Processing Studies of Energetic Materials, using Resonant Acoustic Mixing Technology

Rosie Davey
Energetic Materials Scientist, BAE Systems Land UK
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  - The process: Conventional vs. RAM
  - Material Analysis
    - Chemical composition & Stability, Thermal, Physical, Mechanical analysis
    - Hazard and Performance testing
  - RAM Advantages
- Conclusions

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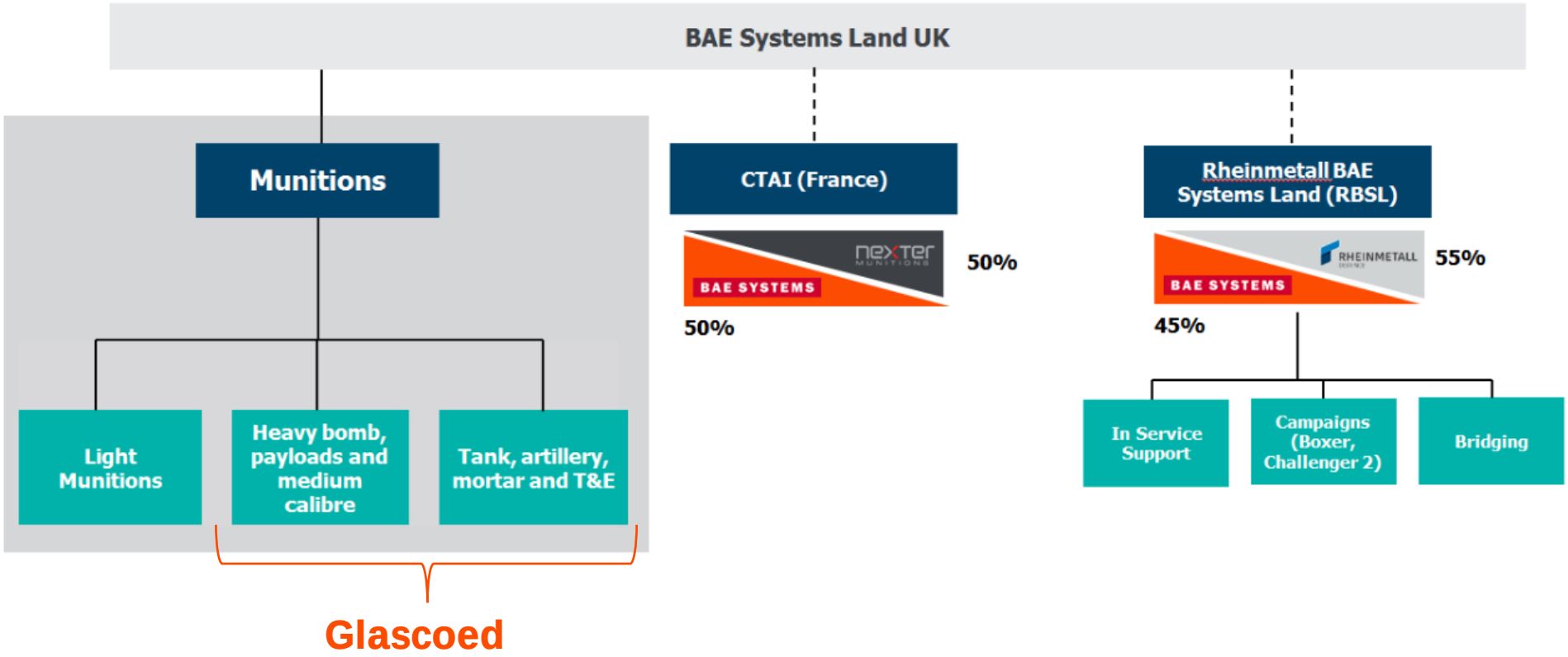
BAE Systems, Land UK: Who We Are



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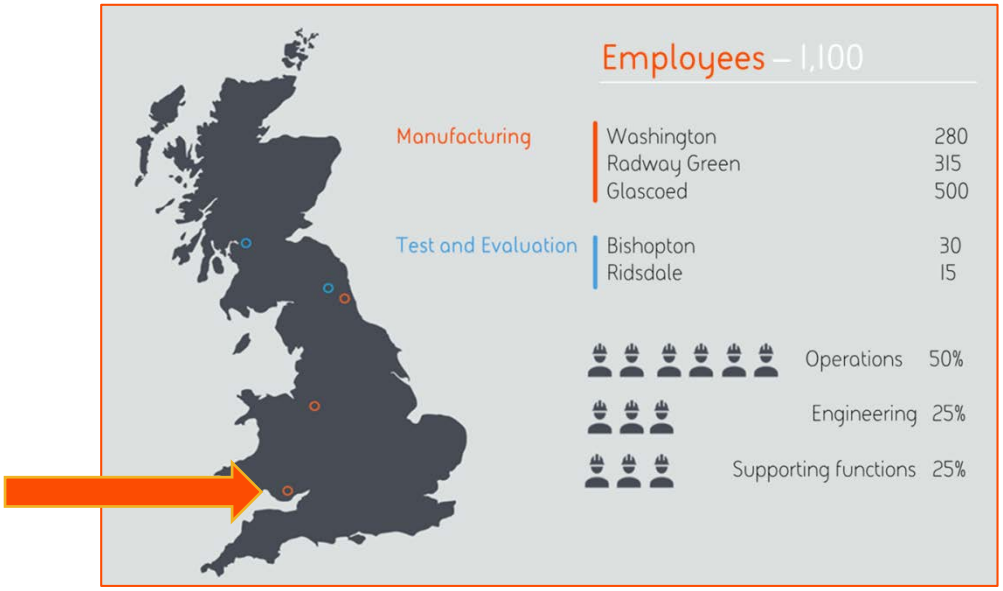
BAE Systems, Land UK: Who We Are



Glascoed:

- 1000 acres
- 500-600 people
- Munitions manufacturing site

- Fill, assemble & Pack
- Heavy & Medium Calibre
- Test Facilities

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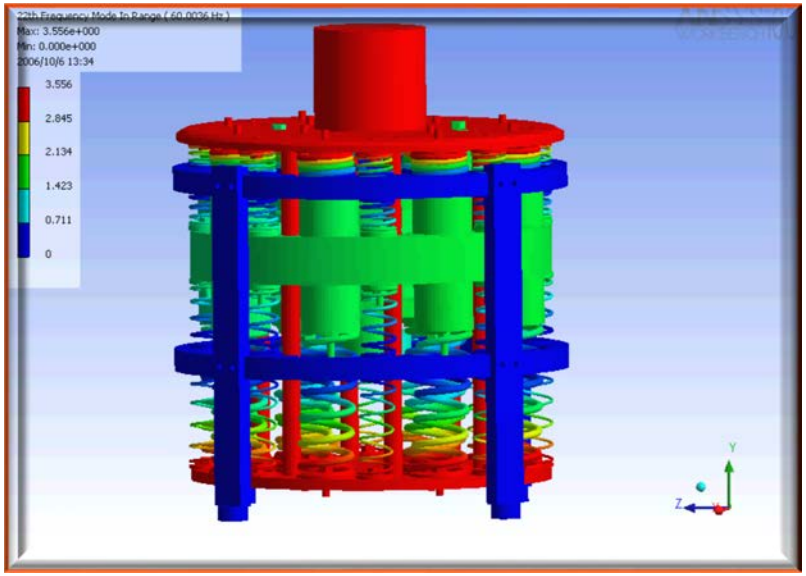
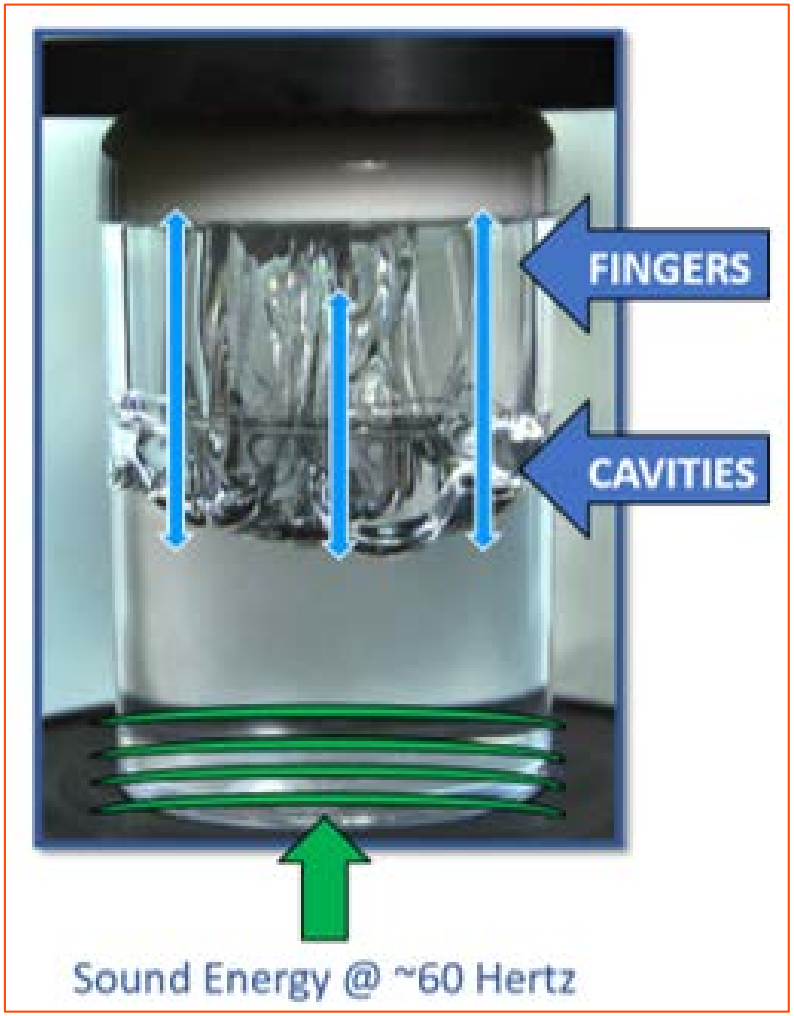
RAM – In brief!

- Resodyn's ResonantAcoustic® Mixing technology
- Acoustic energy transferred to mechanical motion
- Efficient – system operates in resonance
- Low frequency, but high accelerations



Both images are the property of Resodyn



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RAM – In brief!

- The ‘RAM Family’:

LabRAM
500g

LabRAM II
1 kg

RAM 5
36 kg

RAM 55
400 kg

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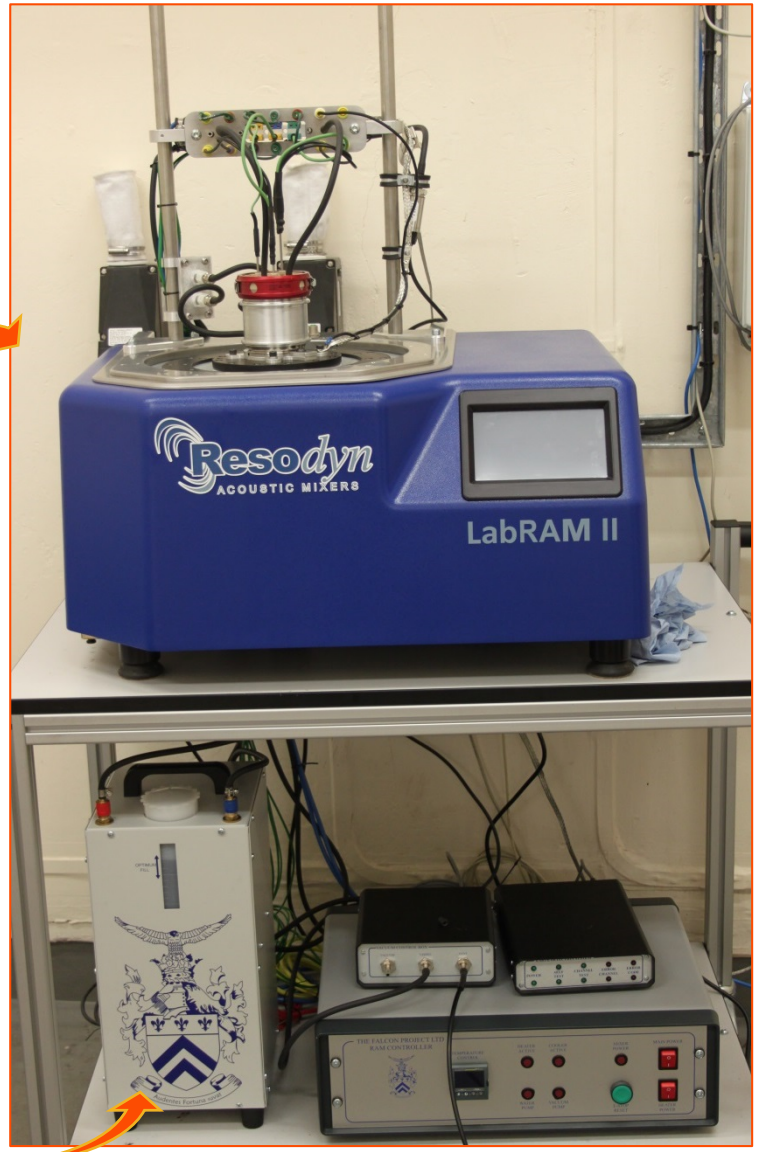
RAM facilities at Glascoed

