Experimental set-up and results of the process of co-extruded perforated gun propellants

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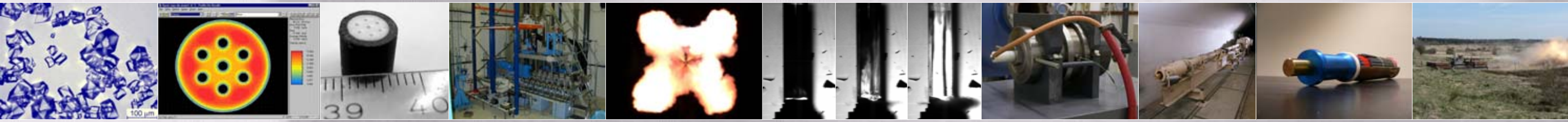
TNO | Knowledge for business

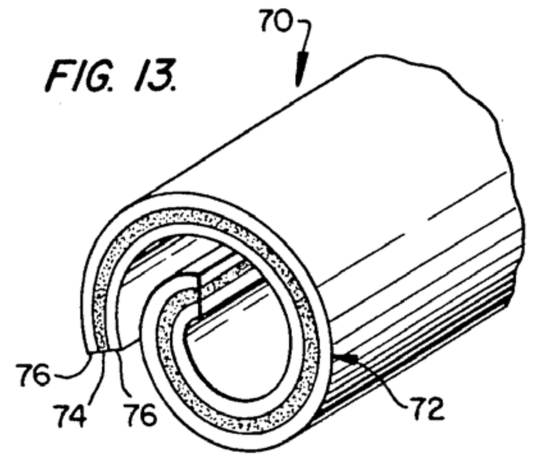
TNO Defence, Security and Safety – Protection, Munitions and Weapons – Energetic Materials



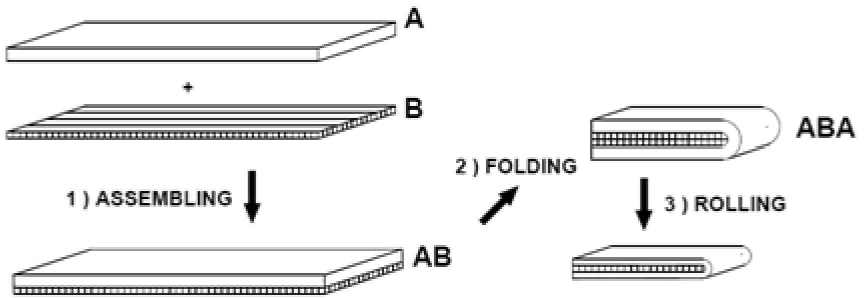
Introduction

- Co-layered gun propellants – advantages and difficulties
- Performance characteristics
- Co-extrusion of gun propellants at TNO
  - Experimental set-up
  - Development steps in recent years
  - Burning characteristics of 1-perf co-extruded co-layered propellant
- Future developments
- Conclusive remarks

Co-layered propellants



- US Patent 4581998 (1986) A.W. Horst et al.
- Advantage: improvement of gun performance by enlargement of the impulse on the projectile
- Ritter ICT 2007
  Manufacture:

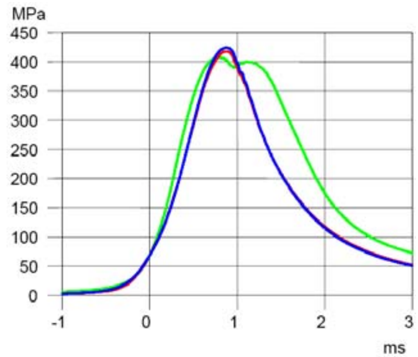


- Disadvantage:
  'The time-consuming manufacturing of assembled propellant sheets proved to be a difficult task.'
- **TNO's approach: co-extrusion**
  → **with proper die design easy manufacturing (not labour intensive and excellent geometries in one step)**

Co-layered propellants

Advantages

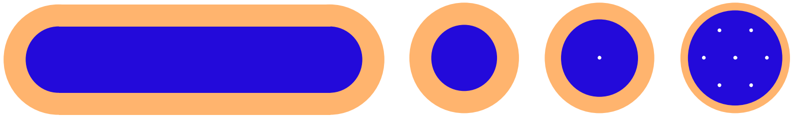
- Increased performance
- High progressivity of co-extruded 0- and 1-perf grains
- Decreased erosivity of high energy propellants
- Increased ignition behaviour (e.g. LOVA propellants)



Ritter, ICT 2007
(note: not multi-perforated grains!)

