Performance of ADN/GAP Propellants Compared to Al/AP/HTPB

V. Gettwert, M. A. Bohn, V. Weiser
Fraunhofer Institute for Chemical Technology, Pfinztal, Germany

Insensitive Munitions & Energetic Materials Technology Symposium (IMEMTS)
18-21 May 2015, Rome, Italy

© Fraunhofer ICT

Fraunhofer ICT

Outline

- Introduction
  - Propellants for Tactical Rockets
  - New Composite Propellants
- Small Scale Motor Testing
  - Selected Propellant Formulations
  - Results
    - Experimantal Determined Specific Impulses
    - Burning Rates
  - Smoke Characteristic
- Gap Test / Chemical Stability
- Conclusion

© Fraunhofer ICT

Introduction

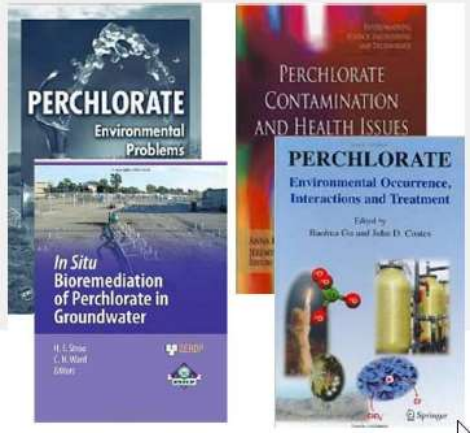
© Fraunhofer ICT

Propellants for Tactical Rockets
Elastomer-bonded Composite Propellants

- „State-of-the-art“ Al/AP/HTPB
- Smoke
  - Hinder concealment
  - Facilitate detection
- AP outstanding oxidator but
  - Health concerns
  - Enviromental concerns
  - Costly disposal
- Risk to service personnel

➔ Call for new composite propellants

Multiple Launch Rocket System - MARS



www.grail-h2020.eu

© Fraunhofer ICT

Fraunhofer ICT

Propellants for Tactical Rockets
NC-based Double Base Propellants

- Low signature, low pressure exponent, plateau burning
- Low performance, low mechanical properties…
- Detonable motors (class 1.1)
- Listed ingrediens or SVHC (REACH)
  - Plasticizer
  - Burning rate modifier

  → Replaced → Refine DB

→ Alternative: Development of

low signature, high performance composite propellant

→ Replace smoky Al/AP/HTPB

SVHC: substances of very high concern

© Fraunhofer ICT

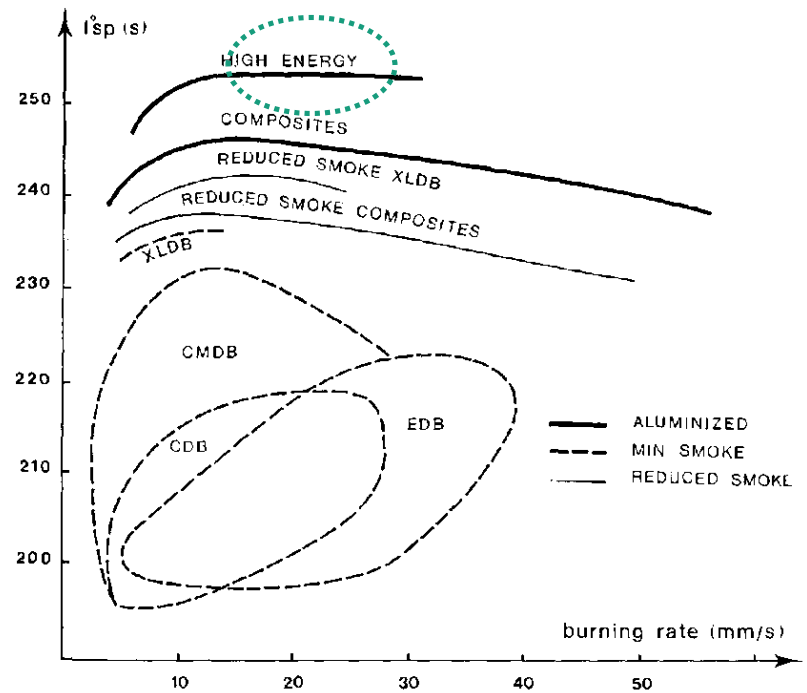
Fraunhofer ICT

New Composite Propellants

- Low signature
  - ➔ AP replaced by chlorine-free oxidator
- ➔ Ammonium dinitramide (ADN)
  - Clean combustion
  - Superior heat of formation
- High performance
  - Lower oxygen content
- ➔ Energetic binder like GAP