- LabRAM and LabRAM II

Resodyn LabRAM systems



Falcon Project Controls

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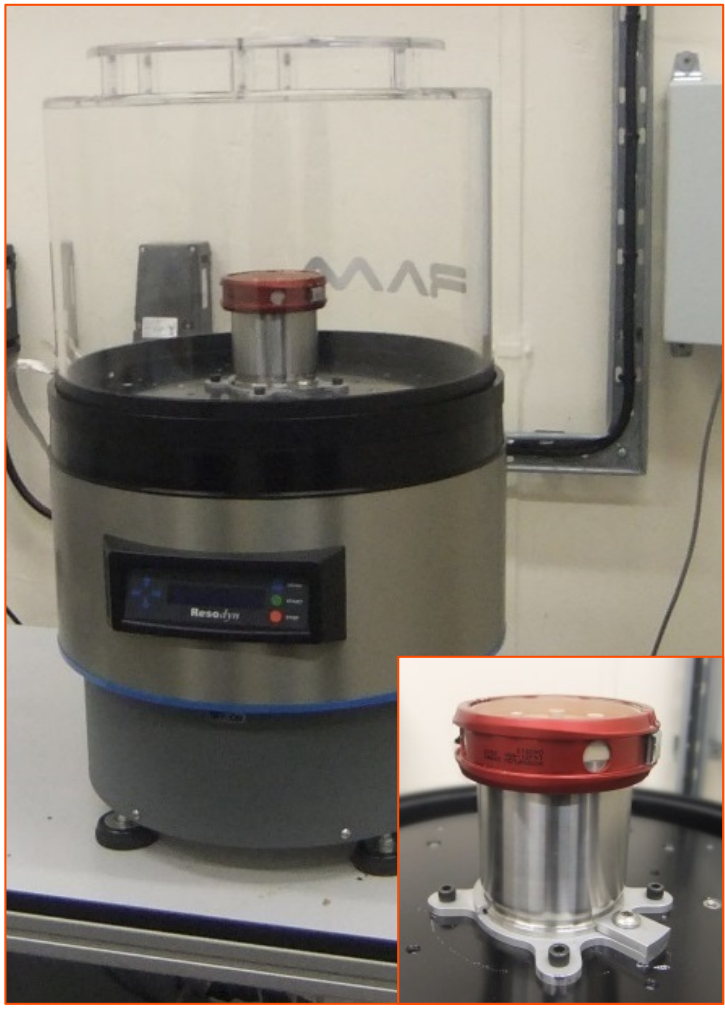
This work: PBX Comparison Trial

Objective: Determine whether the properties of RAM & conventionally processed material are comparable.

- Energetic Materials
- Comparison of processes
- Compare material properties
  - Various RAM parameters
  - RAM vs. Conventional
- Assessment of advantages
- Other work (incl. MIC)



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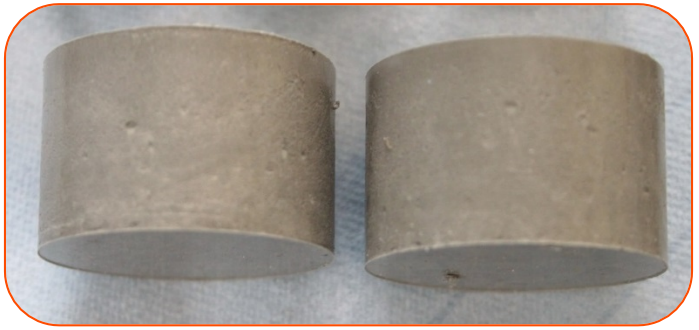
Energetic Materials



Main Topic of Comparison

Polymer Bonded Explosive (PBX)

- BAE Systems proprietary PBX:
  Aluminised RDX / HTPB binder

Other

PBX – RDX / HTPB (non-aluminised)

Low Vulnerability Ammunition Propellant (LOVA)

- Nitrocellulose-free, RDX / EVA binder

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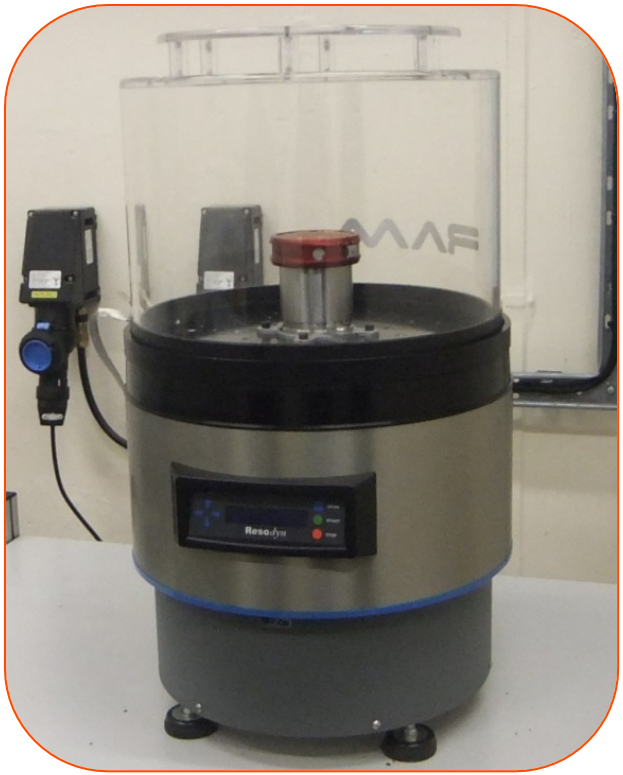
The Processes: Conventional vs. RAM

