HEALTH & SAFETY LABORATORY

Explosion properties of nanopowders

P Holbrow
Explosion Safety Unit

Nanopowders

- Explosible dust
  - Particle size
  - Oxidant
  - Dust concentration
  - Ignition source
  - Turbulence

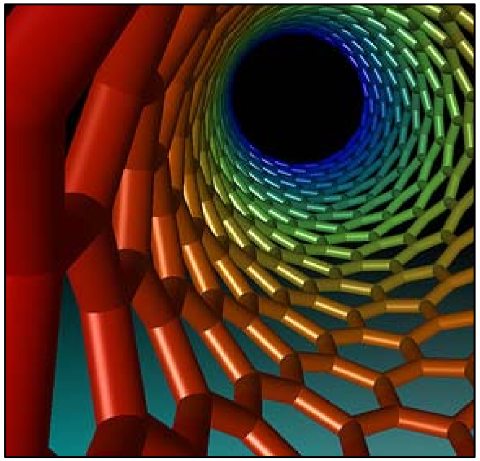
Nanopowders

- Engineered nanomaterials
- Unique shapes
- Unique properties
- Size < 100 nm in one dimension

Medicine

Clean water

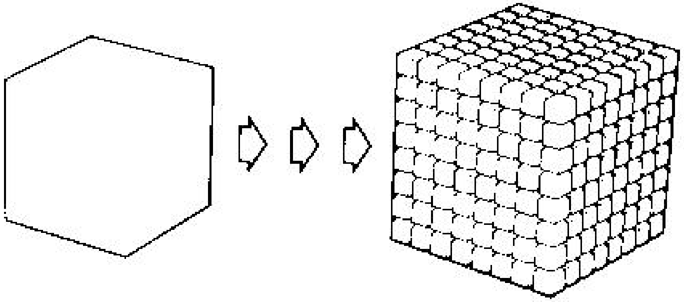
Energy – Solar plastics



Materials

Nanopowders

- HSE project
- Potential fire and explosions hazards
- Nanopowder – increased surface area to volume ratio
- Spherical 1 micron particle reduced to 100 nm particles increases the surface area x 10
- Increased reactivity



Explosions violence, dP/dt and Pmax

Test equipment, micron-scale

20 litre sphere

BS EN 14034 series

Typical values:

