Detonation Characteristics of Ammonium Nitrate Products

Results of the 2005 EFMA study

TNO | Knowledge for business

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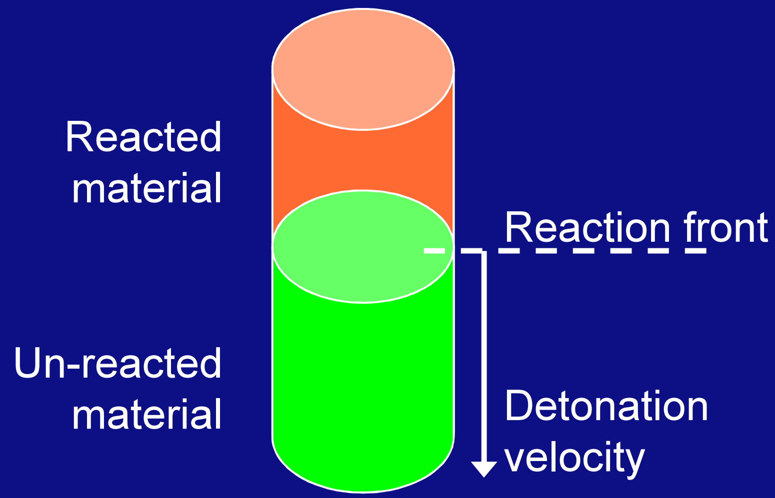
Detonation properties of ammonium nitrate

- Many materials have explosive properties, AN is one of these materials. However, AN
  - is able to detonate under extreme conditions
  - is produced and stored in large quantities
  - is easily obtainable in large amounts

Definition of a detonation

- Heterogeneous chemical reaction in which the reaction is sustained by adiabatic compression (shock) in the front
- Shock and reaction front proceed through the material with a velocity higher than sound (1 - 10 km/s)
- Very high pressures (10-400 kbars), damage at large distance
- Effects are mainly determined by the shock wave
- *Most "industrial" explosive materials have a wide "non-ideal" range in which the detonation properties depend on many parameters*



Detonative properties of AN

- Detonation properties depend on
  - Ammonium nitrate concentration
  - Combustible substances, coating
  - Water, sulphate content, pH
  - Void volume, bulk density
  - Oil retention, size fraction
  - Hardness

- No systematic study on the effect of filler material on the detonative properties is described in literature

What does the non-ideal behaviour mean in practice?

- A detonation can not be sustained below the critical diameter.
  - The sensitivity reduces as the diameter approaches the critical value.

- Whether or not a detonation occurs under given test conditions depends on:
  - The characteristics of the AN
  - The imposed conditions
  - The initiation strength

- Safety of the given material is strongly determined by the "sensitivity"

The 2005 EFMA study

Main objectives

- To determine the order of magnitude of the critical diameter of some typical types of ammonium nitrate and ammonium nitrate based fertilisers
  - Validation of previous work on large scale detonation testing done at Queens University in Canada during the 1980's (Prof. Bauer & al)
  - Relate to both safety and security issues
  - Important parameter to assess detonation risk
- To determine the detonation properties and to assess the influence of product specifications on these properties
  - Initiation sensitivity and blast effect (TNT equivalence)
  - Validation of parameters used in advanced detonation simulation modelling
- To develop further guidelines for safe storage of AN-products
  - Critical storage volumes and separation distances
  - Separation distances for TGAN and FGAN/CAN

Overview of the work in the project

1. Material selection and characterisation
2. Small scale testing (EC, denting, miniautoclave)
3. Medium scale detonation testing in tubes (up to 4 tons)
4. Sensitivity testing by full scale gap tests
5. Large scale detonation testing (28 tons)
6. Determination and evaluation of TNT equivalence
7. Modeling and simulation

Test materials

- Four principle test materials (all granules)
  - Fertiliser grade ammonium nitrate, density of 0.92 g/cm^3
  - Fertiliser grade ammonium nitrate, density of 0.97 g/cm^3
  - CAN-27 (with dolomite without stabiliser)
  - AN and gypsum (AN + gypsum, 27% N)

- Product quality standard in accordance with EU requirements

- Technical grade ammonium nitrate (TGAN) as reference material

The experiments in this project were designed to determine the detonation properties of the various materials. For this reason, optimal test configurations and severe boosters were used.

