Less is More!
OR
One Size does NOT fit all

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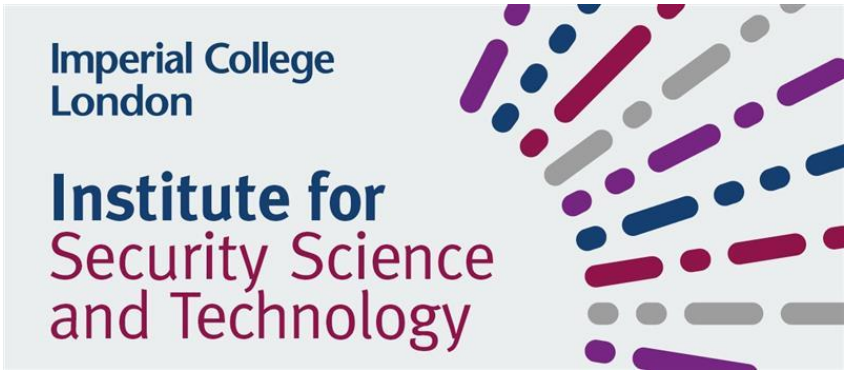
FULMINATION APRIL 2022

Institute of Shock Physics



Acknowledgements

John Field — *Imperial College London*

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Simon Bland — *DSTL*

David Williamson

Chris Braithwaite

QUOTE ATTRIBUTED TO USMC

"If force does not work…use more force"

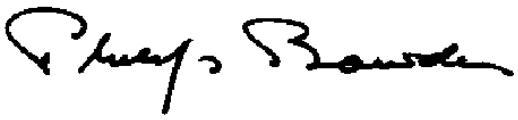
AN OFTEN USED APPROACH

"If your solution is a hammer… all your problems are nails"

CONTENTS

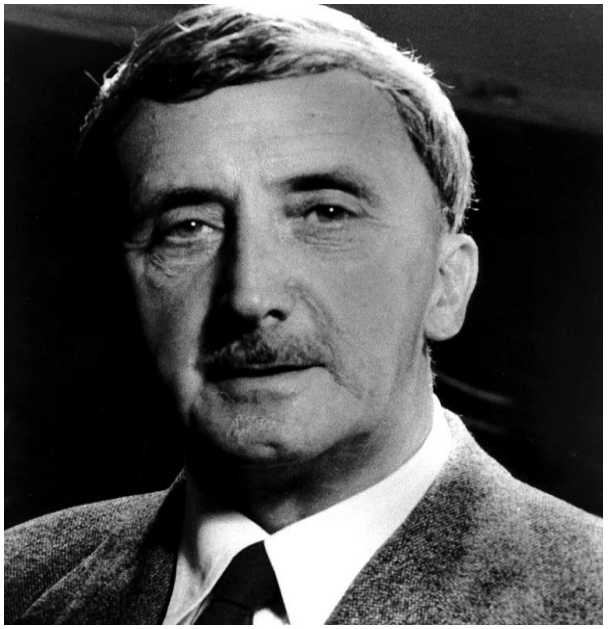
- Five examples of where this does not work (everyone here, can add their own examples)
  - *Spigot Test*
  - *Crystal porosity*
  - *Temperature*
  - *Gas Flow*
  - *Boreholes*

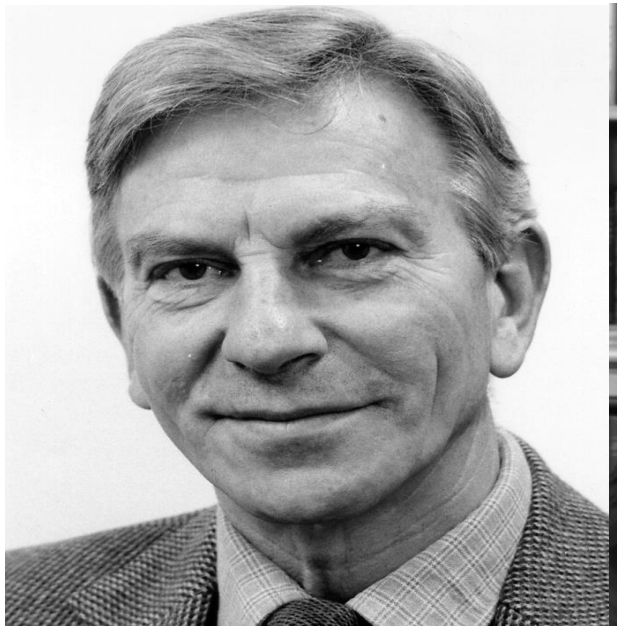
HOT SPOTS

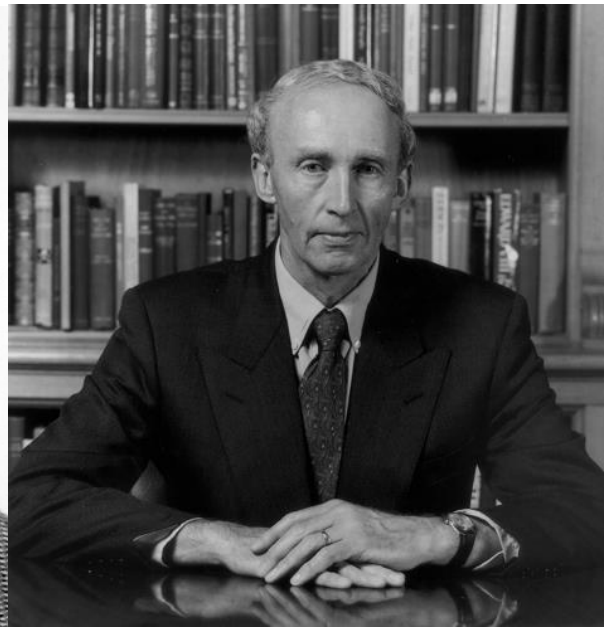


ABE YOFFE

JOHN E. FIELD







IGNITION MECHANISMS

- Bowden and Yoffe (1958)
- Shear Mechanisms investigated by Field (1960's onwards)

- Bulk heating insufficient
- Energy localised at *Hot Spots*
- mechanical stimulus $\Rightarrow$ inhomogeneity $\Rightarrow$ hot spot

- Physical conditions
  - *size 0.1 - 10 μm*
  - *time duration 10 μs - 1 ms*
  - *temperature 700 K*
- Many mechanisms exist; only a few form *critical* hot spots

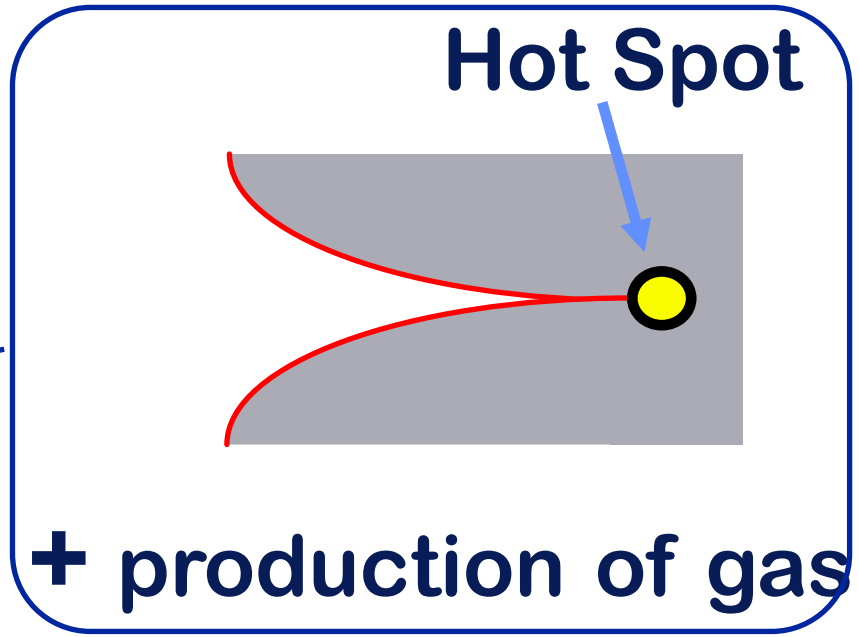
Hot Spot Production

1. Friction
2. Collapse of gas bubbles

   (a) adiabatic heating gas

   (b) shock focussing

   (c) visco-plastic work
3. Adiabatic Shear
4. Viscous flow
5. Fracture



HOT SPOT PRODUCTION

6. Electrical

   (a) spark

   (b) electron injection, decomposition, filaments, Joule heating, breakdown

7. Triboluminescence

   (a) spark

8. Fission tracks

9. Dislocation pile-ups

10. Thermal fluctuations in lattice

CRITICAL HOT SPOTS

1. Friction
2. Gas bubbles
3. Adiabatic shear
6. Electrical

} All Yes

2(c). Viscous flow; only a component since as T increases viscosity decreases.

5. Fracture; not single crystal of explosive since fracture surface energy, γ, only mJ, BUT a *tough propellant or PBX* (γ *many J) then possible*