- Micron-scale aluminium

  Kst 300-700 bar m/s

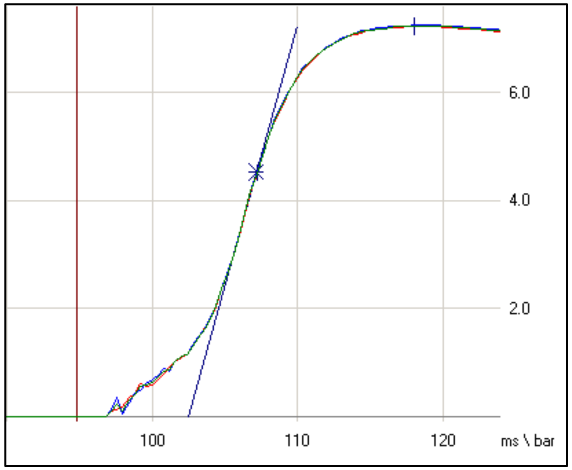
  Pmax up to 12 bar

- Micron-scale carbon

  Kst up to 151 bar m/s

  Pmax up to 8 bar

Test material 0.5 – 1 kg



Nanopowder explosion test apparatus

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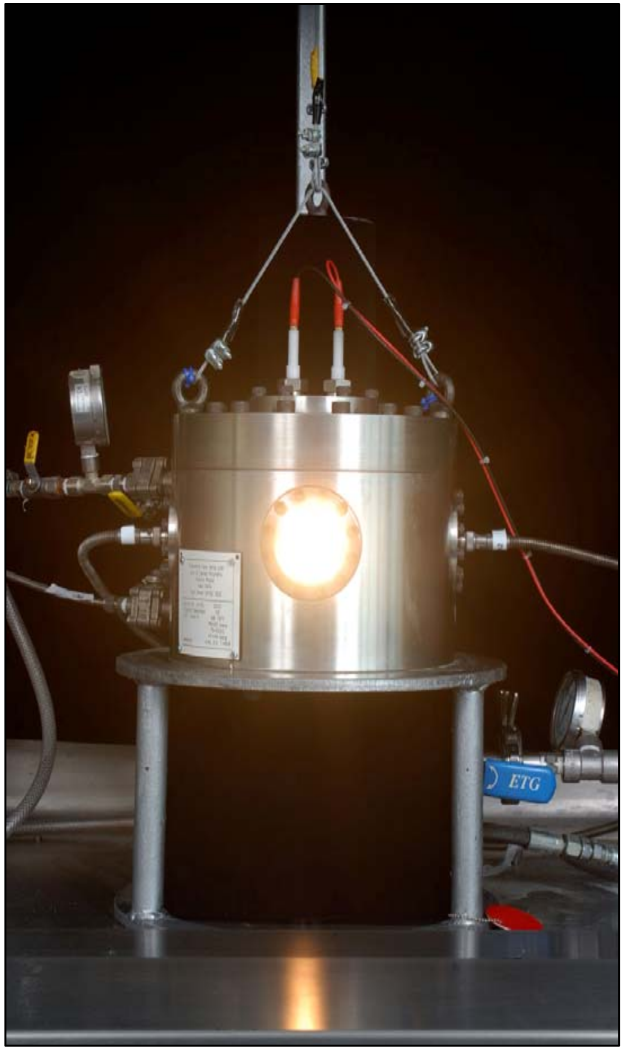
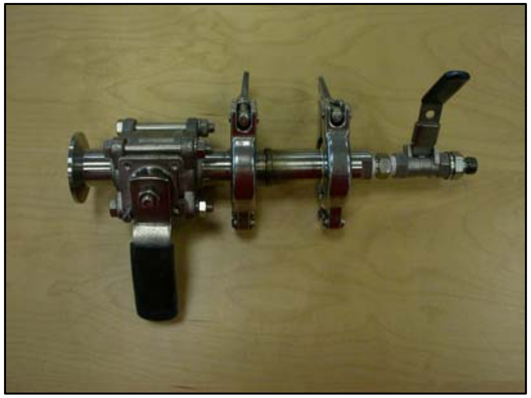
- 2 Litre enclosed spherical chamber
- 20 bar maximum working pressure
- External dust injection
- Central ignition source
- Piezo-electric pressure transducers



Dispersion nozzle



External dust injection

Nanopowders explosion test apparatus

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Control, software, data analysis system

Dedicated fume cupboard and glovebox

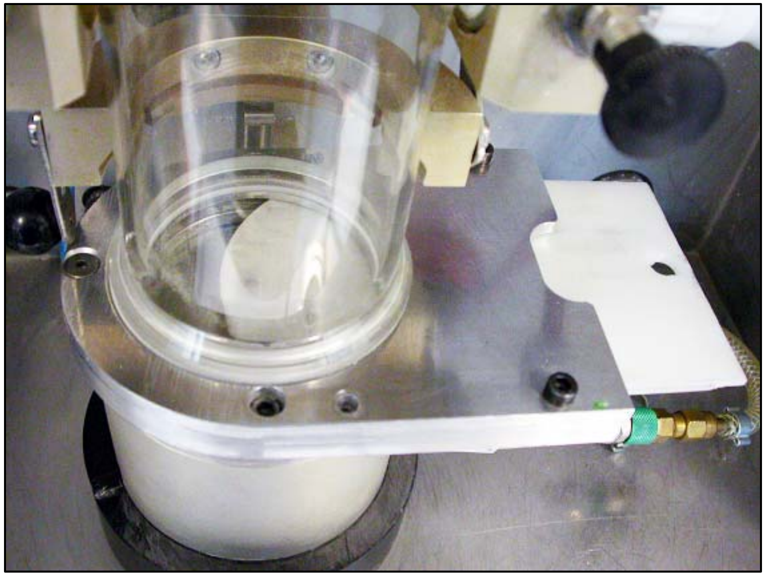
Minimum Ignition Energy

MIE – BS EN 13821:2002

- MIKE3 Kuhner
- Modified Hartmann tube
- 1mJ – 1 J
- Variables: capacitive discharge, dust concentration, ignition delay
- Typical values for micron powders variable: Aluminium <1-10 mJ