Notes

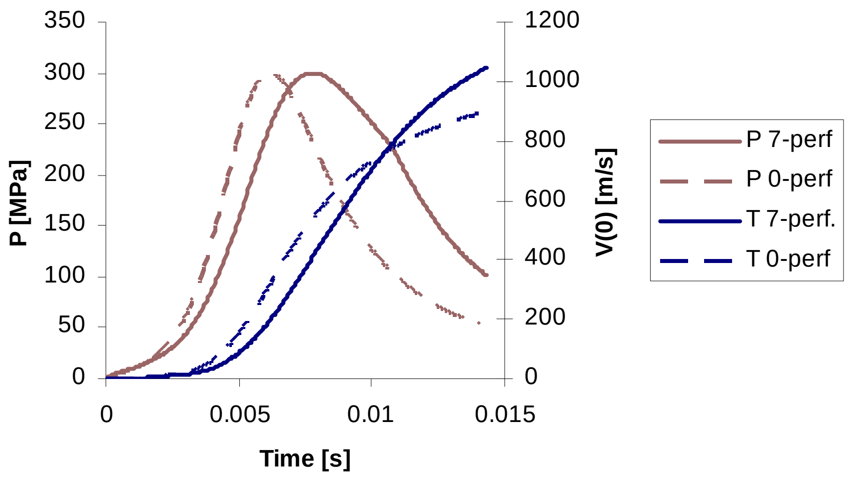
- Increased performance of sheet propellants is comparable to the performance of regular granular multi-perforated propellant
- Variations in layer thickness may result in increased dispersion of V_0
- Contrary to co-layered sheet propellants, co-extruded propellants provide wide variation in geometries, implying a larger number of possible applications