HOT SPOT MECHANISMS ARE ADDITIVE

Spigot Test

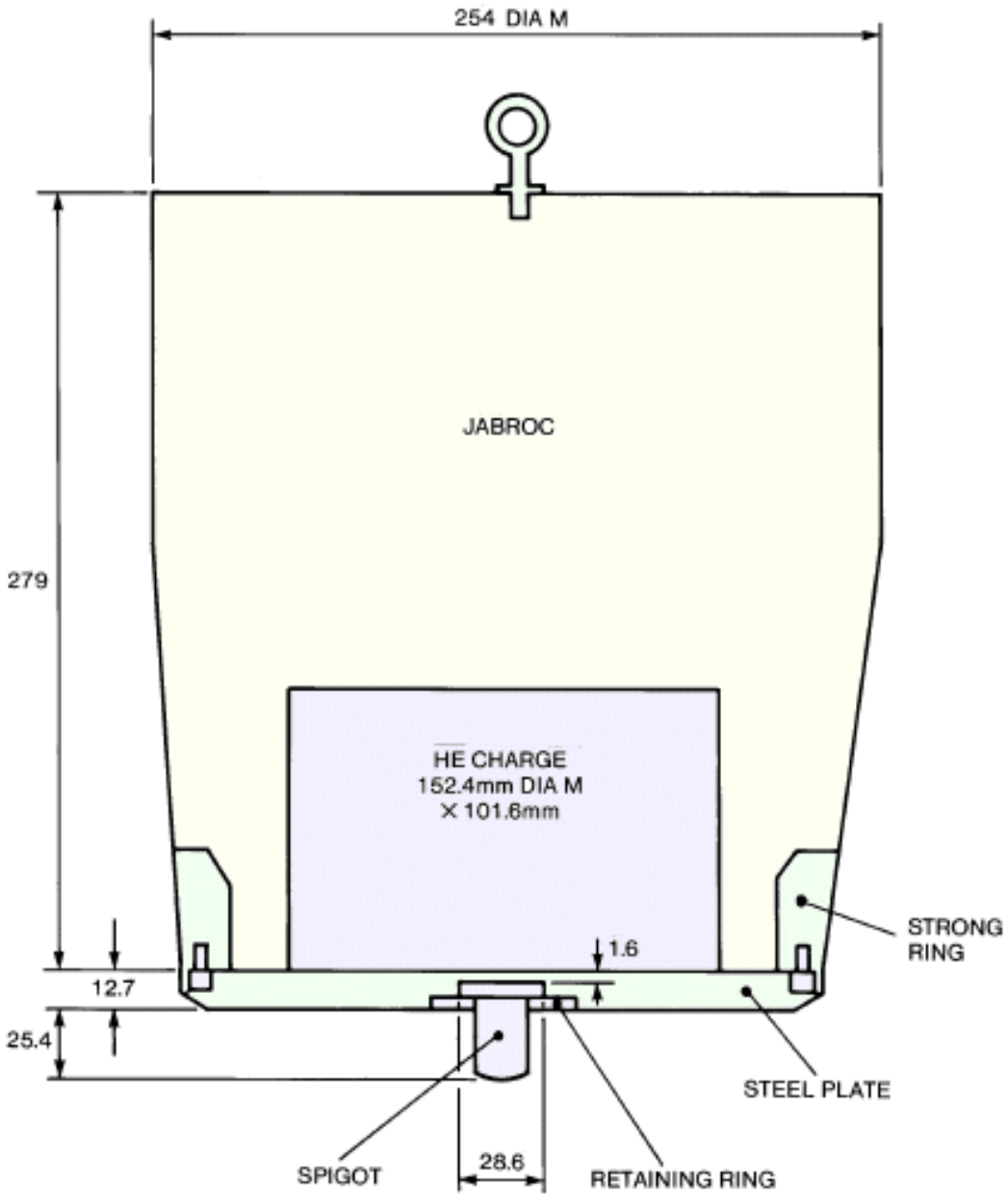
Hazard test – munition falls from a ship (during loading) and lands on dockside furniture…..

DROP A SPIKE ONTO A TETHERED MUNITION

- From say 10 m…
- Strikes munition
- Penetrates the case
- NOTHING HAPPENS!

- Let us drop if from 5 m…
- Should be safe ***BECAUSE*** lower kinetic energy
- Result: Oh dear……

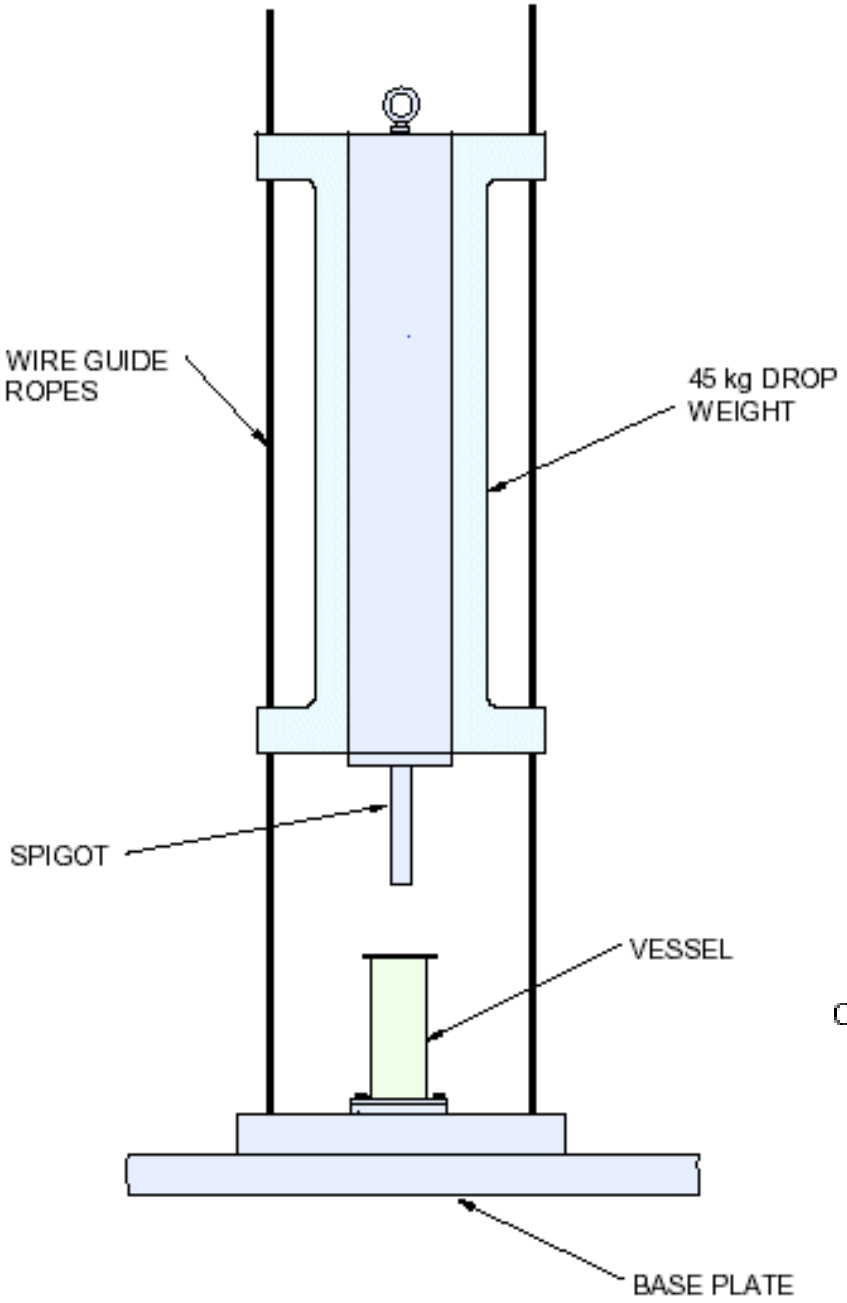
SUBSCALE TESTS

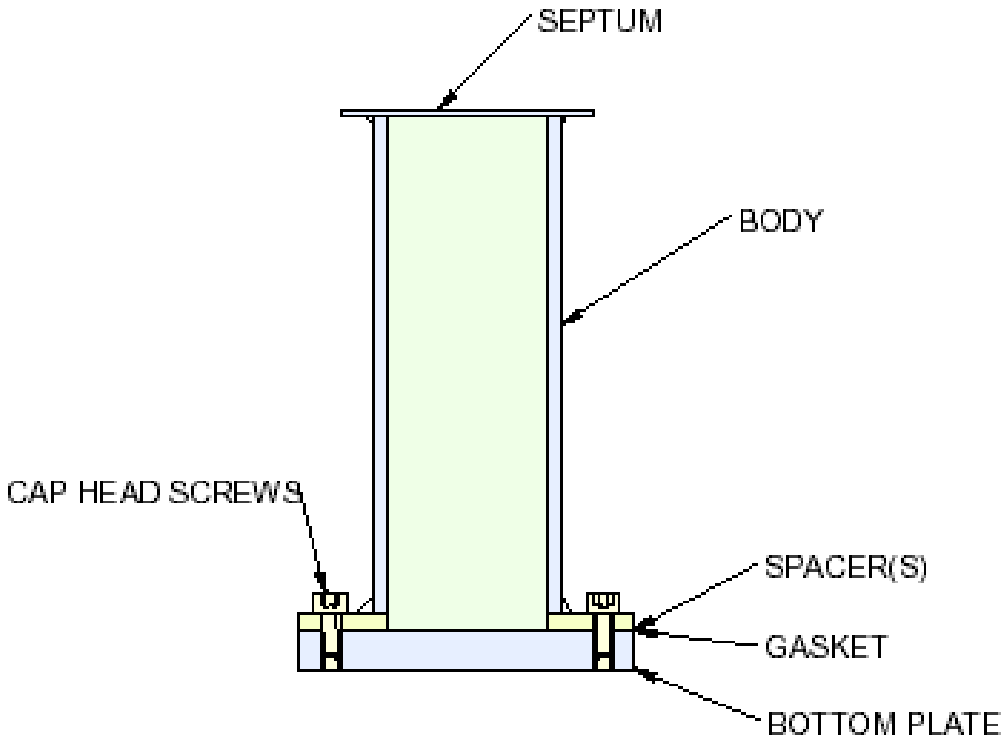


OVERAL WEIGHT 26.8kg

DIMENSIONS IN mm

SUBSCALE TESTS





What happened?