Planetary – HKV5 (5 kg)



LabRAM (350 g)

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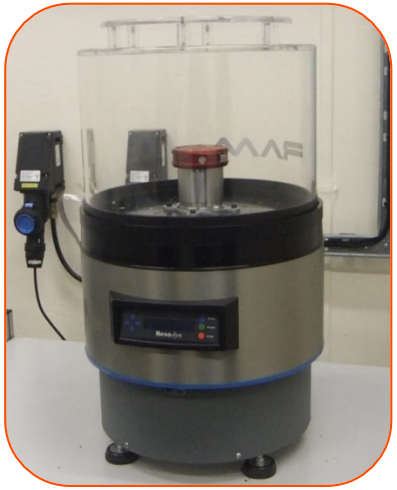
The Processes: Conventional vs. RAM

Planetary – HKV5

- Bladed mixer: High shear, at localised regions
- Mix duration
  - PBX: 4 hours or a few days (5 or 1600 kg)
  - LOVA: 5 hrs, over 2 days (6.5 or 18 kg)
- Incremental ingredient addition: 100 minutes



LabRAM / LabRAM II

- No internal moving parts: Low shear, throughout
- Mix duration
  - PBX: circa. 20 mins (350 g or 1.2 kg)
  - LOVA: circa. 1 hr (<1 kg)
- One-step ingredient addition: 20 minutes

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The Processes: Sample Manufacture

Vacuum Casting (Planetary only):

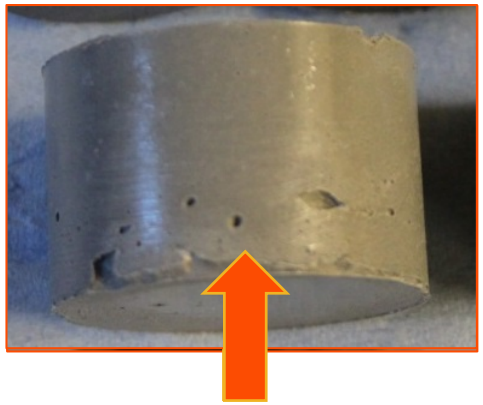
- Direct fill from vessel base into vehicle
- Vessel and filling chamber kept under vacuum throughout

Manually filling (utensils)

- Hand fill from vessel into vehicles
- Vacuum applied to samples post-fill

LSGT Tube

Top of LSGT Tubes



Vacuum Cast

Manually Filled

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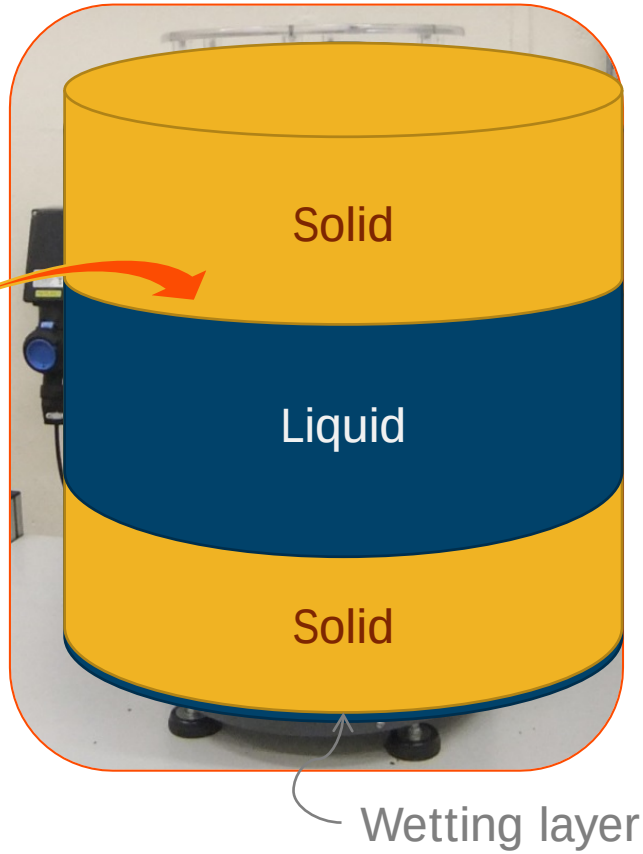
The Process: RAM Parameters

- **Process variables**:
  - Acceleration level (30-80 G)
  - Main mix duration (2.5 – 40 minutes)

- **Process constants**, including:
  - Layering: ‘Liquid Sandwich’ approach
  - Mix Regime:
    - Wetting stage (low G, 2 minutes)
    - Main mix stage (*x* G, *y* minutes)
    - De-gas stage (low G, 5 minutes)



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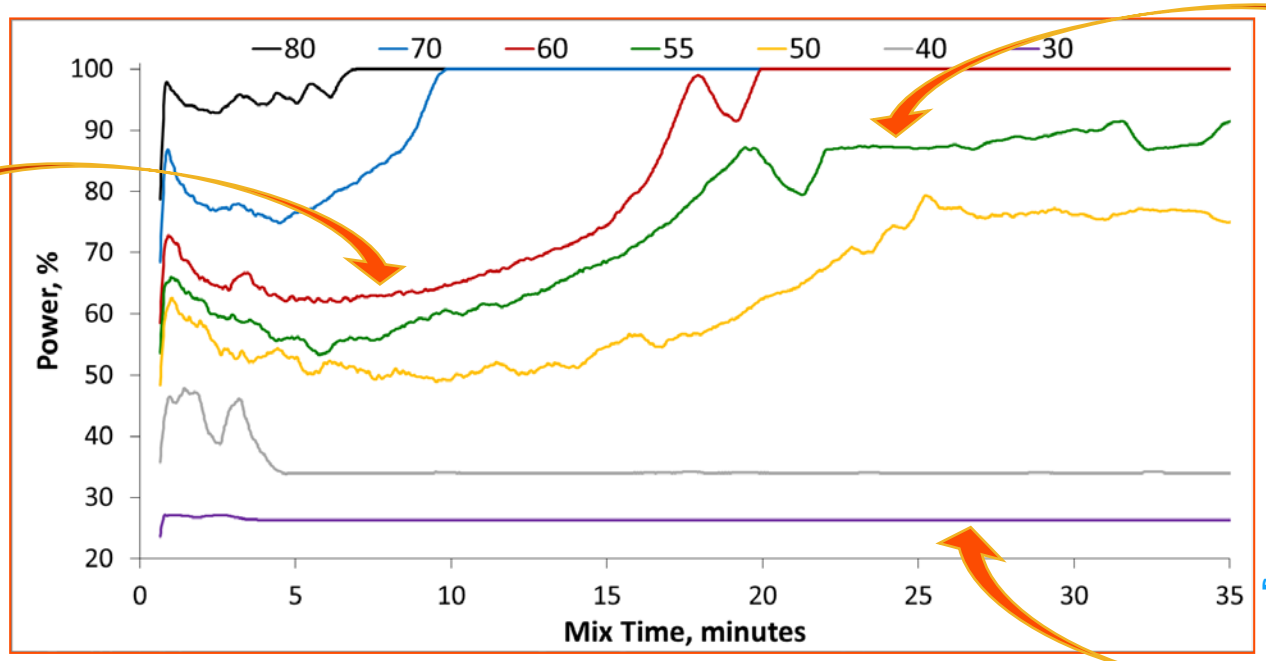
‘Flat-lining’