Material characterisation and small scale testing

- All test materials are fully characterised in terms of chemical and physical properties
  - Density (bulk, tapped, loose)
  - Particle size and distribution
  - Composition, including chloride and moisture
  - Effect of ageing on density

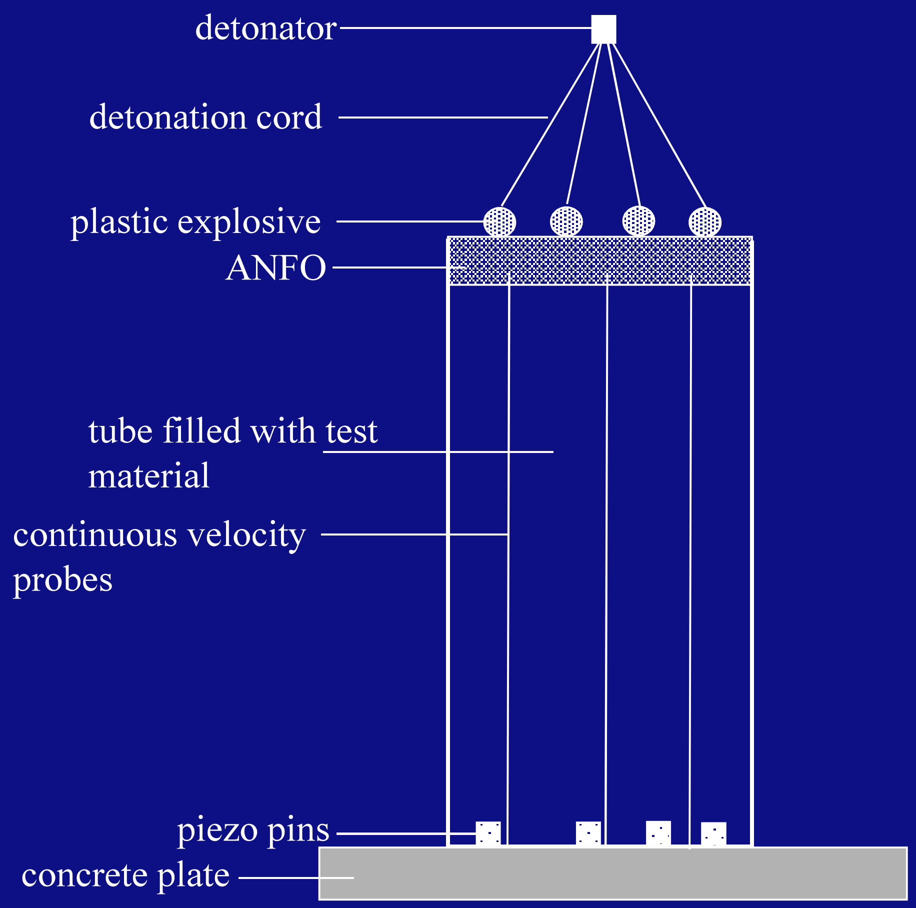
- Small scale detonation tests
  - EC detonation test (4” steel tube test)
    - With and without thermal cycling
    - Including an evaluation of records
  - Denting test

- Small scale thermal stability by miniautoclave testing to determine the stability, phase transitions, melting point and high temperature reactivity

Findings from the small scale detonation tests

- All the fertiliser type of materials (thermal cycled and non-cycled) passed the test
- The thermal cycled materials showed more response to the imposed shock wave than the non-thermal cycled material, except for AN + gypsum.

Medium scale testing



- *Purpose: to determine the critical diameter, detonation velocity and the explosion effect*
- Test material: 30 kg - 4 tons
- ANFO booster (initiated by HE)
  Booster configuration verified by computer simulations
- Velocity probes and ionisations pins to measure detonation
- Free field blast measured in two directions (angle of 90°)
- High speed video recording (6000 fps and 20000 fps)

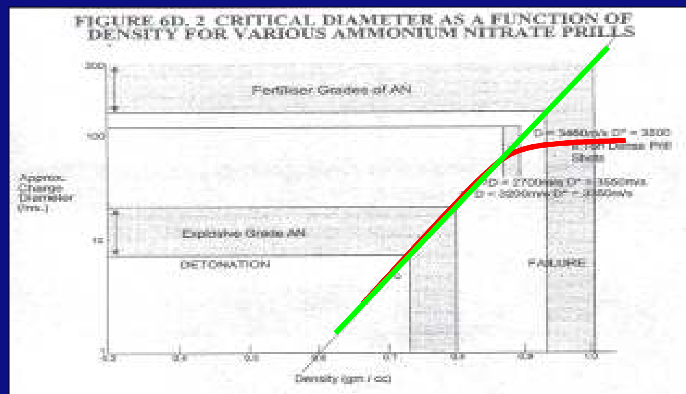
Test set-up


6000 fps
frame : 1035
1/20000 sec
+00:00:00.172333sec
512 x 512
Test 2A left

- Example of a test in which no detonation of the test material occurred.
- The explosion effect is due to the booster