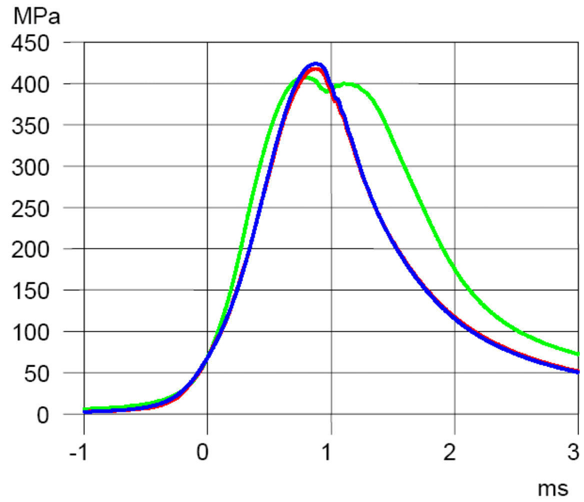
Co-layered propellants

- Examples of simulated performance effects

7-perf versus 0-perf



co-layered sheet propellant

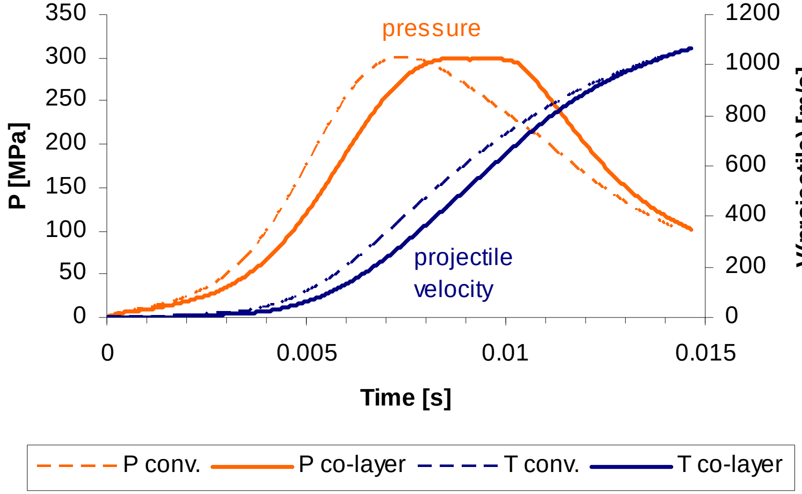


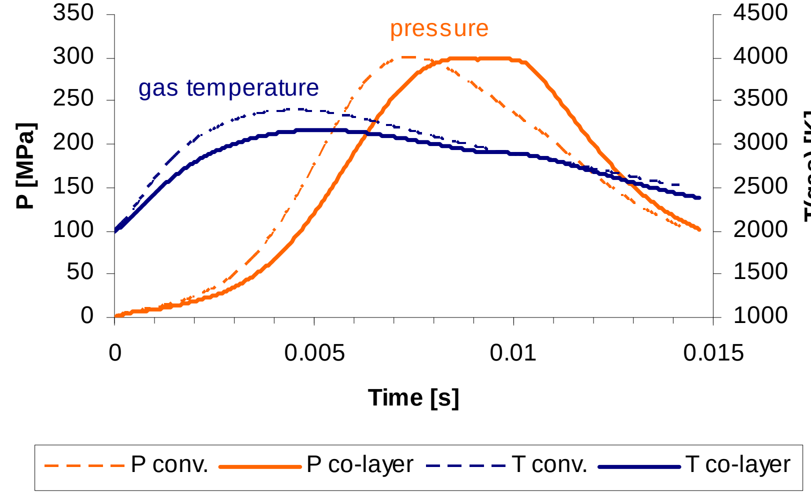
Ritter, ICT 2007

Performance characteristics

- Examples of simulated performance effects

7-perf; T_f(core) = 3515 K; T_f(layer) = 3170 K
factor burning rates = 1.5



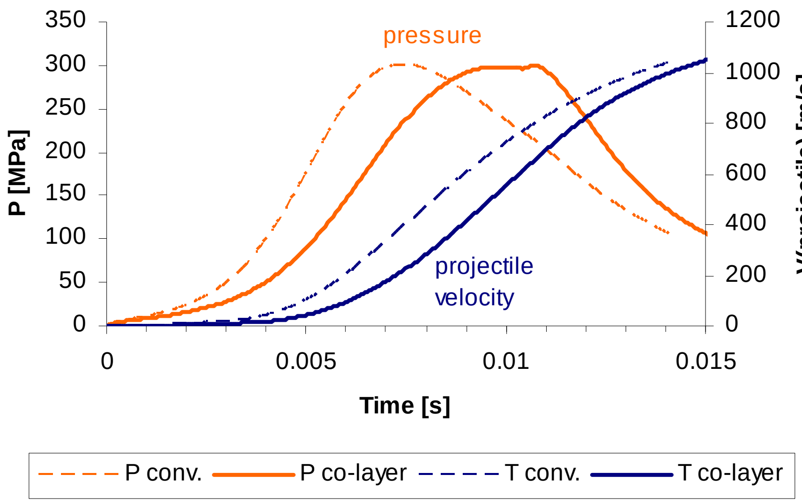


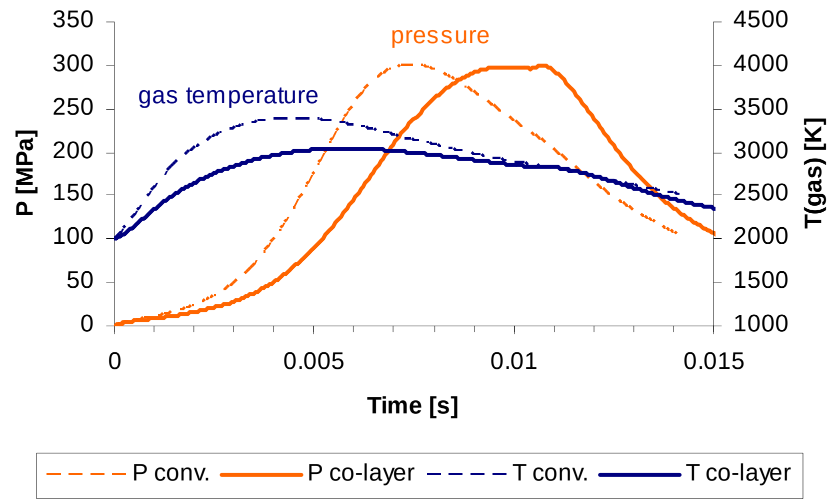
→ T_{max} = 3165 K