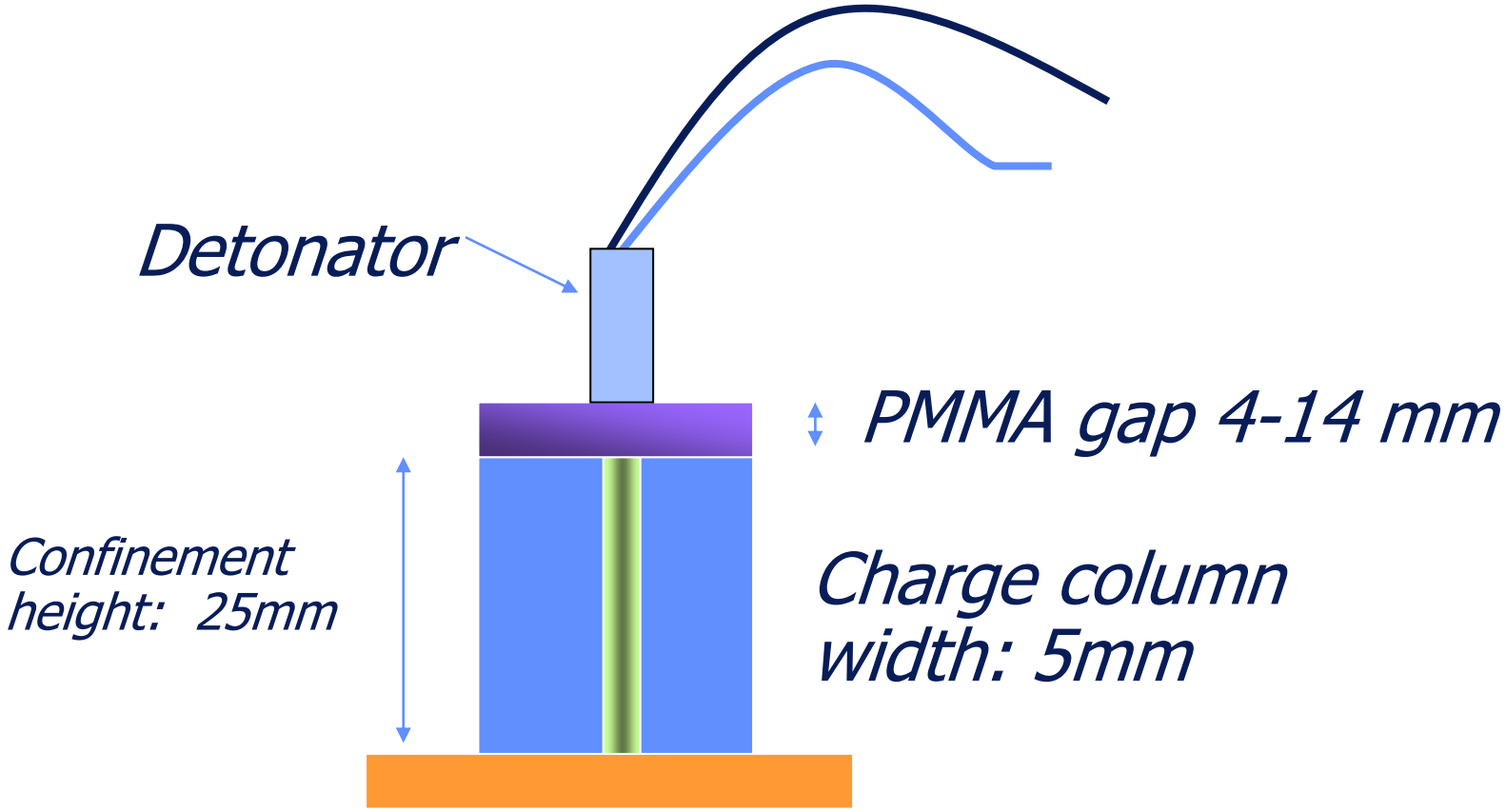
- At the higher drop height the spigot bounced out and any hot product gases were released.

- At the lower drop height the spigot penetrated and stayed in position
- Product gases built up, pressure increased and extended reaction resulted.
- **SUMMARY:** The lower kinetic energy resulted in a different global process

CRYSTAL POROSITY

"Hot spot theory says that internal voids in crystals are a key hot spot mechanism"

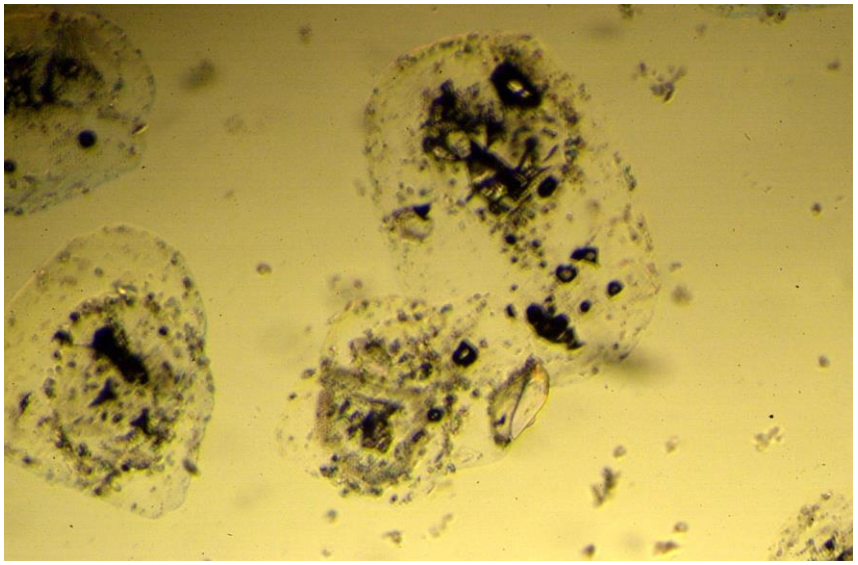
SENSITIVITY TESTING: SMALL SCALE GAP TESTS



