity HU44



HU44 pristine

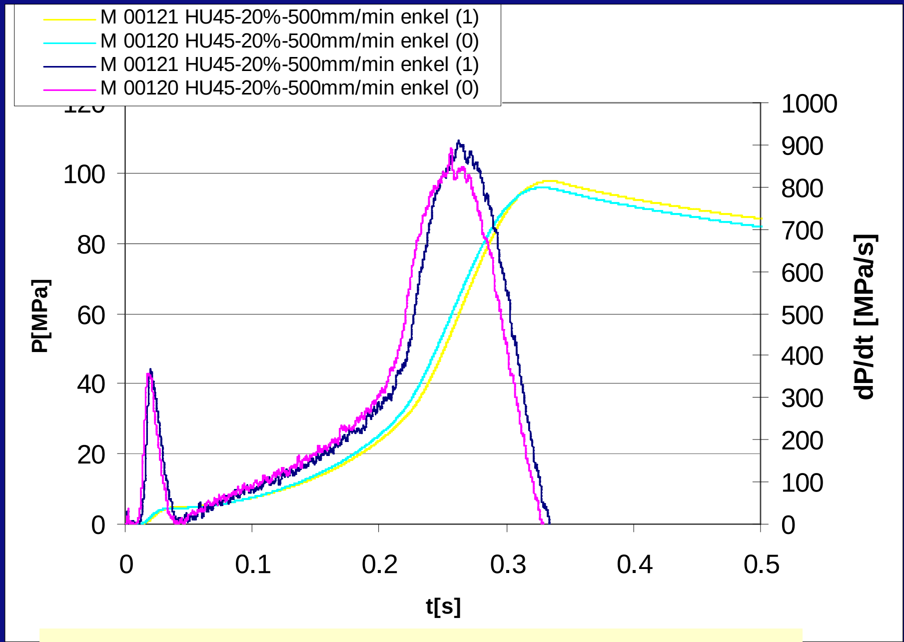


HU44, 60%, 500mm/min

Material	D (km/s)	V_F (km/s)
HU44 pristine	7.9	3.5 ± 0.2
HU44 10%, 50mm/min	7.9	3.2 ± 0.3
HU44 30%, 500mm/min	7.9	3.5 ± 0.2
HU44 60%, 50mm/min	7.1 - 7.7	3.6 ± 0.2
HU44 60%, 500mm/min	6.8 – 7.6	3.3 ± 0.2