= 3385 K without ‘cool’ outer layer

Performance characteristics

- Examples of simulated performance effects

  7-perf; T_f(core) = 3515 K; T_f(layer) = 2900 K
  factor burning rates = 2





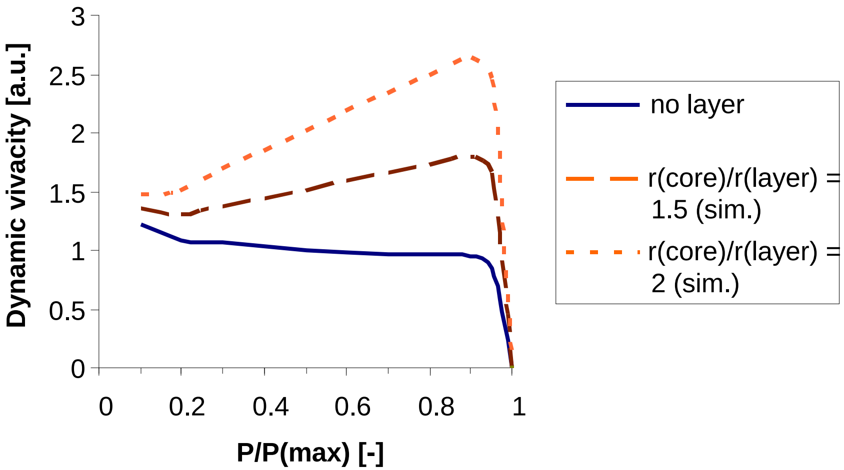
→ T_{max} = 3040 K
= 3385 K without 'cool' outer layer

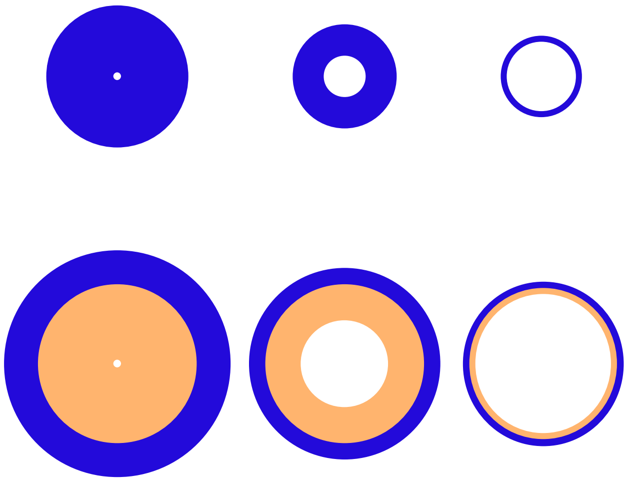
- **Higher charge densities → further performance improvement**

Performance characteristics

- Examples of simulated performance effects

Dynamic vivacity 1-perf grain:
(both layers intact until Z = 100%)