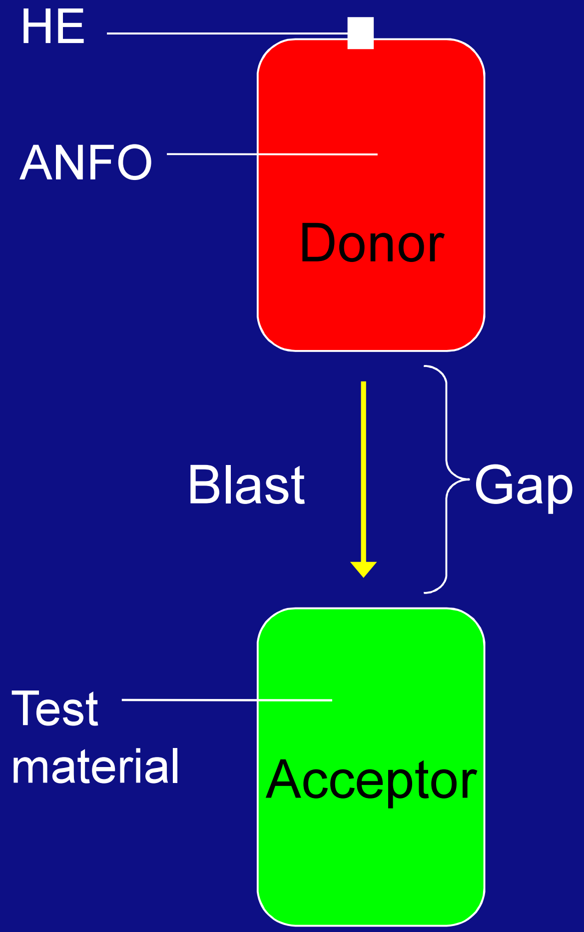
Findings of the medium scale tests

- The test results with AN confirm Bauer's work; the critical diameter increases with density. However
  - Lower critical diameters were found than in Bauer's work
  - The variation of the critical diameter with density is less
- Non-ideal effect clearly observed with increasing density
- CAN and AN with gypsum showed similar behaviour. No detonation occurred in the materials.
- The tests in which a detonation occurred showed a TNT_{eq} of 40 - 50 %

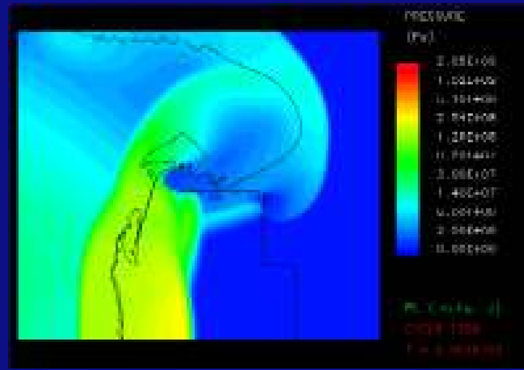


Gap tests (initiation sensitivity)

- Test to determine the initiation sensitivity
- Donor – acceptor principle
- Test design based on results of the medium scale tests
- ANFO donor (initiated at the far end of the acceptor
- The detonation velocity is measured with continuous velocity probes and ionisation pins
- High speed video recording
- The tests were performed with TGAN and FGAN(0.92)



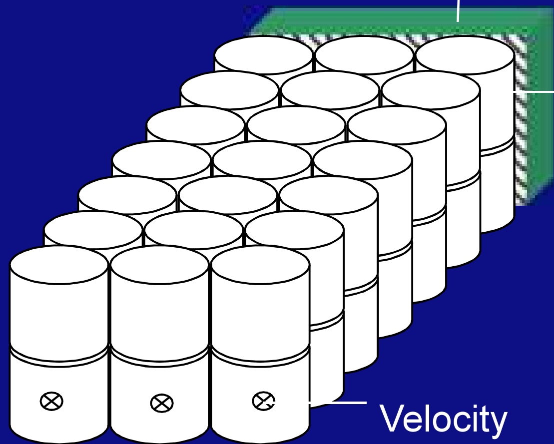
Findings



- Critical gap length (from the tests)
  - TGAN in between 3.5 and 4.5 m
  - FGAN in between 35 and 75 cm
- The results show that FGAN is very insensitive compared with TGAN
- The values determined in the tests can not be used directly for practical situations!
  - In practical situations ANFO is not the donor material
  - Optimal test configurations and severe boosters were used.
- Critial separation distance (simulations):
  - Between stacks of FGAN a critical separation distance of of 0.1-0.7 m was found
  - The critical separation distance for TGAN is much larger for most practical situations. The exact value depends on the configuration of the stags of bigbags, the way of initiation of the donor and the type of material.