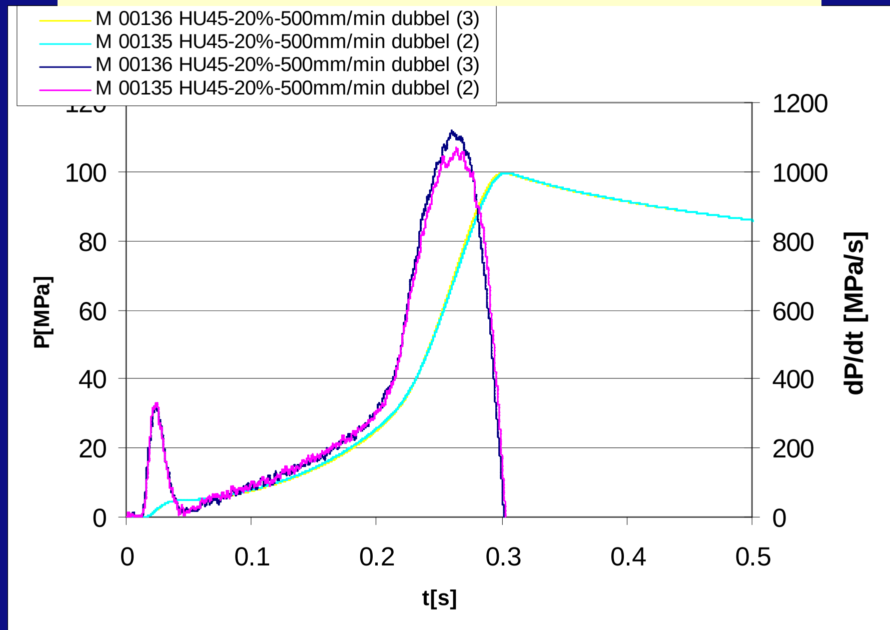
Mechanical damage HU45

Mechanically damaged closed vessel

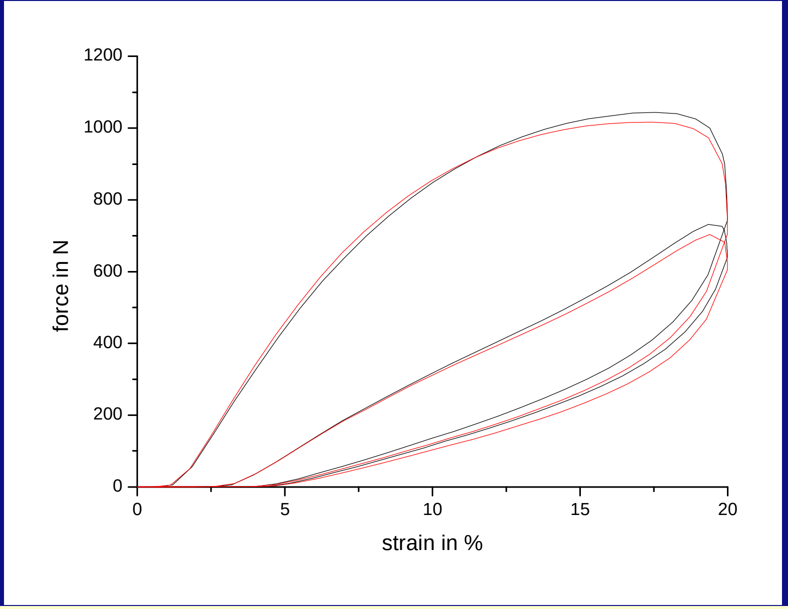


Single compression cycle, 20% strain, 500 mm/min

Double compression cycle, 20% strain, 500 mm/min