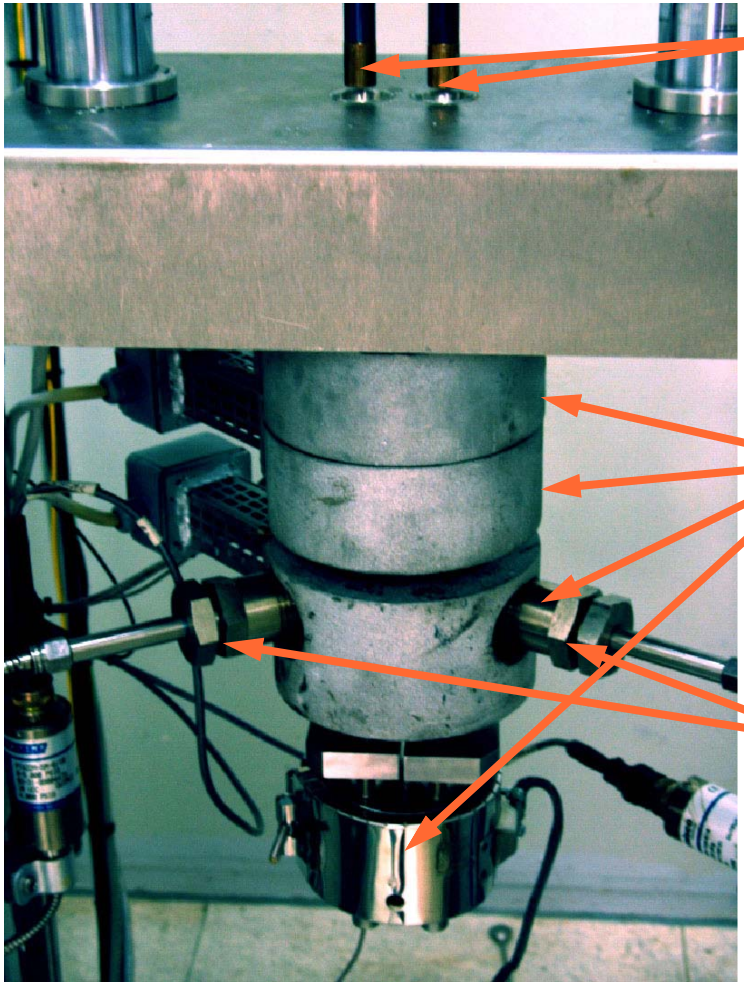


→ increased progressivity, even without double peak;
'low' (usual) pressure exponent

→ with smaller outer layer: progressive + double peak in P-time curve

→ large grains (applicable for both medium and large calibre)

Co-extrusion of co-layered propellants at TNO



2 barrels

double barrel
capillary rheometer

heating zones

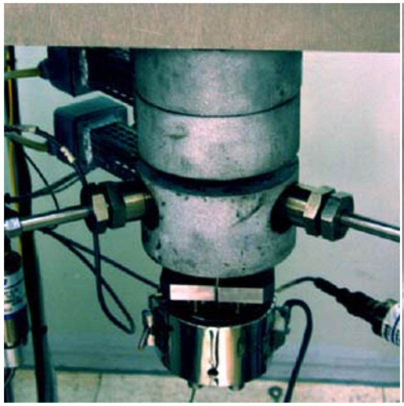
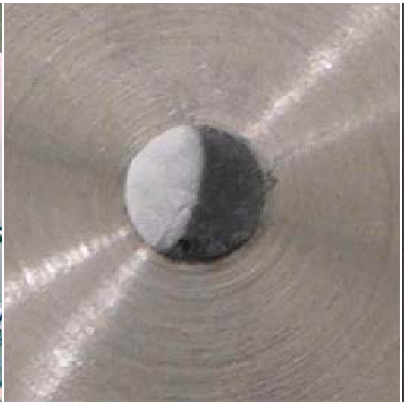
pressure
transducers

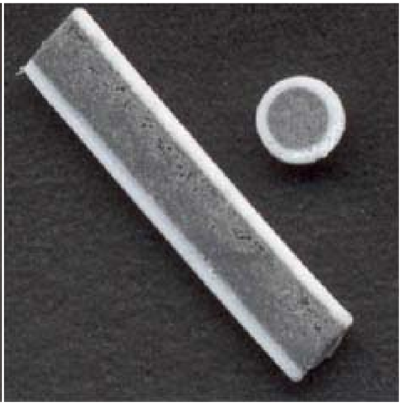
(co-)extrusion block

Co-extrusion of co-layered propellants at TNO

First attempts (2005-2006):