Minimum Ignition Energy

- Existing equipment modifications included:
- Isolation valve and dispersion chamber enables nanopowder to be handled in a sealed system.
- HEPA filtration on the extraction system



Nanopowders

Nanopowder	Sample Number	Information from supplier
Aluminium	EC/104/08	Nominally 100 nm
Aluminium	EC/011/09	Nominally 210 nm
Multi-walled carbon nanotubes	EC/153/07	Outside diameter: 20-30 nm; Inside diameter: 5-10 nm; Length: 10-30 um;
Carbon nanofibre	EC/042/08	Diameter 100-200 nm Length 30-100 micron
Carbon nanofibre	EC/158/07	Outside diameter: 80-200 nm; Core diameter: 1-10 nm; Length 0.5-20 um;
Carbon Nanofibre	EC/116/08	Diameter 70-200 nm Length 2-5 micron
Carbon Nanofibre	EC/117/08	Diameter 70-200 nm Length 2-10 micron
Iron	EC/147/07	APS: 25 nm
Zinc	EC/152/07	APS : 130nm;
Copper	EC/148/07	APS: 25 nm

Commissioning tests – 20 litre sphere

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Ignition source	P_{max} (barg)	dP/dt (bar/s)	K_{St} (bar m/s)
Lycopodium <63 micron (sample EC/026/08)			
Electric fuse head	6.5	243	66
1 kJ Sobbe	7.3	551	150
5 kJ Sobbe	7.0	620	168
10 kJ Sobbe	7.3	673	183
Aluminium 73-109 nm (sample EC/060/07)			
10 kJ Sobbe	9.8	1200	326

Commissioning tests – 2 litre vessel

Ignition source	P_{max} (barg)	dP/dt (bar/s)
Lycopodium (sample EC/026/08)		
Electric fuse head	8.2	200
1 kJ Sobbe	8.7	882
5 kJ Sobbe	9.1	1500
Aluminium (sample EC/060/07)		
1 kJ Sobbe	10.8	1450
2 kJ Sobbe	9.8	1950
5 kJ Sobbe	9.5	5000