EFFECT OF CRYSTAL QUALITY

Sample I: critical gap 7.9mm

1.5mm



Average number of voids: 35 per crystal

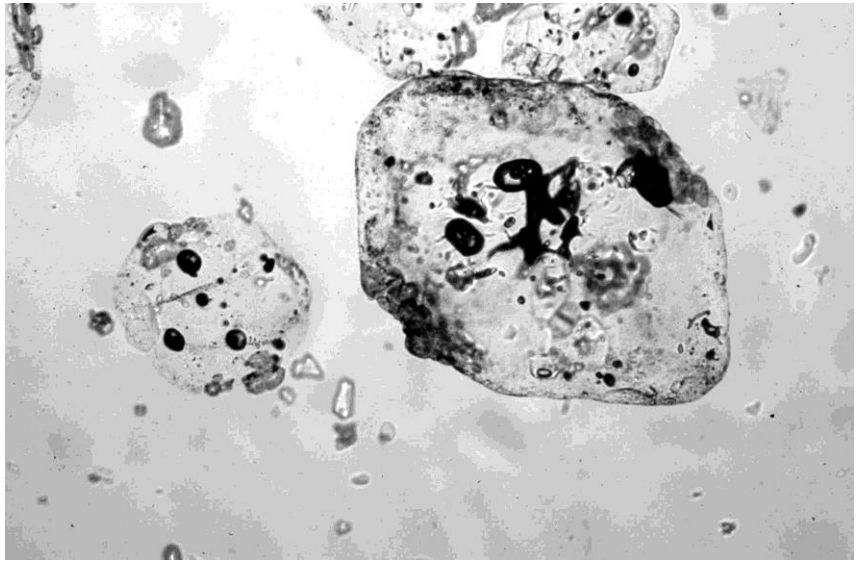
Av. Crystal size: 237μm

50μm

Class 1 Type - 150-250μm

SAMPLE D: CRITICAL GAP 8.3MM

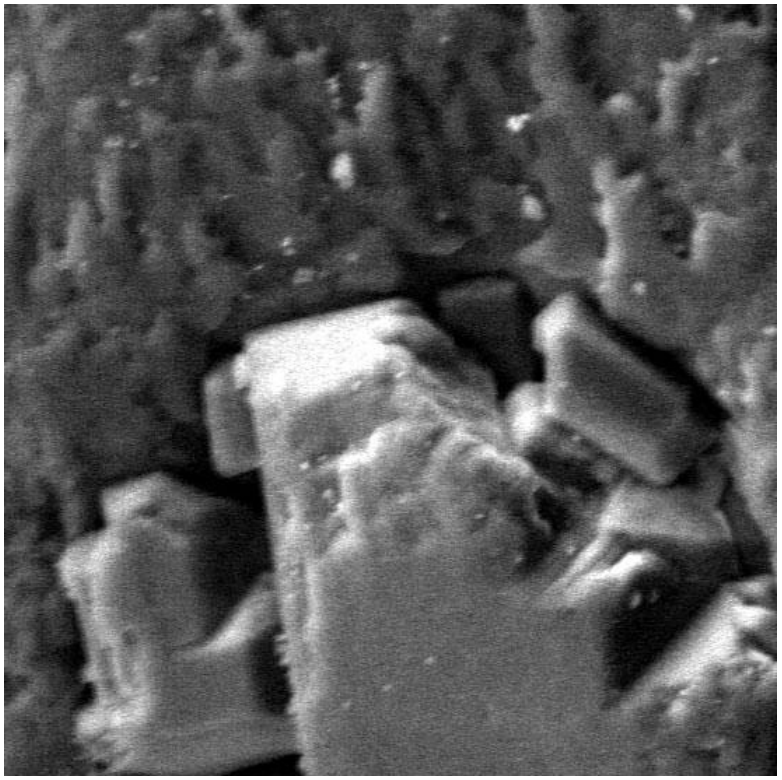
1.5mm



Av. No. of voids per crystal: 21

Av. Crystal diameter: 177μm

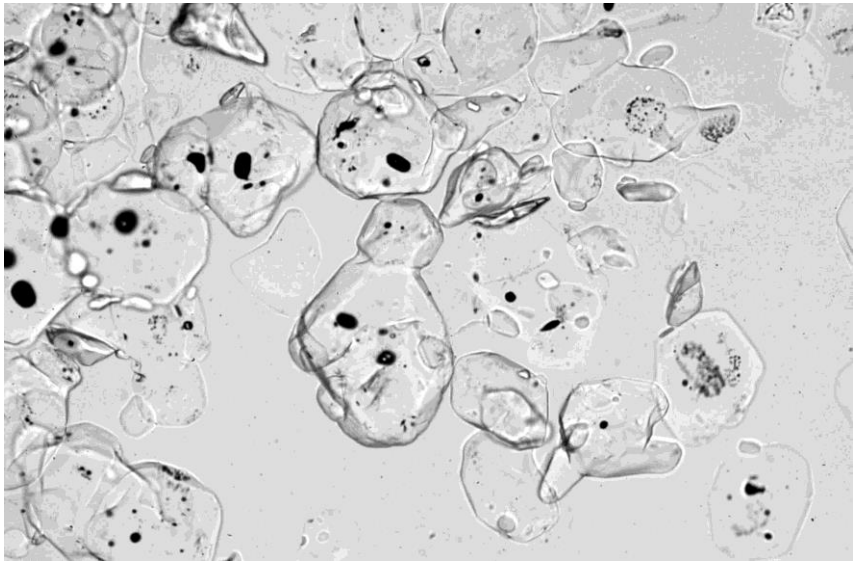
50μm



Class 1 Type - 150-250μm

Sample G: Critical gap: 9.3mm

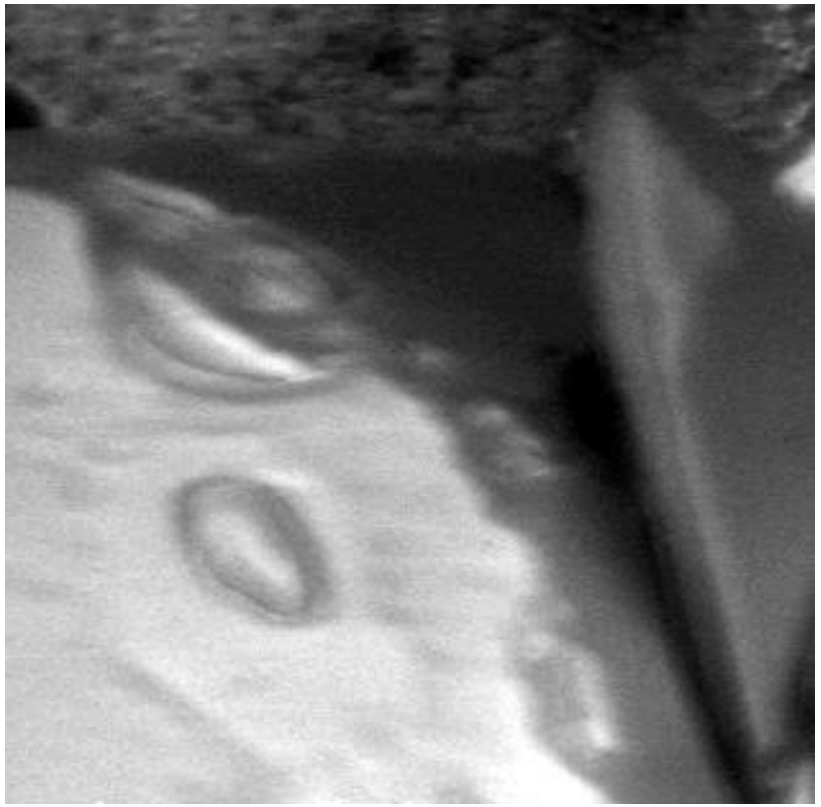
1.5mm



Average number of voids: 9 per crystal

Average crystal diameter: 165μm

50μm



Class 1 Type - 150-250μm

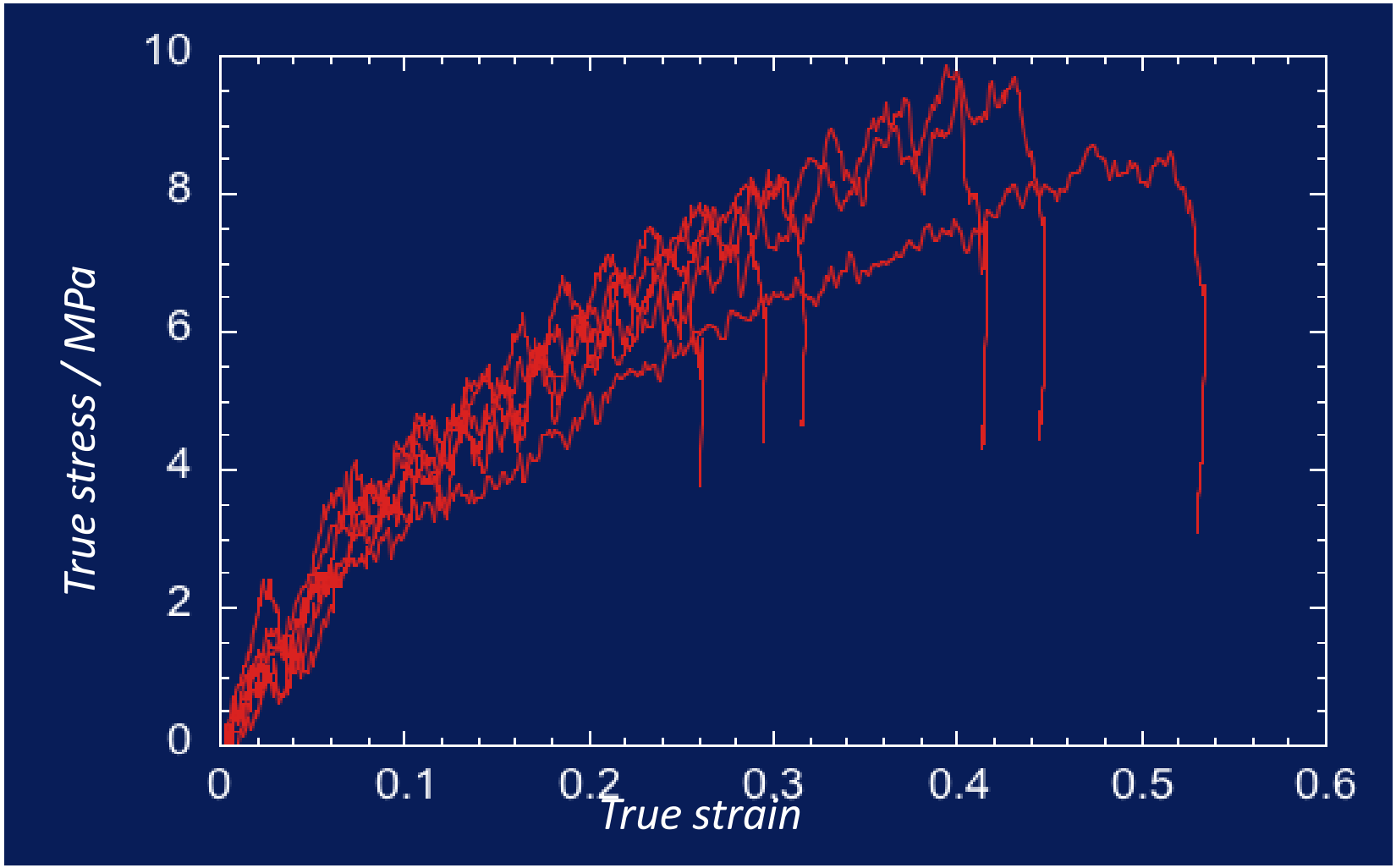
SUMMARY

- *Hot-spot formation and growth is dependant on multiple mechanisms*
- *Additive*
- *In a given situation one or more will be dominant. Surface defect density was the key process here.*
- *The desire or over-reliance on one explanation, in a complex scenario may lead you to be absolutely incorrect in your predictions*
- *Unexpected events lead to progress!*

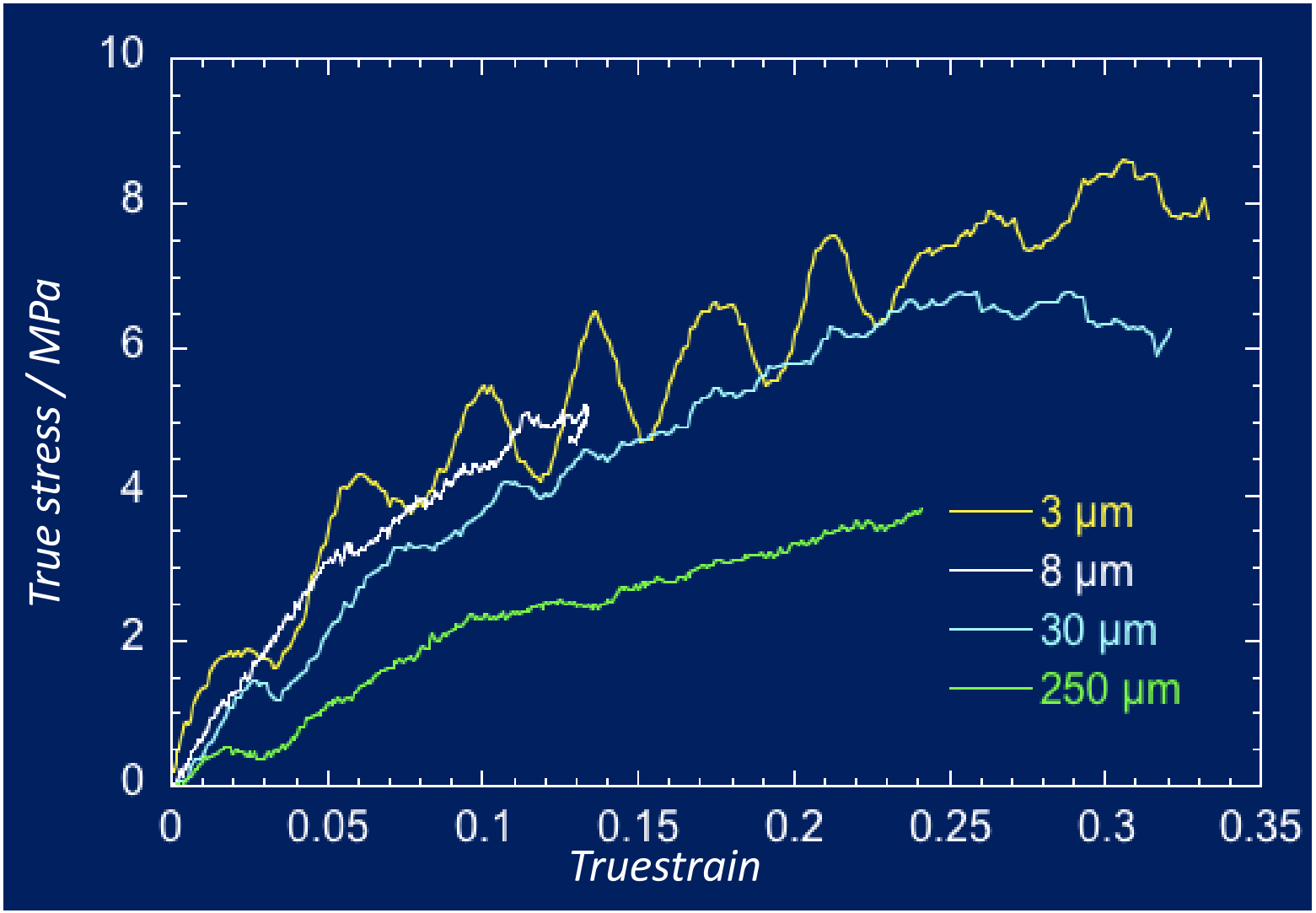
Dropping the Temperature will reduce the chance of reaction

"The required activation energy will be present in fewer molecules and so extended reaction will not be possible, in addition increased thermal cooling will prevent extended reaction"