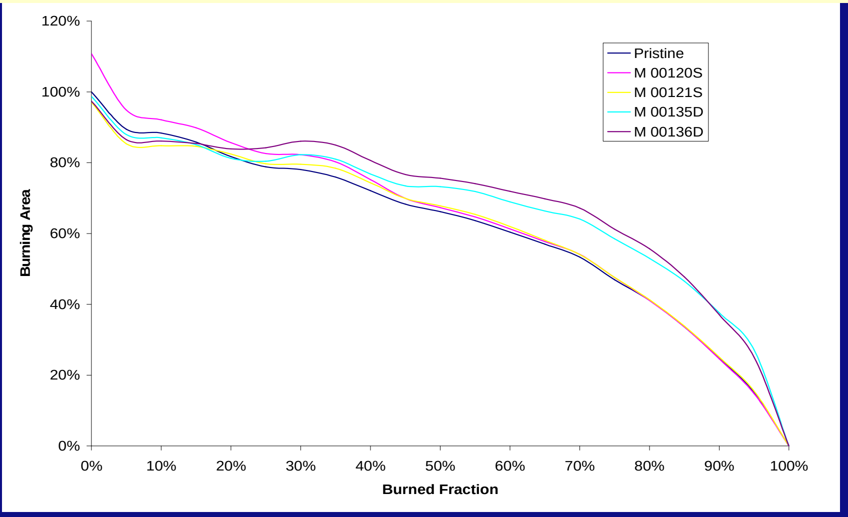


Mechanical damage HU45



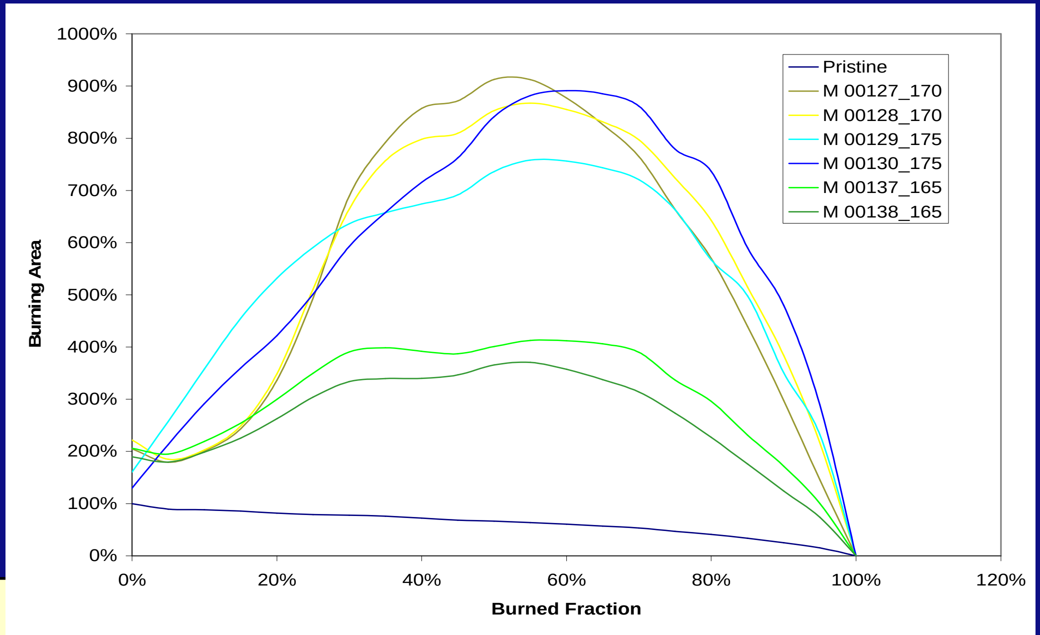
Force strain curve HU45 double cycle at 20% strain at 500 mm/min

burning areas of the pristine, single and double cycle damaged HU45 at 20% compression