➔ ADN/GAP composite propellant

$Isp_{Theo} \geq$ current propellant



A. Davenas: "Solid Rocket Propulsion Technology" Pergamon Press, Oxford 1993

© Fraunhofer ICT

Fraunhofer ICT

Small Scale Motor Testing

© Fraunhofer ICT

Selected Propellant Formulations

- Three **ADN**/GAP based formulation
  - Aluminized ADN/GAP propellant
    - Comparison Al/AP/HTPB reference propellant
  - Two non-aluminized ADN/GAP propellant
    - ADN/HMX/GAP (58.5/11.5/30)
      - High performance propellant
      - → Smokeless replacement for AP based propellants
    - FOX 12 modified ADN/GAP (20/50/30)
      - Similar Isp to double base
      - Reduced sensitivity to shock
      - → Replacement for DB
- Reference Al/**AP**/HTPB (18/68/14)

© Fraunhofer ICT

Selected Propellant Formulations

Reference

ADN/GAP based propellants

aluminized

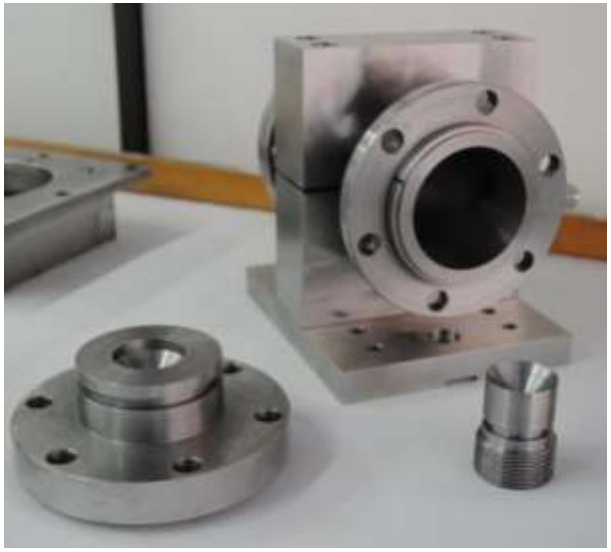
non aluminized

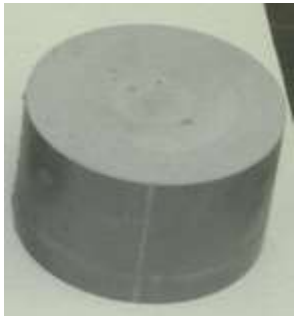
Ingredient	Al/AP HTPB	Al/ADN GAP	ADN/HMX GAP	ADN/FOX12 GAP
Binder	9.55	24.0	25.5	25.6
Plasticizer	4.1	---	4.5	4.4
Additives	0.35	---	---	---
AP	68.0	---	---	---
ADN	---	60.0	58.5	50.0
HMX	---		11.5	---
FOX12	---	---	---	20.0
Al	18.0	16.0	---	---

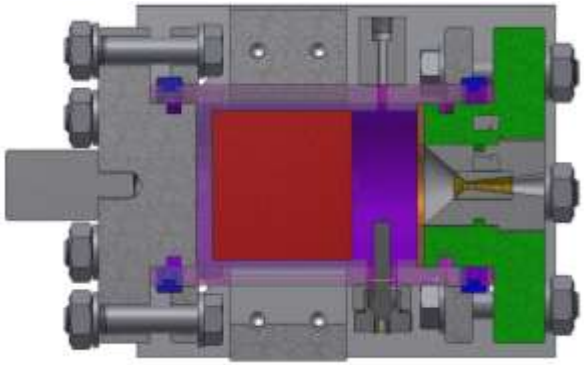
© Fraunhofer ICT

Small Scale Motor Testing

- End burning grain configuration
- Grain
  - Diameter 64 mm (2.52 inches)
  - Web thickness 50-60mm
  - Weight ~300-400g
- Different chamber pressure