The Process: RAM Parameters – **Acceleration**



Power variation

‘t_p’

‘Flat-lining’

LabRAM power input traces (moving average) for 40 min mixes

- Acceleration: 30-80 G Duration: 40 minutes continuous
- LabRAM power input & visual inspections
- Near-consistent power (plateau point t_p) was taken as level of sufficient mix completeness
  - 50 G was lower limit for mixing – ‘flat-lining’ of trace or powdering
- Power variation a sign of mixing action / change in mix composition (> 50 G)

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Material Comparison

LSGT Set-Up

- Compare material properties:
  - Various RAM parameters
  - RAM vs. Conventional

- Material Analysis :
  - Visual Observations
  - Chemical composition and stability
  - Thermal characterisation (DSC, T_g)
  - Physical characterisation – Density & Hardness
  - Mechanical – Compressive strength
  - Hazard & Performance – EMTAP tests, LSGT & VoD

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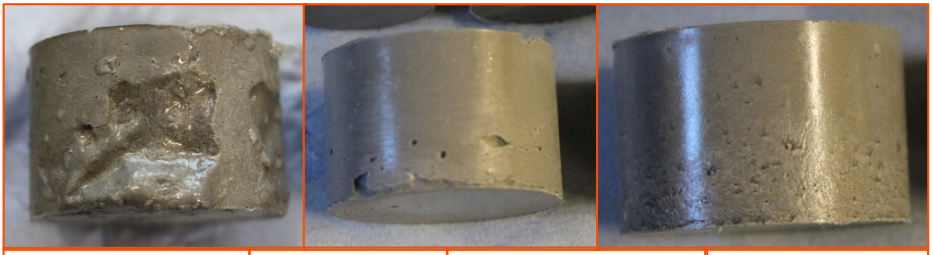
Material Comparison



Variation in sample quality – 40 G, 60 G, 60 G with vacuum

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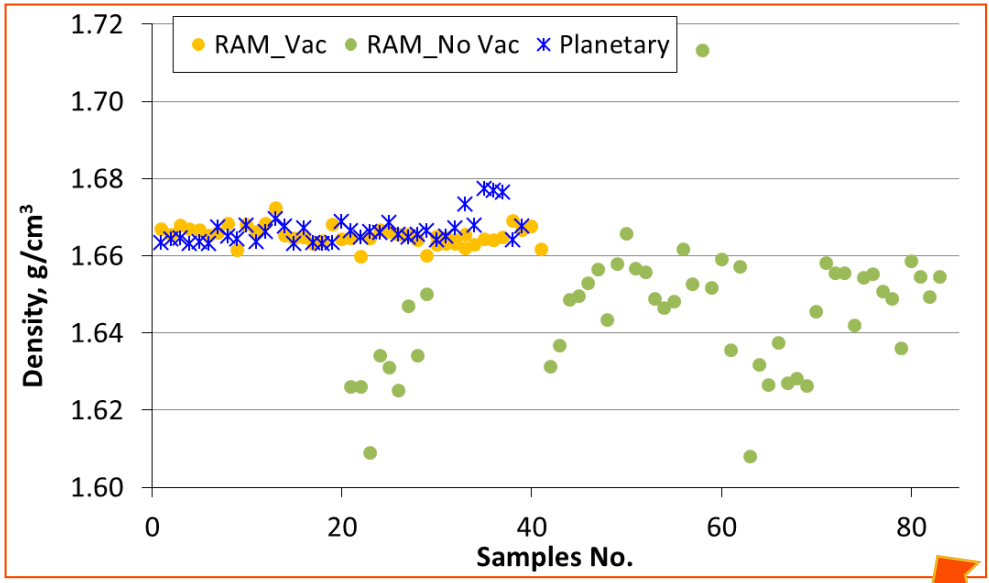

- Visual Observations: ≤50 G, or $<½t_p$ at 55-80 G → Uncured material / incomplete mixing
- Chemical composition, vacuum stability, and thermal properties (DSC & T_g):
  - Little variation with acceleration level, or mix duration
  - RAM and planetary samples were comparable
- Density: Comparable densities for all samples (RAM and planetary)
  - Increased consistency when prepared with vacuum