Thermal damage HU45

Thermally damaged HU45

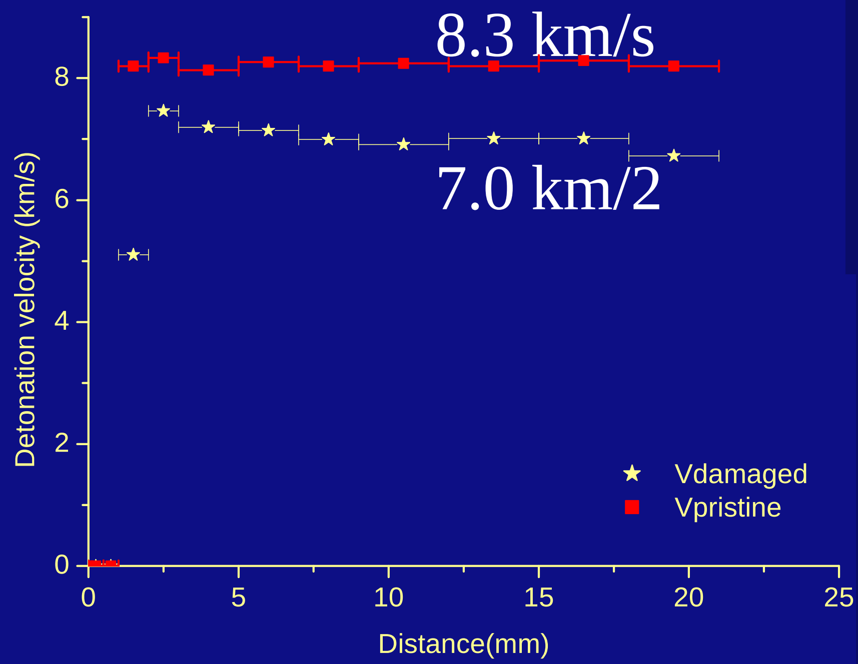


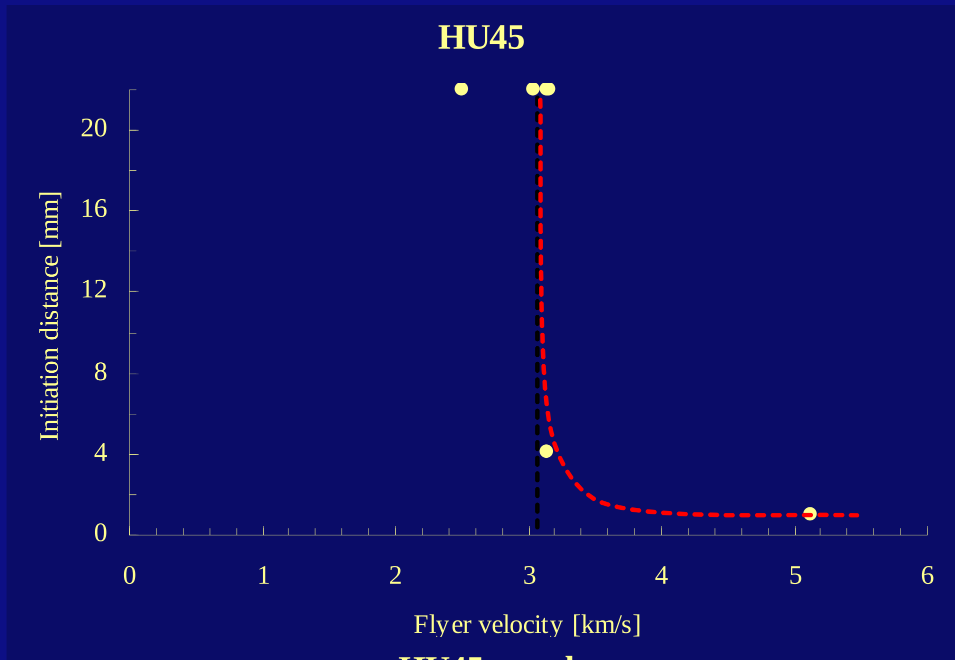
Material	D (km/s)	V_F (km/s)
HU45 0°C	8.3	3.1
HU45 165°C	7.8	2.6
HU45 170°C	6.8	2.7
HU45 175°C	7.0	1.9

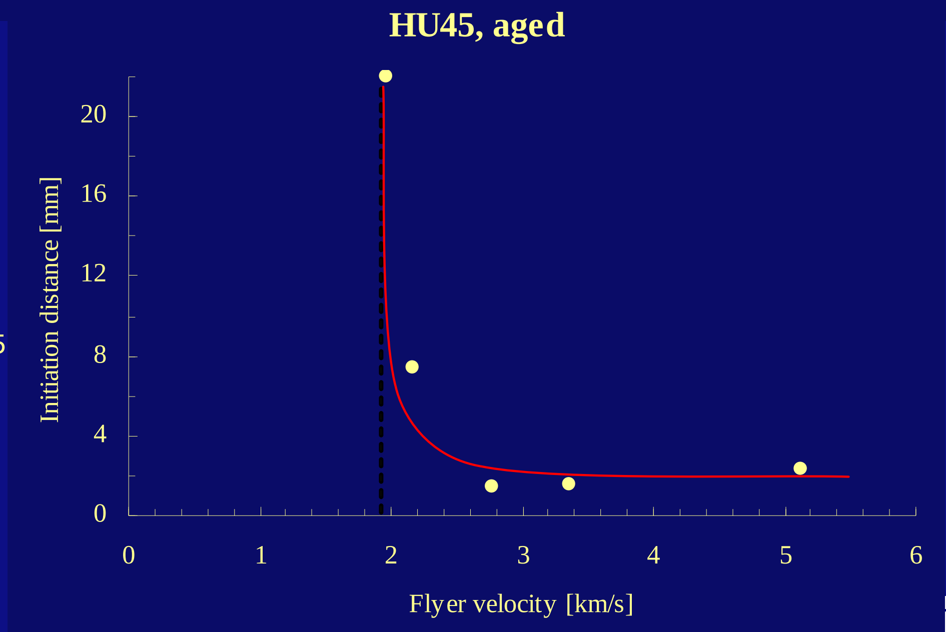
170ºC/175ºC → 900% burning area increase