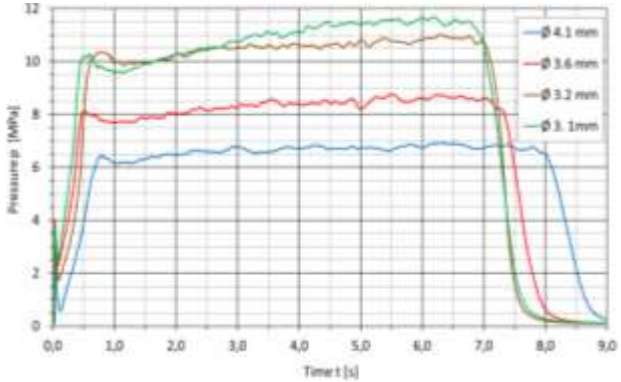




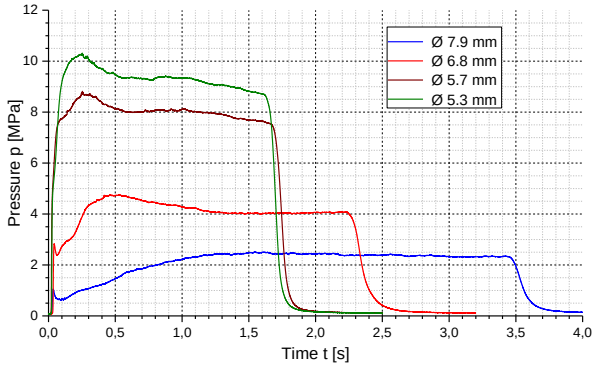
© Fraunhofer ICT

Pressure Cources
at different Nozzle Diameters

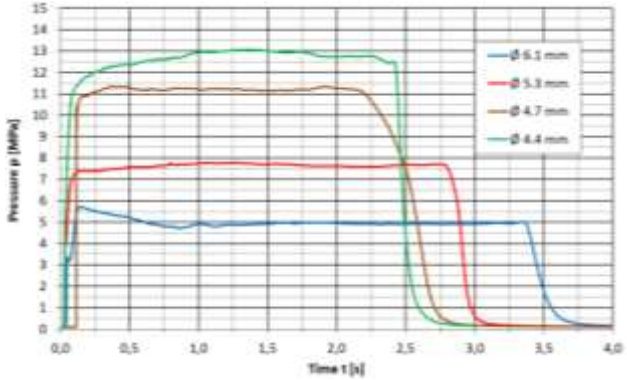
Al/AP/HTPB



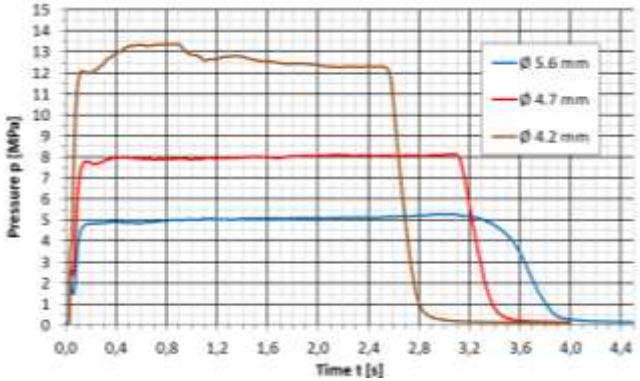
Al/ADN/GAP



ADN/HMX/GAP



ADN/FOX12/GAP



© Fraunhofer ICT

Fraunhofer ICT

Results of the Propellant Tests

Chamber Pressure ~ 7 MPa (pressure ratio of 70:1)

- Higher molar number of gases
- Lower mean molecular masses of gaseous products
  - ➔ Isp and C* ↑
- Gravimetric Isp
  - $Isp_{Exp.}$ aluminized ↓
  - Isp_{Theo} aluminized ↑
  - Lowest Al/AP/HTPB