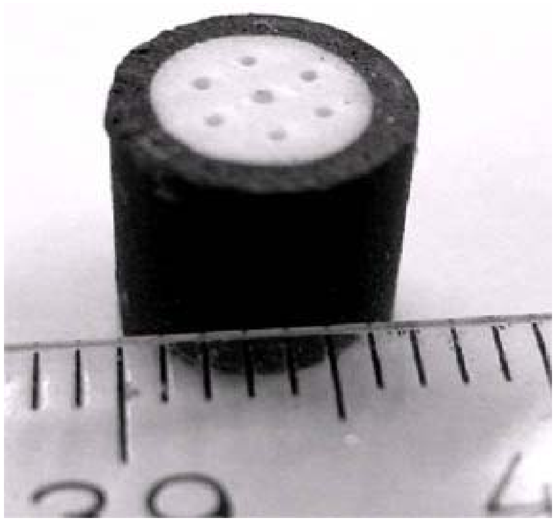
- Non-perforated co-extruded propellant
- ‘Self-encapsulation’ is theoretically possible for a large viscosity difference (factor 2.5), but appears to fail
- Improper die design leads to slip, resulting in a ‘rope of beads’
- Experiments resulted in good insight in the problem of co-extrusion



Co-extrusion of co-layered propellants at TNO

- Improved die-design using special simulation software in 2007 (applying available knowledge from polymer processing)
- First die for demonstration purposes
  - This die is restricted to equal mass flows of outer layer and core (application with two-barrel capillary rheometer facility)
  - Perforation positions not optimised for 7-perf geometry (depend on propellant compositions and burning rates)



Co-extruded LOVA propellant

Co-extruded DB propellant

Co-extrusion of co-layered propellants at TNO

Bond integrity at high pressures:

→ Closed vessel tests with DB single-perforated co-extruded grains

- Manufacturing:
  - Excellent distribution of both layers
  - Excellent bonding

6.8 mm

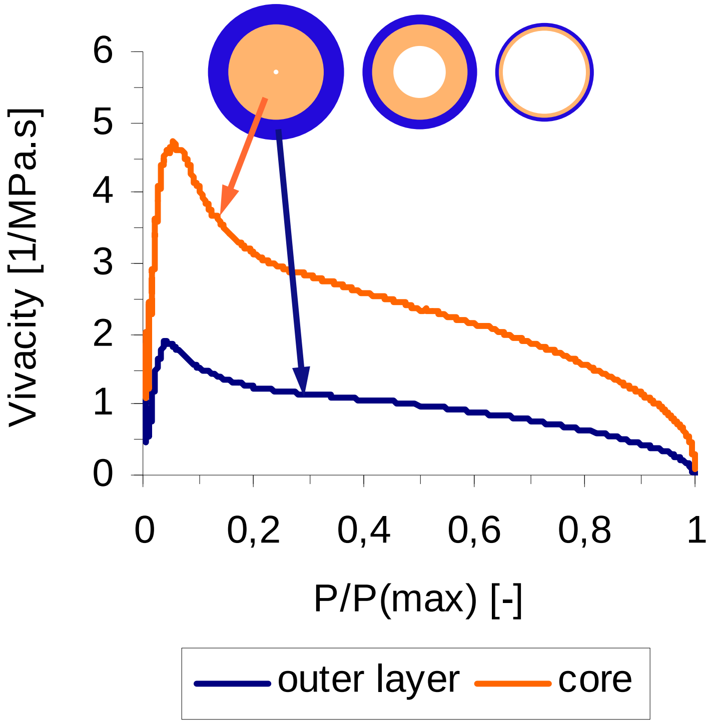
Co-extrusion of co-layered propellants at TNO

Bond integrity at high pressures:
→ Closed vessel tests with DB single-perforated co-extruded grains

Determination burning rates:

- non-perforated grains
  L = 10 mm
  D = 1.45 mm
  → burning rate ratio ≈ 2.3

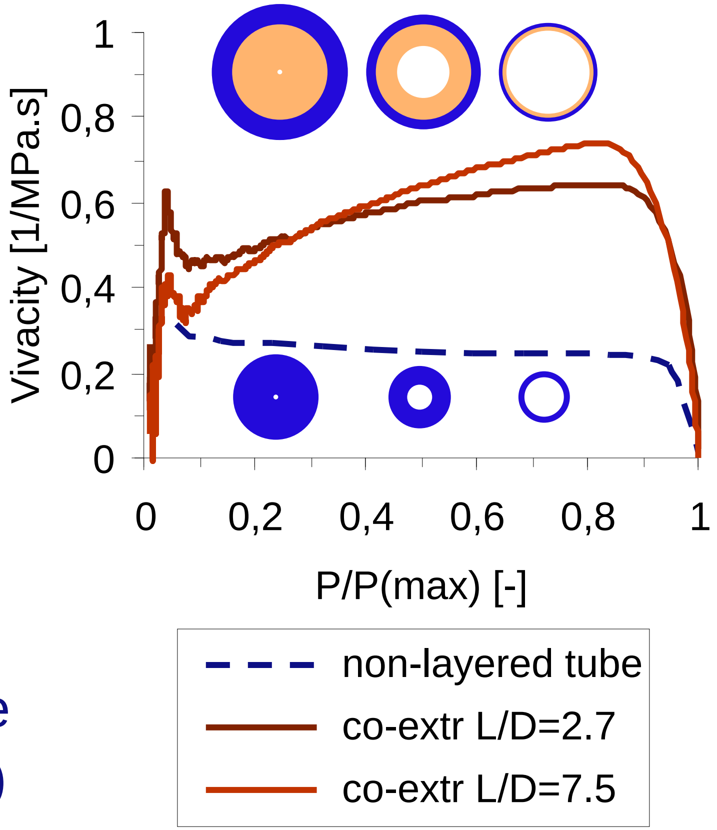
- Layer thickness ratio ≈ burning rate ratio
  → both layers are consumed at the same time (no vivacity jump)



Co-extrusion of co-layered propellants at TNO

Bond integrity at high pressures:
→ Closed vessel tests with DB single-perforated co-extruded grains

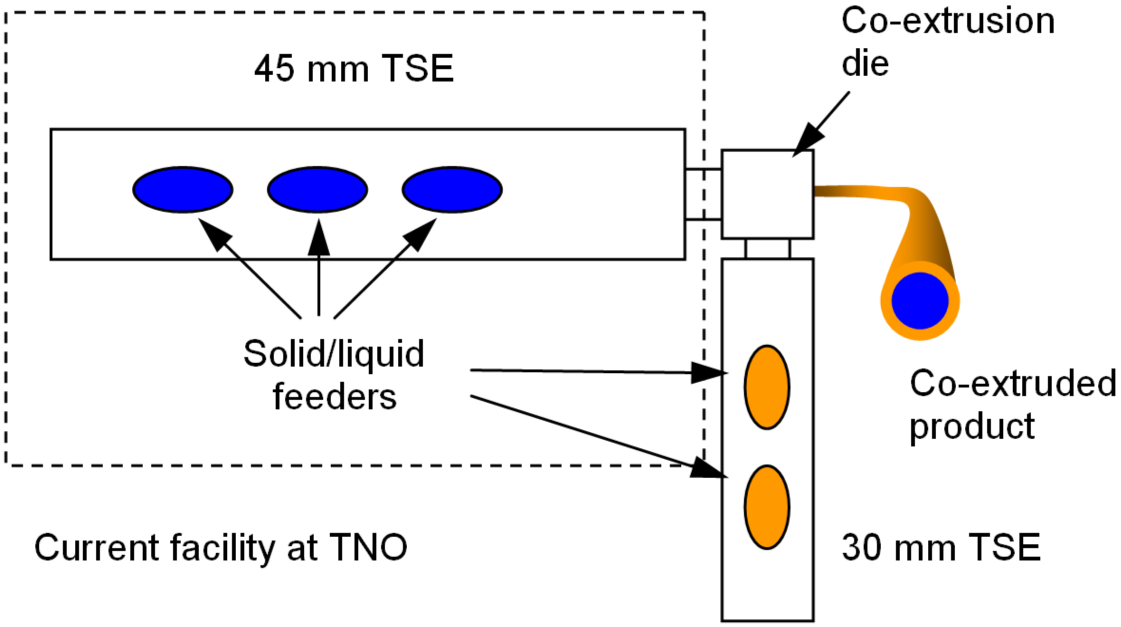
- Non-layered tube: neutral burning behaviour
- Layered propellant: progressive
  Progressivity determined by:
  - burning rate ratio
  - L/D ratio
- P_{max} = 260 MPa: good bonding
- Extra performance increase possible for thinner outer layer (vivacity jump)