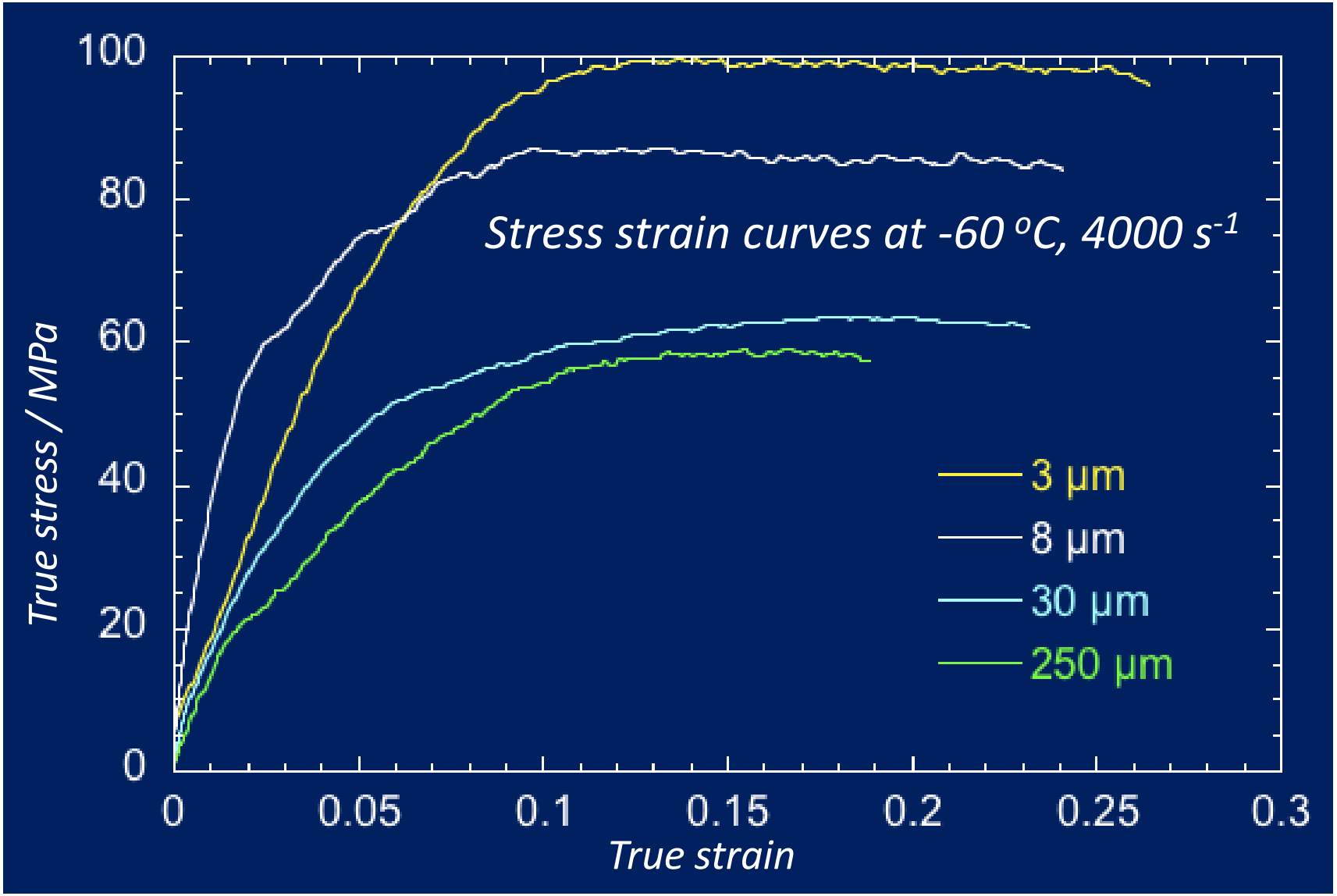
AP / HTPB: Room temperature



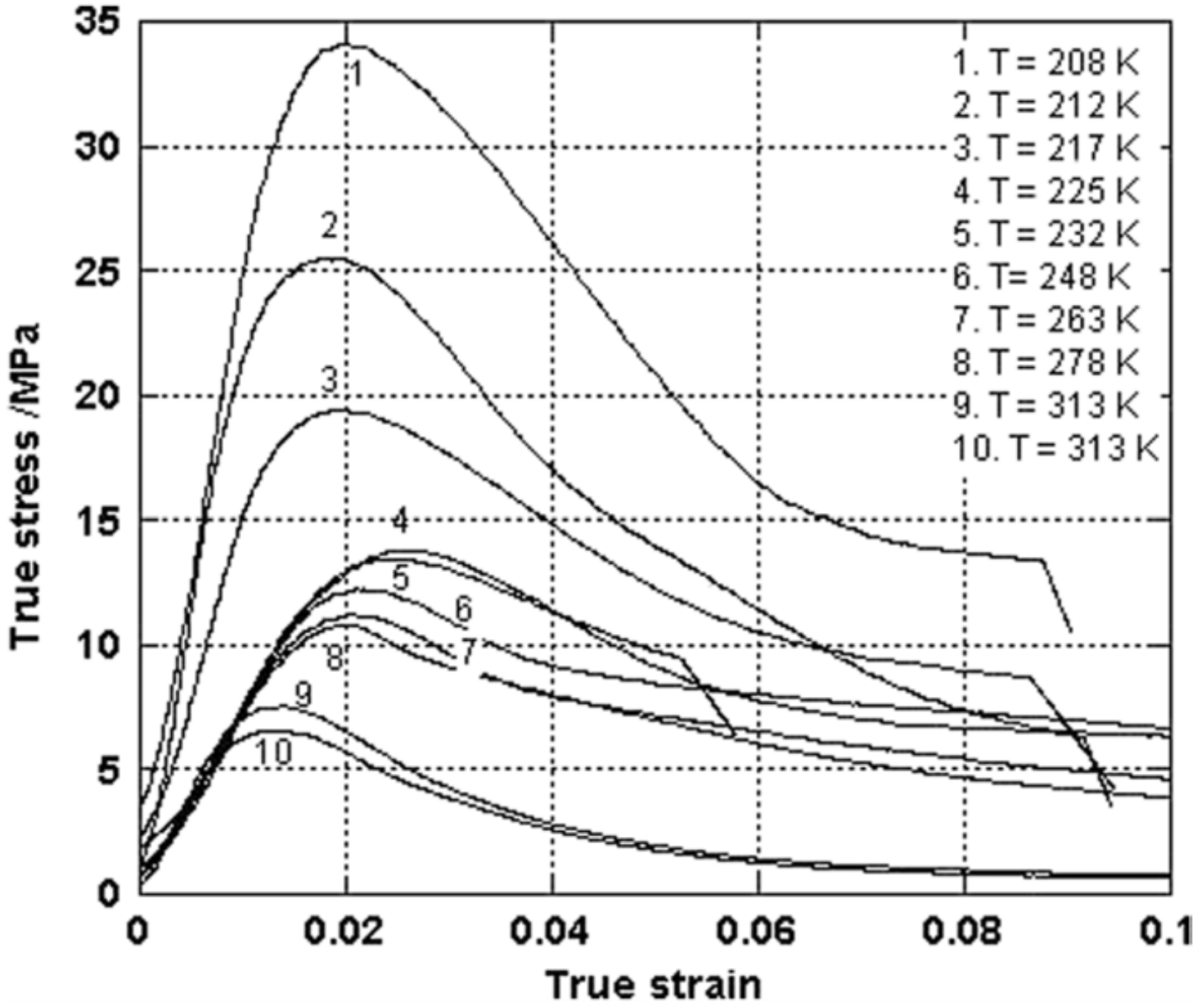
EFFECT OF PARTICLE SIZE



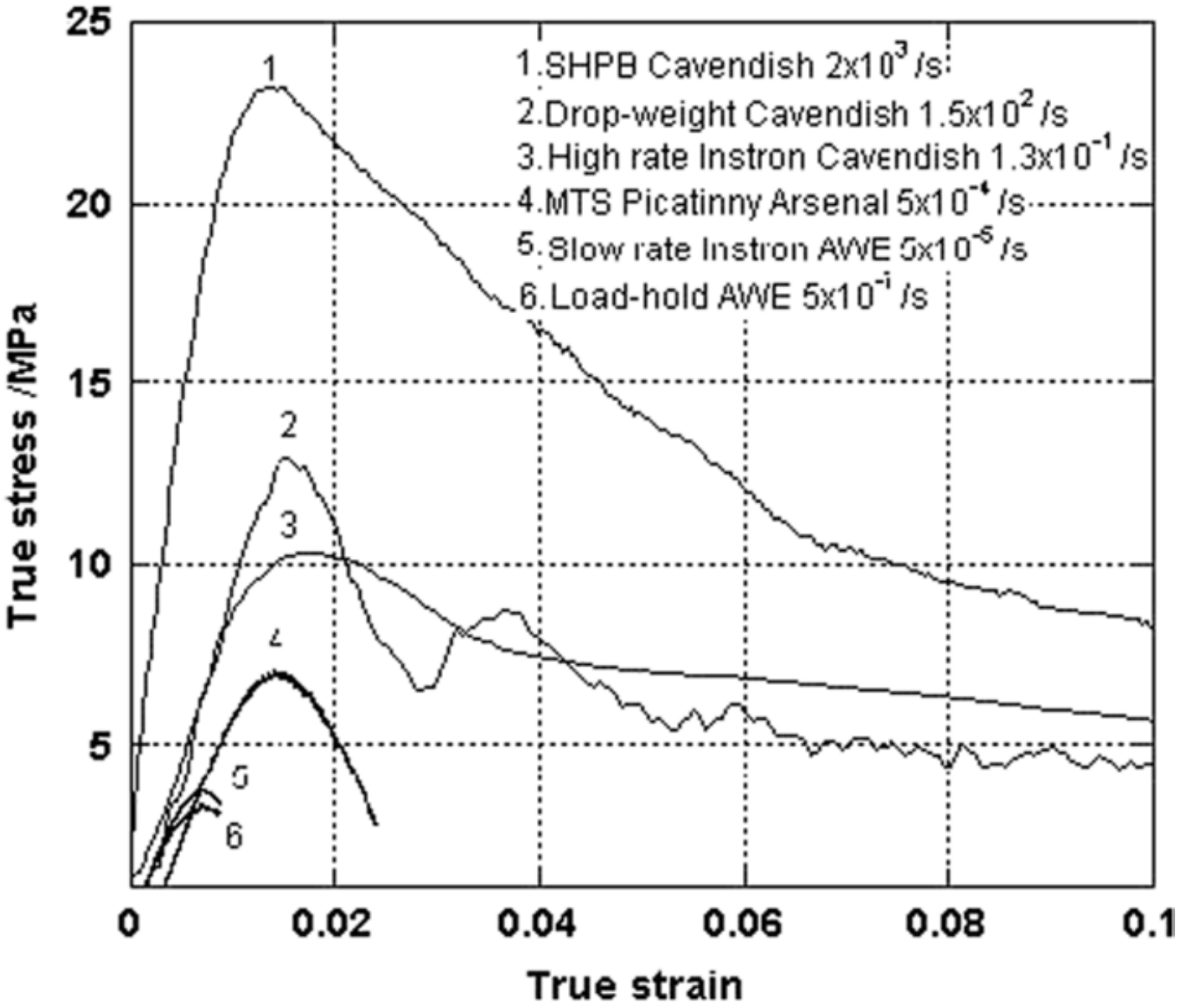
LOW TEMPERATURE



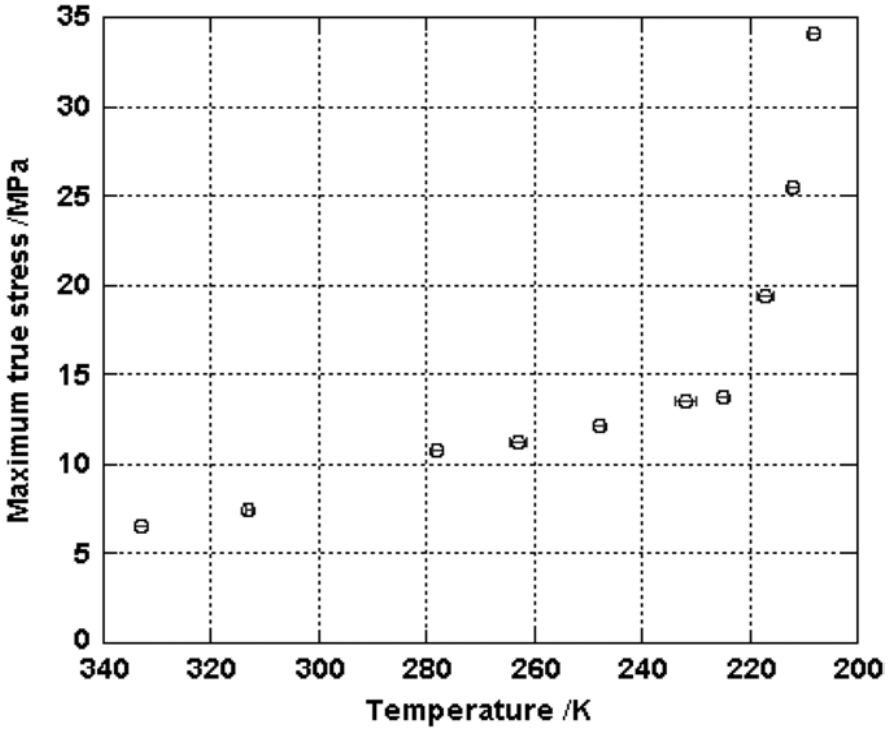
TEMPERATURE VARIED - HOPKINSON BAR

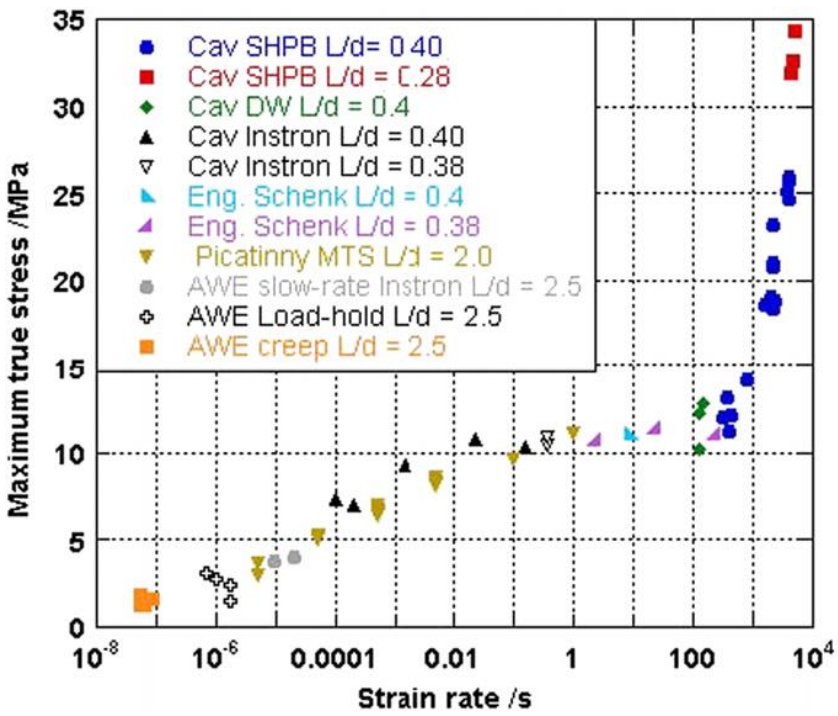


RATE EFFECTS....