Propellant	Al/AP HTPB	Al/ADN GAP	ADN/HMX GAP	ADN/FOX12 GAP
Density [g/cm³]	1.759	1.713	1.584	1.577
Oxygen balance [%]	-33.61	-30.23	-26.17	-29.71
Chamber temperature T_C [K]	3455	3518	2765	2458
Total molar number [mol/kg]	37.6	39.9	45.6	46.8
Mean mol. mass of gas [g/mol]	29.2	27.0	21.9	21.4
Chamber pressure $p_{theor.}$ [MPa]	7	7	7	7
Chamber pressure p_{exp} [MPa]	8.2	7.9	7.6	7.9
Burning rate r_{exp} [mm/s]	8.2	24.1	21.1	19.0
$Isp_{ICT\ Code}$ [Ns/kg]	2600	2698	2462	2335
Isp_{exp} [Ns/kg]	**2070**	**2247**	**2237**	**2099**
$Isp_{exp}/Isp_{ICT\ Code}$ [%]	80	83	91	90
Vol. Isp_{exp} [Ns/dm³]	**3632**	**3840**	**3546**	**3305**
$c^*_{ICT\ Code}$ [m/s]	1523	1596	1561	1486
c^*_{exp} [m/s]	1231	1346	1426	1341
η_{C^*} (c* efficiency)	0.81	0.84	0.91	0.90

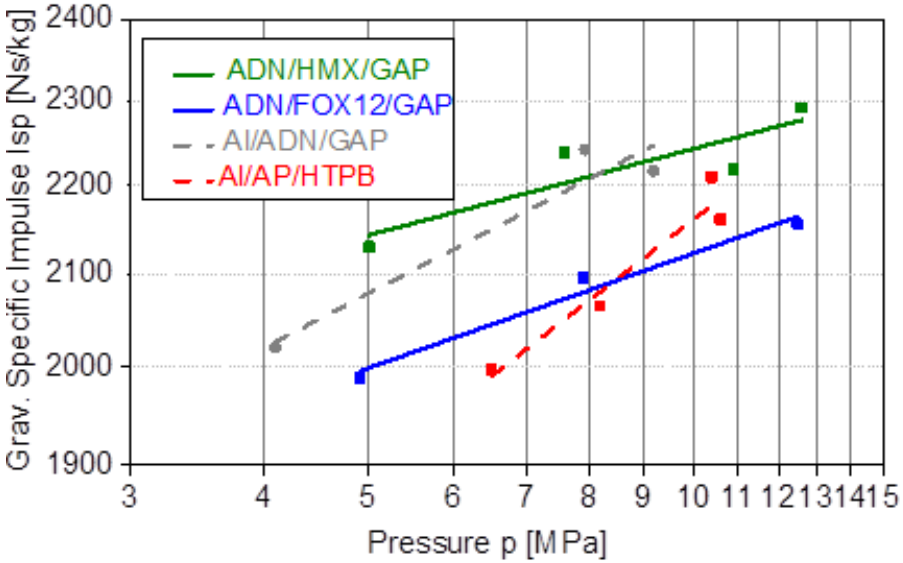
(blue fonts represent experimental data)