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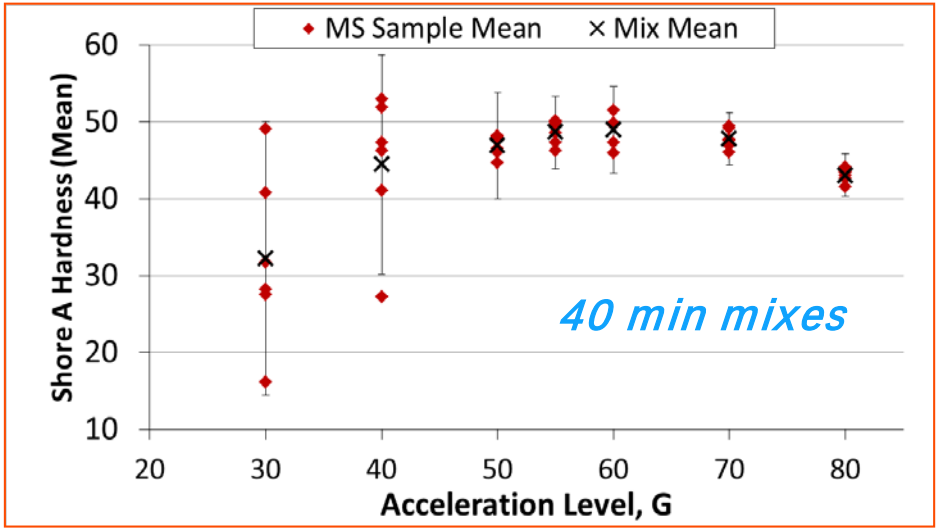
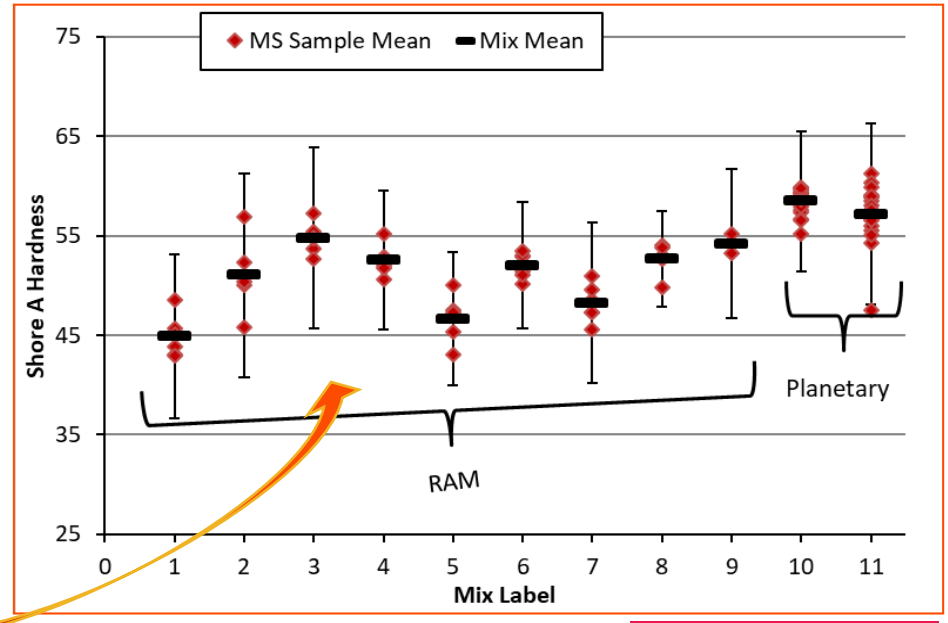
Material Comparison

Shore A:

- Correlated to visual observations
- Values generally increased up to t_p
- <50 G:
  - large range → poor curing characteristics
- ≥50 G:
  - Reduced range (within specification)
  - RAM & planetary samples reasonably comparable
    - Possible signs of harder surface with planetary





RAM Repeatability

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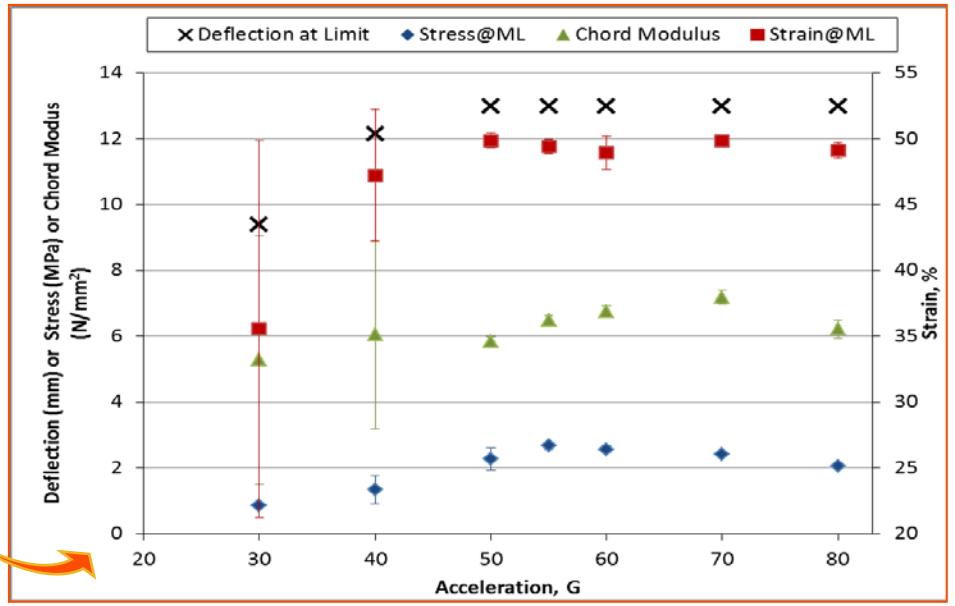
Material properties

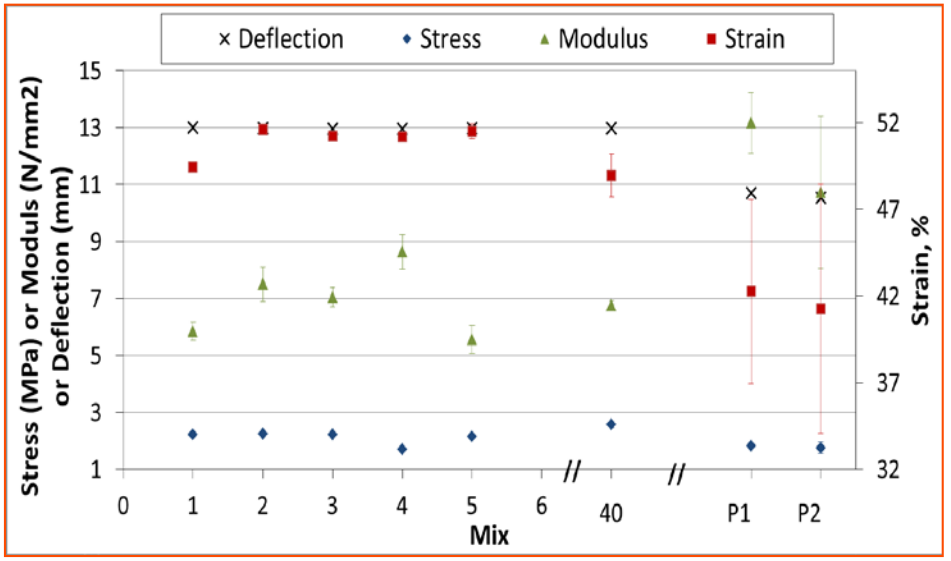
Compressive Strength Properties:

- Improved properties with increasing RAM mix duration (nearer to t_p) & >50 G



RAM (≥55 G) vs. planetary

- RAM samples: greater compressibility
- Planetary sample: appeared stiffer
  - Supports Shore A data
- Differing mix characteristics altering polymer matrix formation (?)