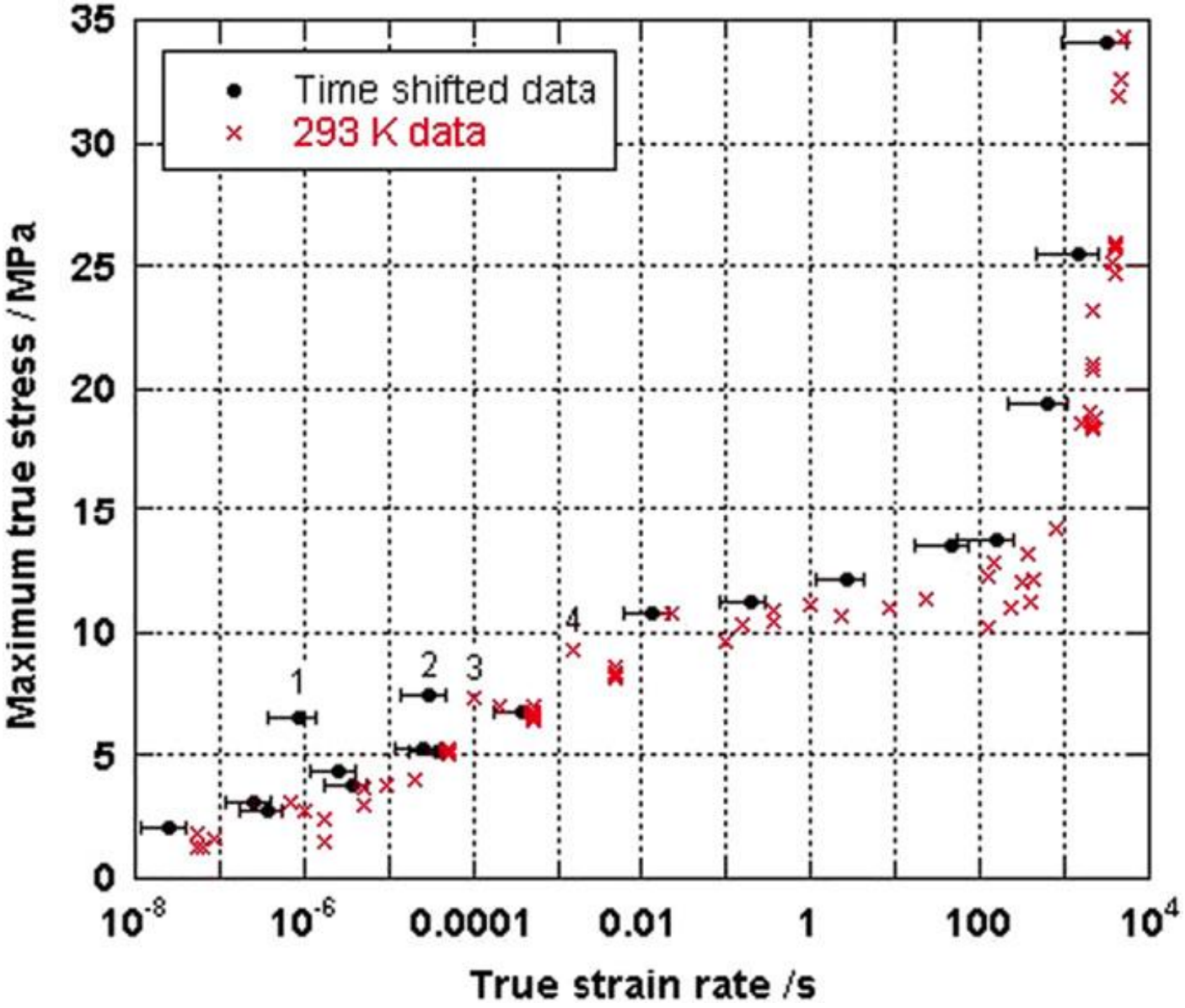


TIME - TEMPERATURE SUPERPOSITION





COMBINED DATA



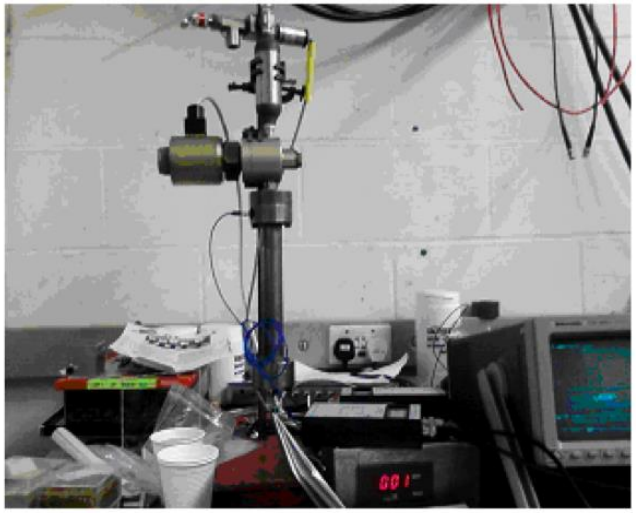
SUMMARY

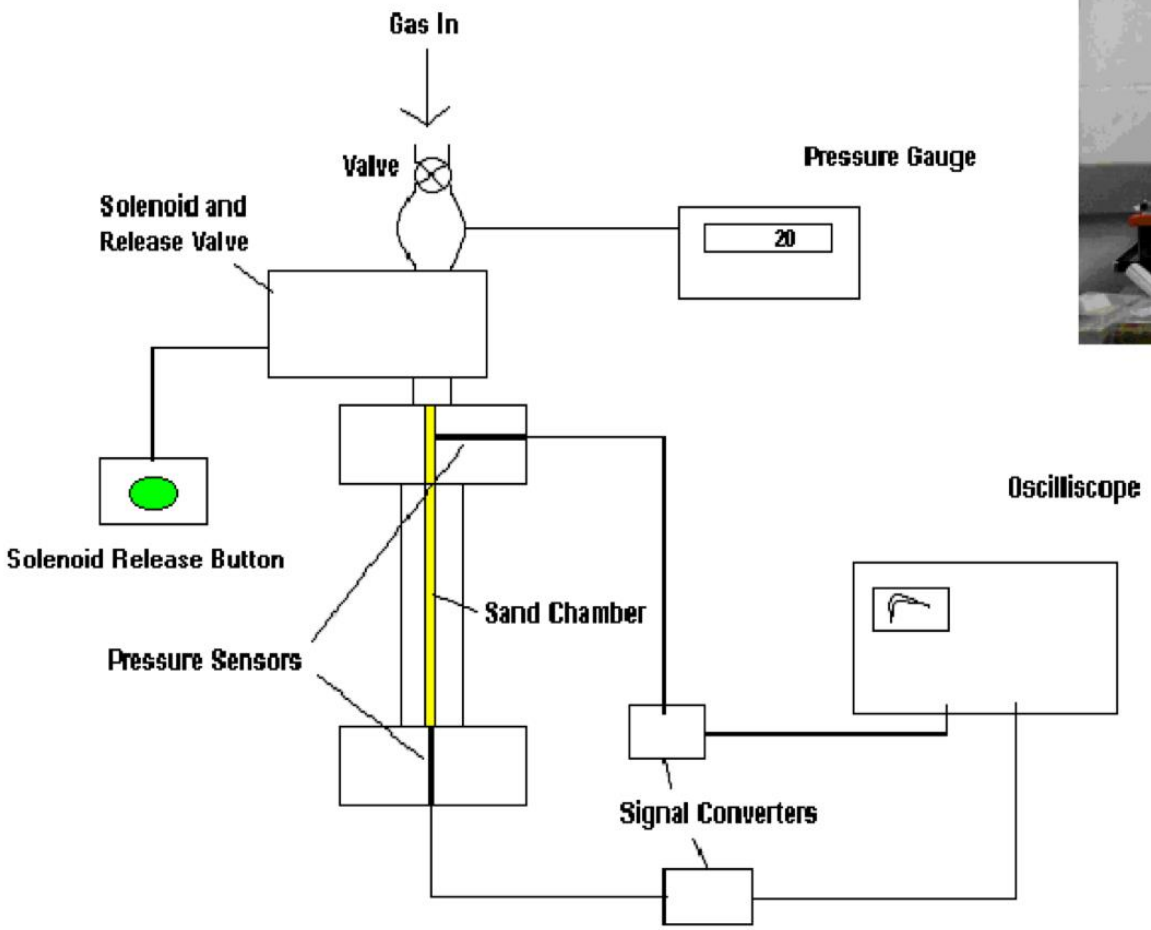
- Often multiple factors will be in balance and produce an overall result/effect.
- Changing the temperature strongly affects the mechanical properties of the PBX. The bonding to the munition case will also change… as well as energy levels within the molecules
- Fracture energy, often **forgotten** as a contributory factor, becomes a dominant mechanism