© Fraunhofer ICT

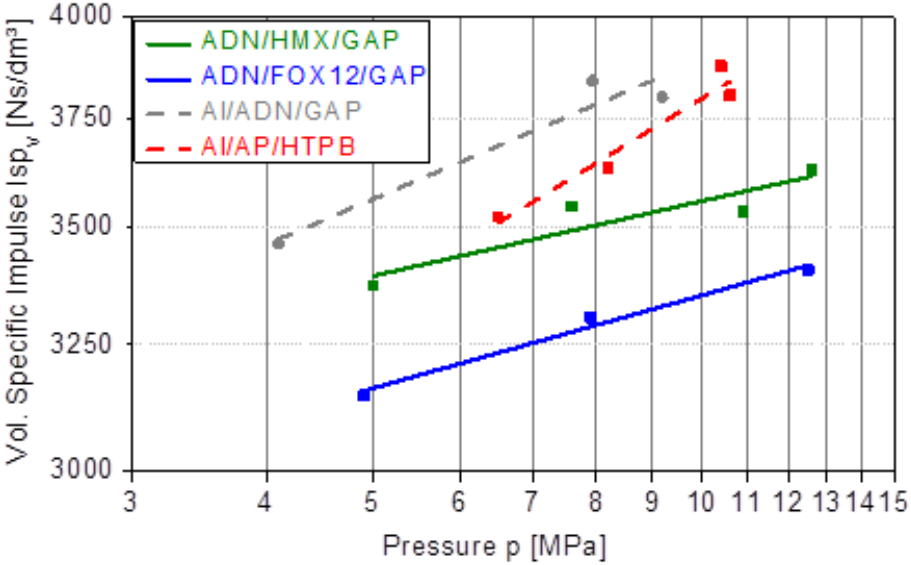
Fraunhofer ICT

Experimental Determined Specific Impulses at Different Pressures

Gravimetric Isp



Volumetric Isp



- ADN/HMX/GAP > Al/AP/HTPB
- ADN/FOX12/GAP beats Al/AP/HTPB in lower pressure range

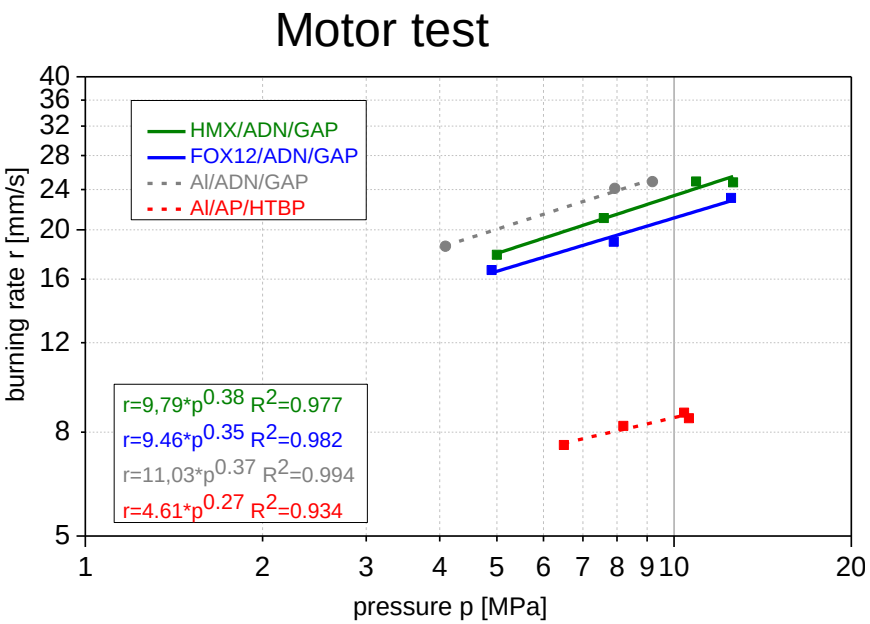
- Aluminized > non aluminized
- Al/ADN/GAP > Al/AP/HTPB up to 10 MPa