165ºC → 400% burning area increase

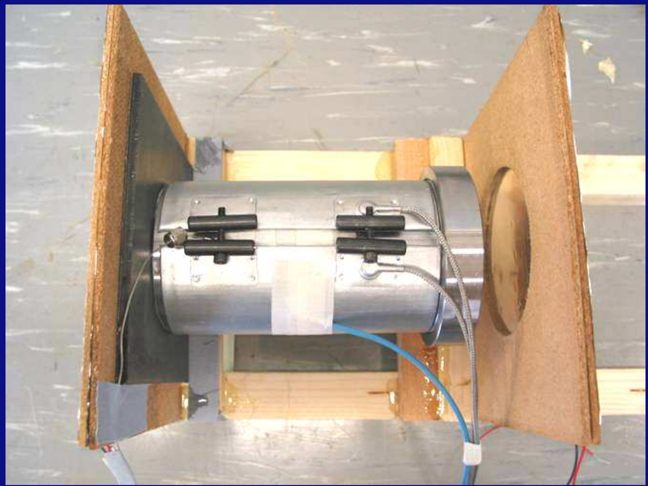
Shock Initiation test (5 hours at 175℃)

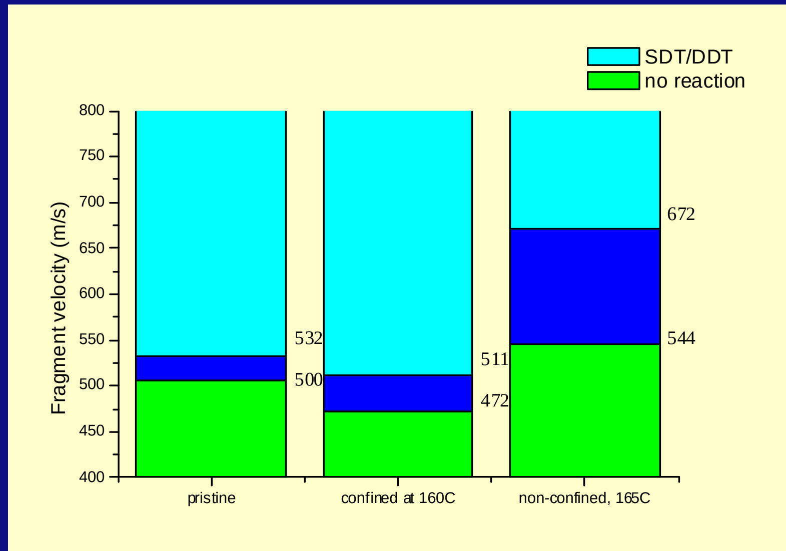






Bullet and Fragment Impact





Remarks

- Closed vessel test was improved (100cc vessel)
- Thermal damage: need more control of sample temperature → tailored oven is needed and individual T measurement preferred
- Double cycle increases damage (e.g. HU44, 60% and HU45, 20%)
- Point of discussion: collapse of voids due to pressure (changes) during burning
- Burning area increase will be used in ignition and growth modelling in improved Lee Tarver model with pore collapse

Modelling

- Autodyn code based on Lee Tarver model
- Pore collapse implemented but still does not work properly (example secondary flyer impact estimates)
- Burning area implementation→ increased shock sensitivity in damaged materials

Conclusions

- Mechanical properties/damage has a (major) influence on sensitivity of explosives
- Research program to find a relation between the amount of damage (thermal as well as mechanical) and the sensitivity of explosives/PBXs
- Temperature influences mechanical properties already in early stage
- Mass loses significant at high temperatures (1% at 175℃)
- Thermal damage of HTPB-HMX starts around 150℃ and re sults in oxidation and porosity leading to a brittle material
- Temperatures up to 160℃ (5 h) seem to have a minor in fluence on the sensitivity of HMX-PBX
- Between 160 and 170℃ (shock) sensitivity starts to increase

Conclusions (cont'd)

- Sensitivity increase shown by impact and friction testing
- The change in sensitivity in the fragment impact tests is not fully understood → confinement, temperature, rehealing?
- Mechanical damage in HU44 by compression comparable with gas gun experiments in dP/dt, but different burning area's
- Collapse of voids during burning due to pressure → permeability research in the future
- A start for proof of relation between area in load-unload cycle and burning area was determined by HU45 double cycle

Future

- Attention to modeling of (macroscopic) damage process on ignition and growth and link to porosity and burning area
- Collapse of voids due to pressure (changes) during burning
- Optical/Microscopical inspection of damaged samples
- Permeability measurements
- Set-up of a macroscopic damage model

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