GAS FLOW

"Introducing more mass into a mitigation barrier in a blast scenario will absorb more energy and strongly mitigate the effects"

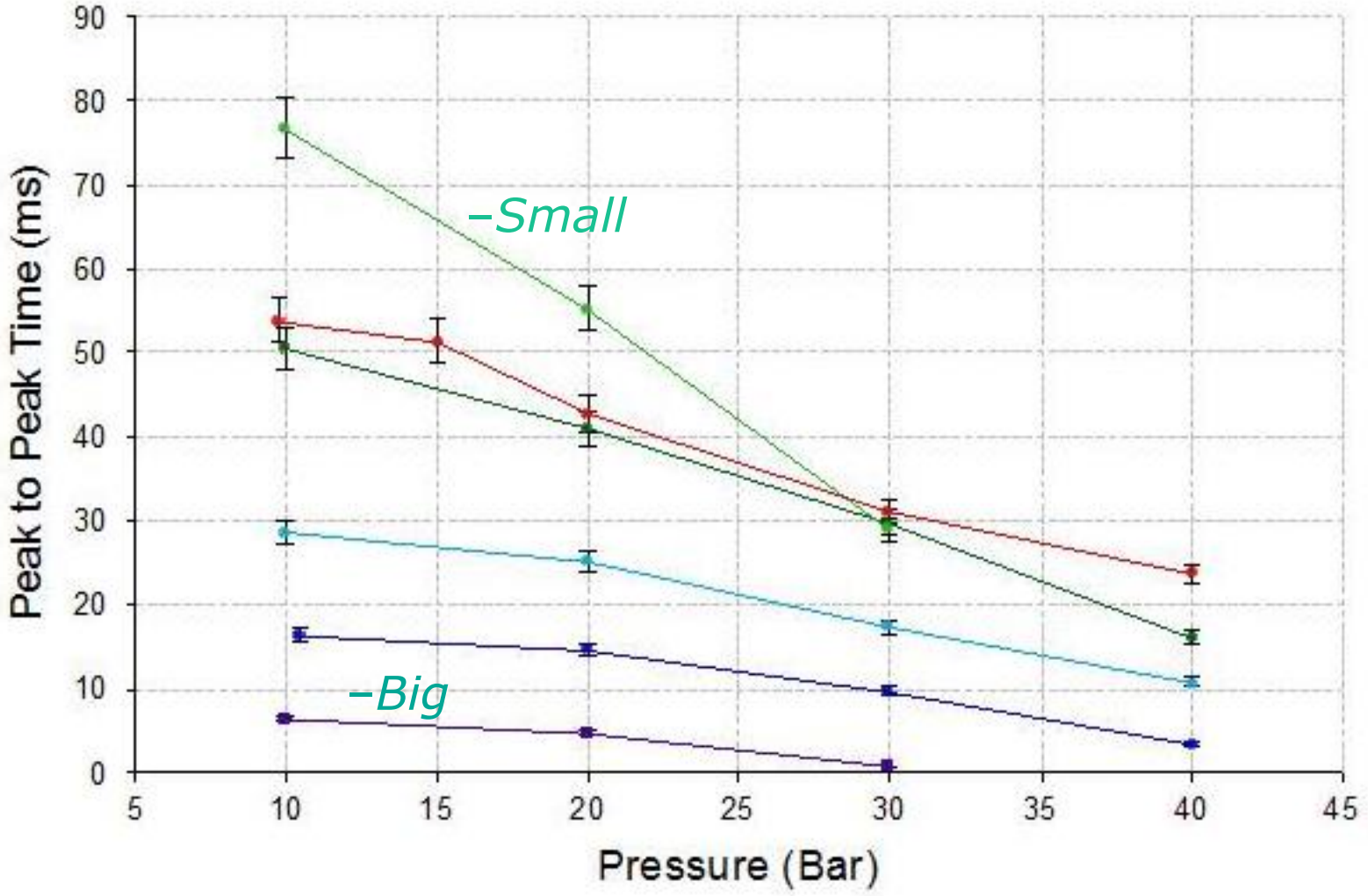
EXPERIMENTAL SET-UP



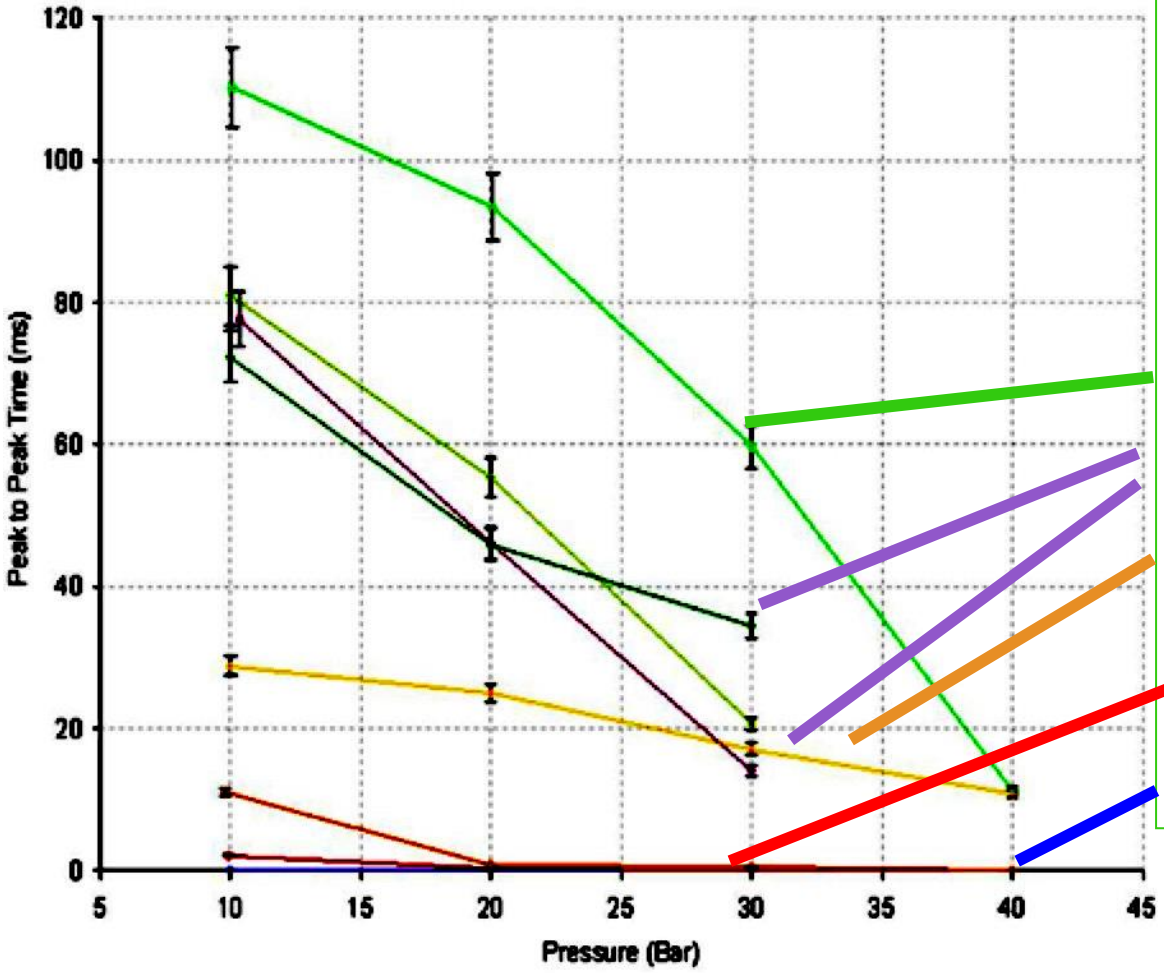


Sand Column
6mm diameter
210 mm long

Comparison of Peak to Peak Times with Pressure - Size



Peak to Peak Effect of Water Content



Sand = 57% volume (+/- 3%)
1.5 g / cm^{-3}

Water = added by mass
(0.5:10 / 2:10 / 3:10 / 4:10)