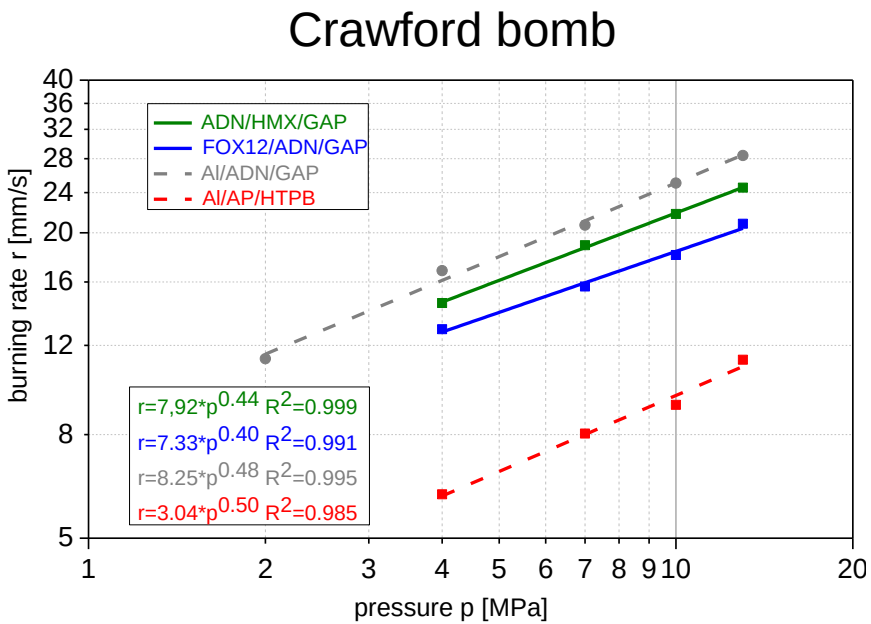
© Fraunhofer ICT

Fraunhofer ICT

Burning Rates at Different Pressures

- Burning rate r (ADN/GAP) > r (Al/AP/HTPB)
- Pressure exponent $n_{Exp} \leq n_{Crawford}$ [≤ 0.5]





© Fraunhofer ICT

Fraunhofer ICT

Smoke Characteristic

- Al/AP/HTPB produce a lot of smoke during combustion
- Aluminized ADN/GAP
  - No secondary signature
- Non-aluminized ADN/GAP
  - No visible signature

Propellant	**Al/AP HTPB**	**Al/ADN GAP**	**ADN/HMX GAP**	**ADN/FOX12 GAP**
AGARD class*	CC	CA	AA	AA

* The exhaust plume smoke characteristic is estimated by the author

© Fraunhofer ICT

Gap Test

- 21 mm in charge diameter (ICT small scale gap test)
- ADN/GAP **with** FOX12
  - Fox 12 reduced the sensitivity
  - ➔ most probably classified as 1.3
- ADN/GAP **without** Fox12
  - ➔ not finally clarified if they are class 1.3

Propellant	**Al/AP HTPB**	**Al/ADN GAP**	**ADN/HMX GAP**	**ADN/FOX12 GAP**
PMMA [mm]	0	4	4	1
Initiation pressure [kbar]	>83	~62	~62	~77
Class	1.3	Probable 1.3*	Probable 1.3*	1.3

© Fraunhofer ICT

Chemical Stability
Example Al/ADN/GAP

- Heat loss
  - << 5% of the total energetic content
- Vacuum stability
  - 80°C for 144h → data converted to 100°C for 40h
    - → According to STANAG 4556 definition the propellant is stable
- Dutch mass loss → Formally fulfilled
  - 80°C → converted to 105°C
- Prediction of the in-service time period
  - Mass loss measurement at 70, 75, 80, and 85°C for 30 days → Arrhenius parameterization
  - If a mass loss of 0.5% is assumed
  - → Storage temperature of 50°C: 36 years (55°C: 12 years)

© Fraunhofer ICT

Fraunhofer ICT

Conclusion

- Experimental investigations showed that *ADN/GAP based composite propellants* have the potential as a
  - Replacement for smoky Al/AP/HTPB composite propellant
    - ➔ avoid the AP
  - Alternative for the low signature double base propellants
    - Combination with less sensitive energetic materials (like FOX 12)
    - ➔ Low signature composite propellants with similar specific impulse but lower shock sensitivity
  - Class 1.3 possible
  - Stability is sufficient for application

➔ High energy and low signature composite propellant in future application

© Fraunhofer ICT

Motor Test of
ADN/HMX/GAP

© Fraunhofer ICT

Fraunhofer ICT

„Next propellant should be developed using today‘s energetic materials, not yesterday‘s“

Contact:

Dr. Volker Gettwert

volker.gettwert@ict.fraunhofer.de
+49(0)721-4640-406

Fraunhofer ICT
Joseph-von-Fraunhofer-Str. 7
D-76327 Pfinztal
Germany

© Fraunhofer ICT

Fraunhofer ICT