Future developments

Continuous co-extrusion

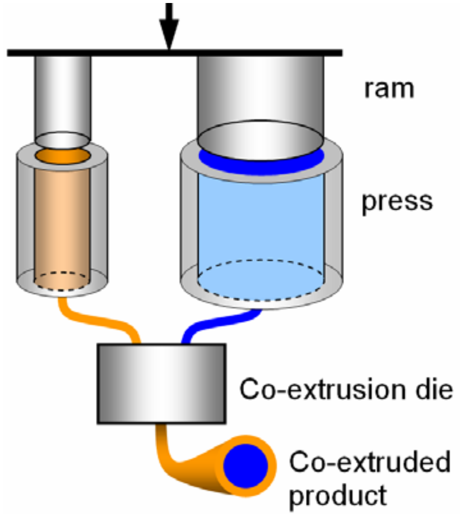
- Current twin-screw co-rotating extruder: 45 mm; 5 – 15 kg/h
- Second extruder: 30 mm; 1.5 – 5 kg/h
- Outer layer: ~10 – 50% of total strand volume



Future developments

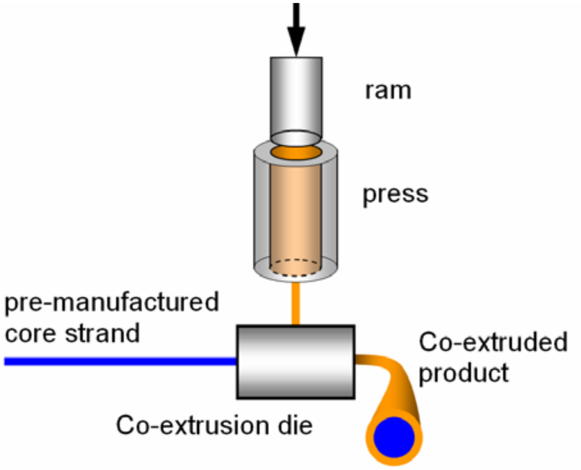
Double ram press

- Mass flow ratio of both layers is always constant
- Excellent reproducibility
- Flow outer layer is adjustable, which creates a variable process for several applications

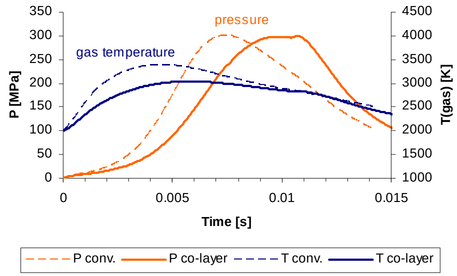


Alternative ram extrusion set-up

- Well controllable process
- Inner and outer layer can be variable (i.e. composition and size)
- No dramatic change of facilities

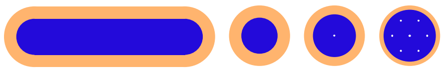


Conclusions



Co-extrusion

- Relatively easy, one-step manufacturing process
- High progressivity / increased performance
- Decreased erosivity of high energy propellants (– 300 K or more)
- Other advantages (improved ignition behaviour, IM, …)
- Several grain geometries possible
  - non-/ single-/ multi-perforated
  - wide range of applications / calibres



Experiments

- Successful application of co-extrusion technique
- Excellent bonding between core and outer layer