Porosity ~ gas volume

Sand /Water – 11% Porous

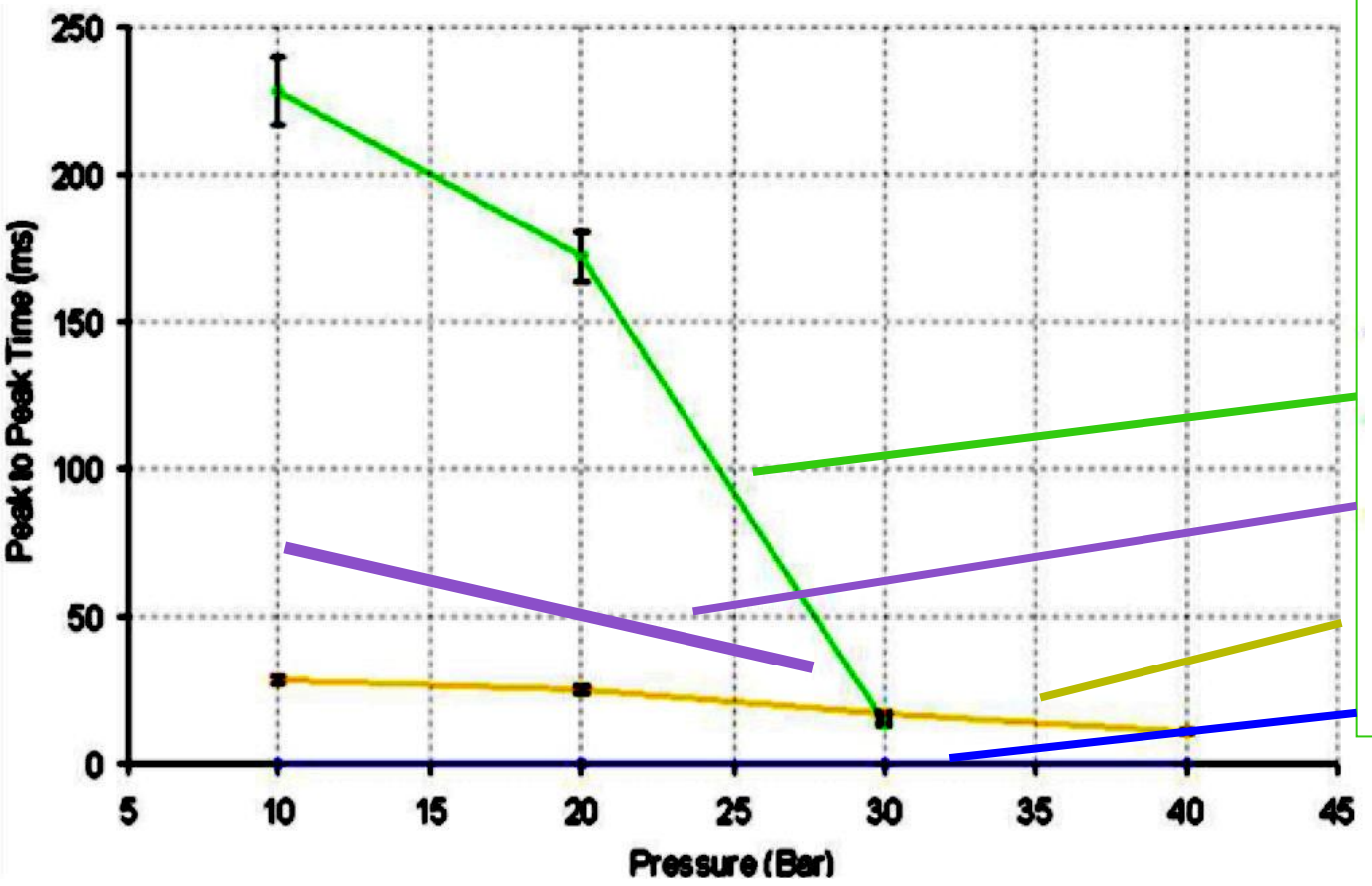
Sand / Water – 22% Porous

Dry Sand (43% porous) and Sand/Water – 38% porous

Sand/Water – ~3% porous

Water

.... ADDING OIL



Oil = added by mass
1.18 g / cm^{-3}
(2:10)

Sand /Oil – ~18%
Porous
Sand / Water – 22%
Porous
Dry Sand

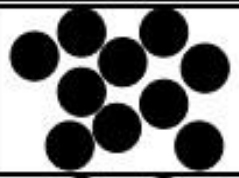
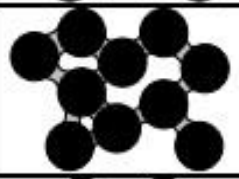
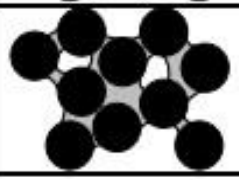
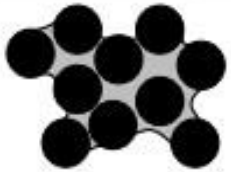
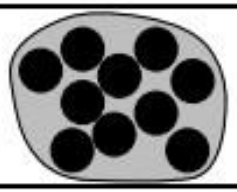
Oil

Viscosity (castor oil) viscosity is 985x10^{-3} at 25^{0}C
Viscosity of water is 0.89x10^{-3}

SUMMARY

- Grain size decreases, time taken for a pressure pulse to pass increases.
- For equal weight mixture of two grain sizes causes a peak to peak time closer to that of a sample with the smaller grain. (Despite an obvious porosity difference!)
- Completely saturated sand / water / oil give sub-millisecond transit time.
- Range of samples with adding LIMITED amounts of water exhibit increased peak to peak times compared to dry sand samples. Limited BUT SIGNIFICANT liquid motion

DESCRIPTION OF SATURATION LEVEL

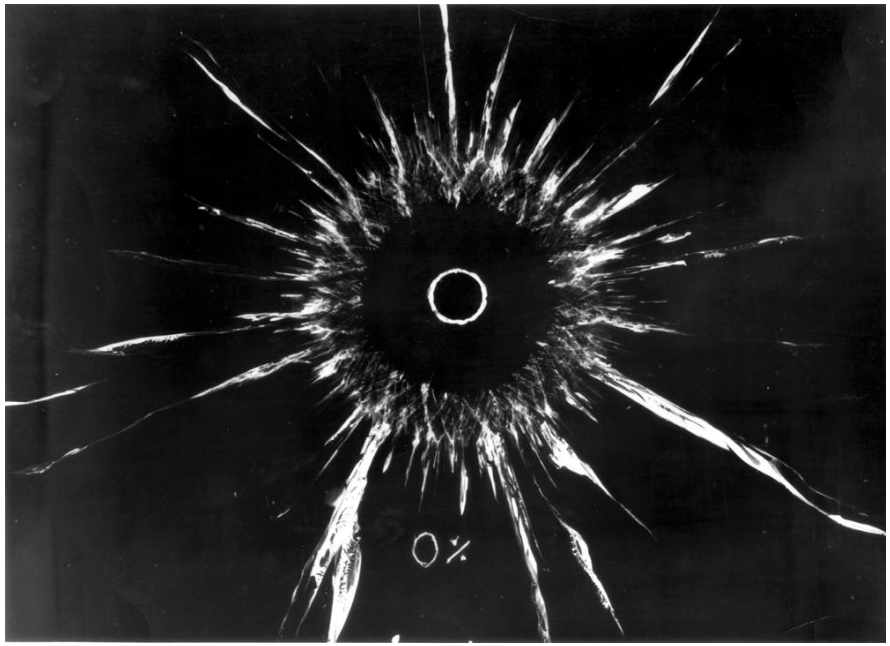
Liquid content	State	Schematic diagram	Physical description
No	Dry		Cohesion between grains is negligible.
Small	Pendular		Liquid bridges are formed at the contact points of grains. Cohesive forces act through the liquid bridges.
Middle	Funicular		Liquid bridges around the contact points and liquid-filled pores coexist. Both give rise to cohesion between particles.
Almost saturated	Capillary		Almost all the pores are filled with the liquid, but the liquid surface forms menisci and the liquid pressure is lower than the air pressure. This suction results in a cohesive interaction between particles.
More	Slurry		The liquid pressure is equal to, or higher than, the air pressure. No cohesive interaction appears between particles.

Namiko Mitarai and Franco Nori. Wet granular materials. arXiv, 55:1–4 (2006)

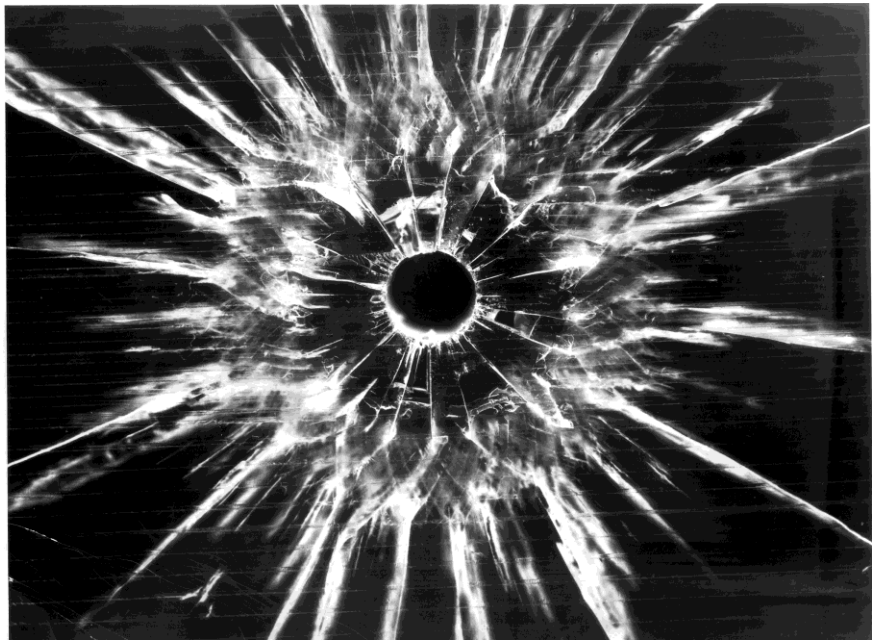
BOREHOLES

"If force does not work….. use more force"

CHANGING THE EXPLOSIVE LOADING



100% HMX



50% Salt 50% HMX

SUMMARY

- The extra pressure around the borehole causes the material to comminute intensely OR, for the polymer compress strongly which leads to greater confinement
- Less gas penetration
- More intense localised damage
- Reduced long distance effects

GLOBAL SUMMARY

Edgar Box:

"All models are wrong, some models are useful"

Albert Einstein (slightly misquoted):

"Nature is simple, but not that simple"

OVERALL

- Rules of thumb and experience are very useful in the planning and explanation of events
- Qualitative explanations can give insight and, in some circumstances will provide ideas for experiments and quantitative models.
- Over-reliance on one or two parameters can lead to incorrect predictions
- Counter examples can be found to all of the material presented here…..
- **Which is exactly the point!**

THANK YOU AND HAVE A WONDERFUL CONFERENCE!

Institute of Shock Physics