Full scale test

- Purpose: To validate the medium scale results and to assess large scale behaviour
- Tests performed with CAN and FGAN(0.92)
- Approximately 28 tons of test material. Severe and optimised booster (ANFO).
- The holes in between the bigbags are filled with material to simulate a bulk (simulation of bulk storage, worst case)
- Detonation velocity is measures at three places in the bottom row of bigbags over a length of 6 meters
- Blast is measured in 2 directions: Perpendicular and parallel to the row
- High speed video recordings



Findings full scale tests

- CAN
  - No propagation of detonation.
  - Significant contribution to blast effect of the booster
- FGAN (0.92)
  - Propagation of detonation
  - A TNT equivalence of 25 to 30 % was determined

Summarised results and discussion (1)
Detonation properties

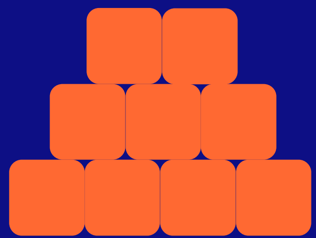
- Large boosters and close to ideal conditions are required to detonate FGAN. The critical diameter increases with density.
- FGAN is very insensitive towards initiation. Relatively small separation distances are sufficient to prevent sympathetic detonations.
- The results on CAN and AN+gypsum show that the critical diameter significantly increases with an decreasing nitrogen concentration
  - No detonation in tests
  - Contribution to blast of the booster

Summarised results and discussion (2)
TNT equivalency

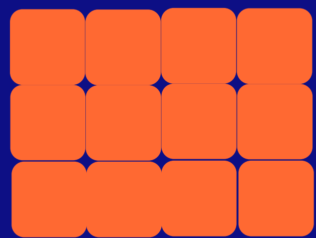
- TNT equivalency for practical situations is a combination of “explosive power” and “efficiency”
  - Explosive power is determined in the full scale tests
  - Efficiency is based on expert opinion and incidents in the past
- For FGAN a TNTeq of 10-20% seems appropriate for practical situations.
  - Slightly higher in present experiments due to ideal conditions
  - In agreement with major accidents
- For TGAN a TNTeq of 20 – 25% appears to be appropriate

Summarised results and discussion (3)
Critical separation distance

- For stacks of FGAN it was found that the critical separation distance is between 0.1 – 0.7 m
- The critical separation distance of TGAN is dependent on
    - stack configuration
    - initiation point
    - density and type of material
- Values of 5 m to larger than 13 m were deterined
- A ‘stepwise configuration’ gives smaller separation distances than a ‘straight’ configuration



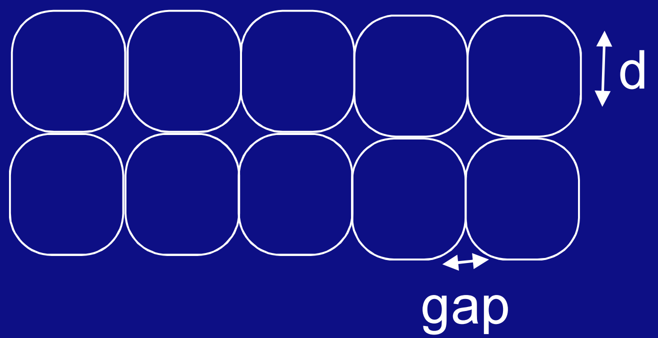
stepwise



straight

Summarised results and discussion (4)
“Passive” safety

- The full scale test was arranged to simulate a bulk storage
- The propagation of a detonation can be more difficult when an air gap is present between the bigbags in a stack (low sensitivity, bag diameter<<critical diameter for FGAN)
- Hence, passive safety (no propagation) can be obtained provided that the proper size of bigbags is chosen in relation to the detonation properties of the AN material.



Some final remarks…..

- The results relate to the materials as manufactured
- An assessment of safety and security issues has to include aspects such as
  - Contamination
  - Aging
  - Behaviour in fire
  - Misuse
  - Etc.
- *Safety of AN or AN based materials (with respect to the detonation hazard) is not an absolute property!*