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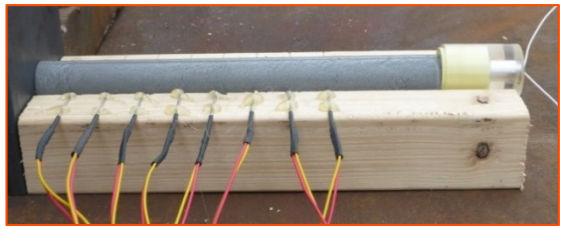
Hazard and Performance testing

- All performance and hazard data suggests RAM and Planetary mixing produce material with very similar Hazard and Performance characteristics

VoD Set-Up



Test	RAM	Planetary
F of I	111	112
T of I	209.8	214.3
Electric Spark	Ignitions at 0.45J, No ignitions at 0.045J	
Ease of Ignition	Fails to ignite	
Train Test	Ignites and supports the train steadily throughout	
LSGT, 50% point & Pressure	32.00 mm 4.401 GPa	29.30 mm 4.776 GPa
VoD, m/s	7393 ±641 (7503 ±228)	7483 ±578 (7563 ±145)
GLS (no voids)	No Goes up to 300 MPa	No Goes up to 300 MPa

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Assessment of Advantages

- Material Comparison
  - Shows that RAM & Planetary samples are not significantly different
  - Results expected given formulation is identical

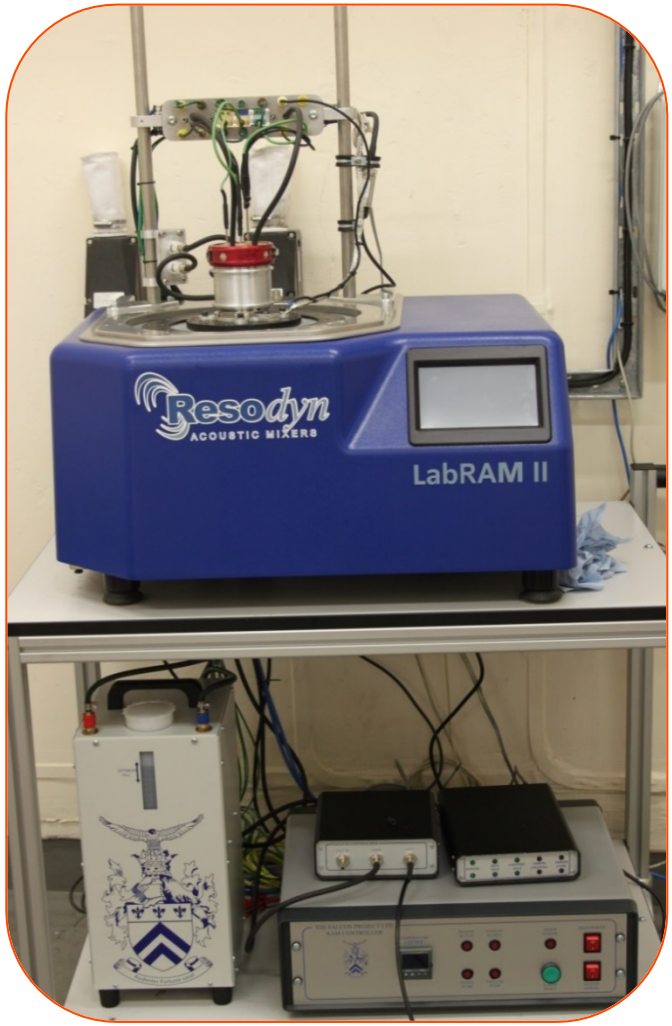
- Why Change? – Advantages during this Project
  - Mix duration: <30 vs. 100 minutes mix time
  - Single addition step vs. Incremental

Examples Demonstrating Advantages

LOVA

- Mix Duration: 1 hr vs 5 hrs
- Process time (incl. extrusion): <1 day vs 2 days
- Additional Advantage: Reduced solvent required

LOVA Dough & Granules



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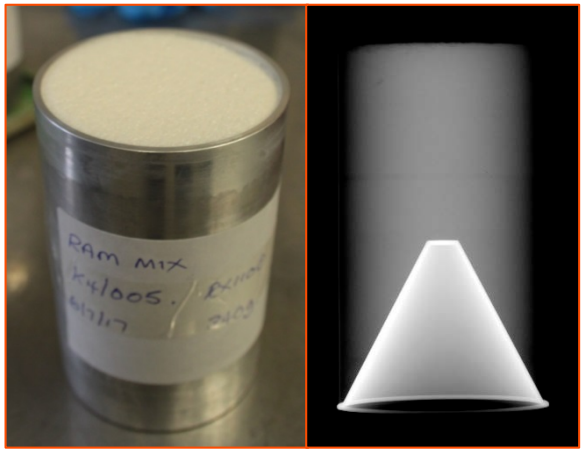
Examples Demonstrating Advantages

SC Fill & X-ray



Flexibility: Shaped Charges MIC

- Planetary vs. RAM-Batch vs. RAM-MIC
- RAM reduces time, process steps and significant waste
- Table – Parameters for producing 6-off Shaped Charges:

Parameter	Conventional Batch (5kg mixer)	RAM – Batch (1.1 kg ≡ 3-off SCs)	RAM – MIC (one at a time)
Mix Preparation (ingredient adding)	100 mins	40 mins (~20mins per batch)	120 mins (~20mins each)
Mix Duration	100 mins	36 mins (18 mins)	102 mins (17mins)
Mix mass	5 kg	2.2 kg (1.1 kg)	2.1 kg (350 g)
Waste	3.08 kg	280 g (140 g)	180g (~30 g)
Filling Time	~40 mins	60-80 mins (40 mins)	N/A
Total time	240 mins	156 mins (78 mins)	222 mins (37 mins)
Cleaning	Cleaning of vacuum cast assembly, mixing bowl and lid. And general cleaning of room and weighing utensils	Cleaning of vacuum cast assembly, mixing bowl and lid. And general cleaning of room and weighing utensils	Cleaning of header and lid. General cleaning of room and weighing utensils

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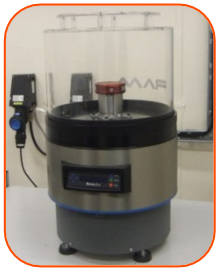
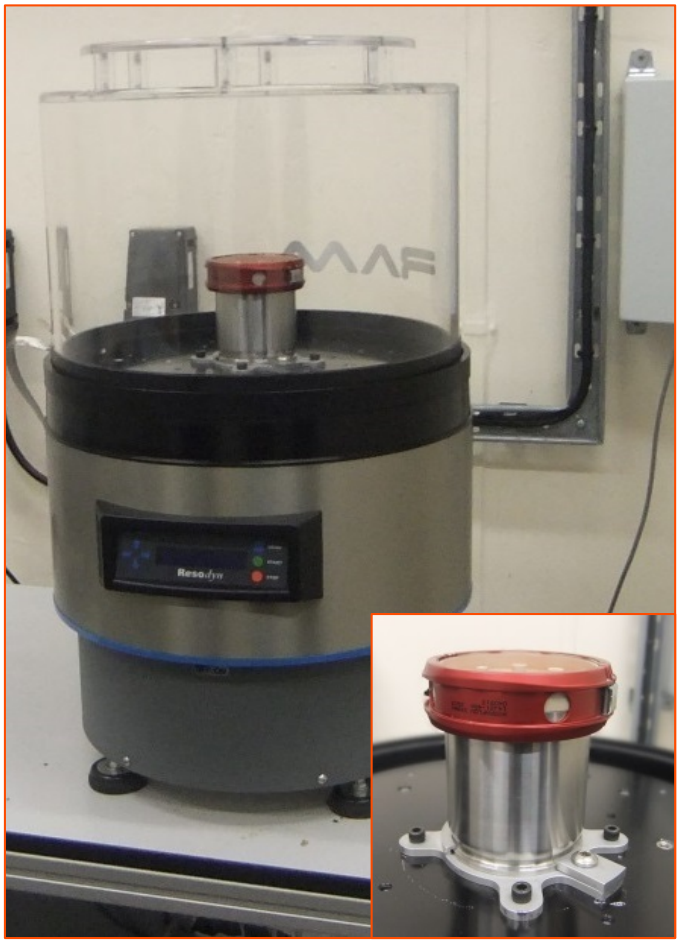
The Processes: RAM Scale-Up



	Mix Mass	Mix Time	Waste
LabRAM	0.3 kg	20 mins	
LabRAM II	1 kg	20 mins	
RAM 5	36 kg	20 mins	
RAM 55	400 kg	20 mins	20 kg
Conventional	1600 kg	3 Days	200 kg (minimum)

Conclusions (1)

- Comparison study of PBX manufactured via RAM & Conventional Planetary methods
- RAM Processing (for BAES LabRAM set-up):
  - Highest consistency and quality samples when ≥55 G, times > ½ t_p
  - Power input analysis (variation)
  - Visual appearance (vessel & level of curing)



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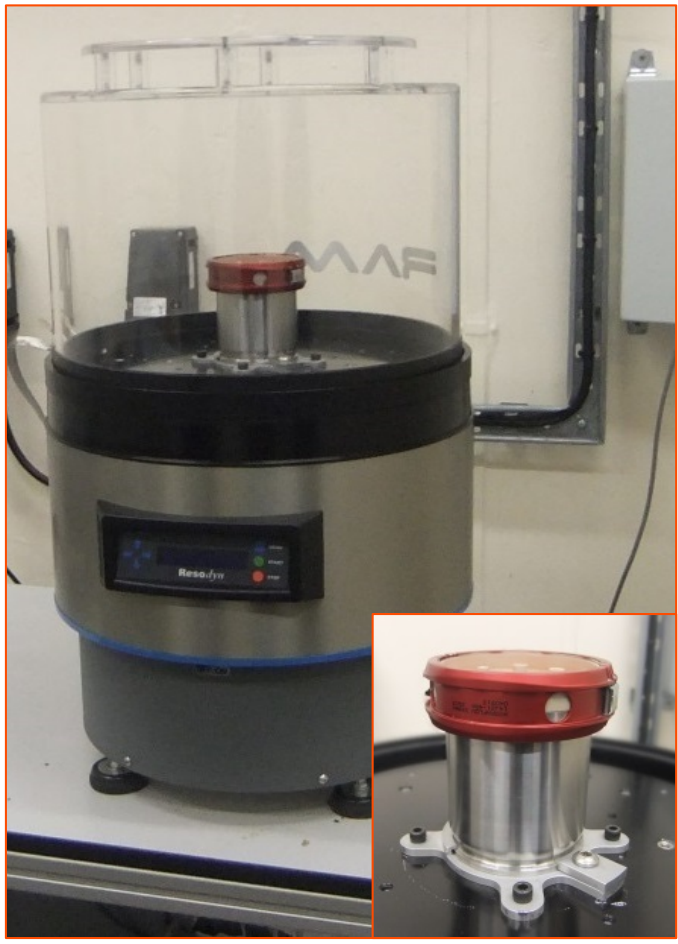
Conclusions (2)

- RAM samples were very comparable to planetary samples, with respects to:
  - Physical, chemical, and thermal characterisation
  - Small scale hazard sensitiveness & performance data
- Possible Variation in polymer matrix formation – Compression and Shore A (?)
- Advantages – emphasised with scale up
  - Mix duration
  - Number of process steps
  - Solvent reduction
  - Flexibility of method, on a single platform
  - Waste reduction



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Acknowledgements

- UK Ministry of Defence
- Falcon Project

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Thank you and Any Questions?

For any further Question, please email me at:

Rosie.Davey@baesystems.com

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