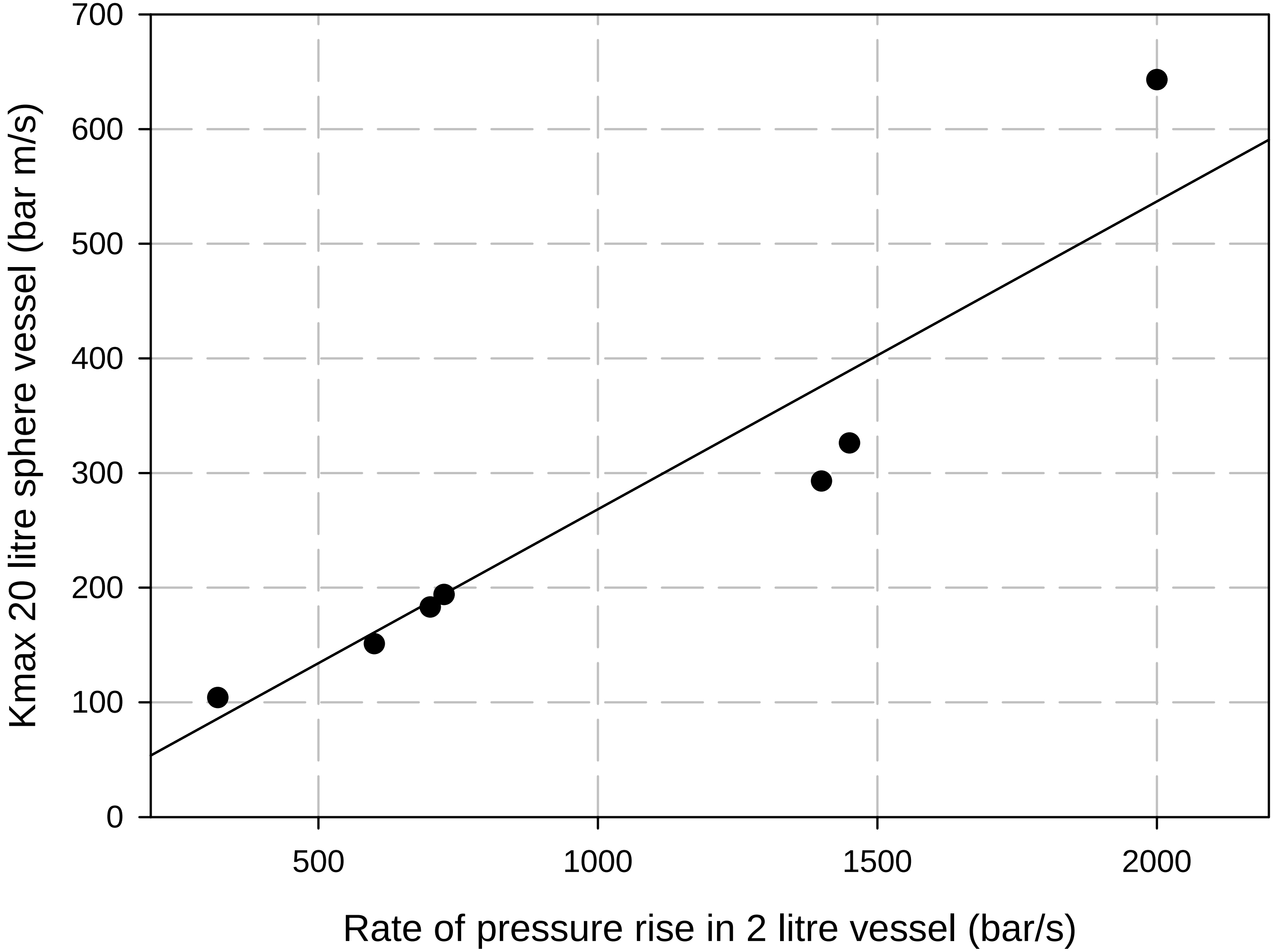
Commissioning tests – Ignition strength in the 2 litre vessel (without dust)

Ignition source	P_{max} (barg)	dP/dt (bar/s)
Electric fuse head	0.2	3.3
1 kJ Sobbe	1.05	75
2 x 1 kJ Sobbe	1.5	154
5 kJ Sobbe	4.2	250

Commissioning tests – comparison of 20 litre and the 2 litre vessel

Material	20 litre sphere results			2 litre sphere results	
	Rate of pressure rise (bar/s)	K_{St} (bar m/s)	P_{max} (bar)	Rate of pressure rise (bar/s)	P_{max} (bar)
Lycopodium EC/026/08	673	183	7.3	700	7.7
Aluminium EC/060/07	1200	326	9.8	1450	10.8
Zinc stearate EC/118/08	1080	293	7.6	1400	8.2
Coal EC/120/08	558	151	7.4	600	7.3
Toner EC/122/08	714	194	7.5	725	6.3
Carbon black EC/076/07	382	104	7.8	320	6.2
Aluminium EC/104/08	2368	643	12.0	2000	11.2

Commissioning tests – comparison of 20 litre and the 2 litre vessel



Nanopowder explosion tests

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Material	Pmax (bar g)	dP/dt (bar/s)	Equivalent Kst (bar m/s)	MIE (mJ)
Aluminium nanopowder (210 nm)	12.5	1677	449	<1
Aluminium nanopowder (100 nm)	11.2	2000	536	<1
Iron	2.9	68	18	<1
Zinc	5.6	377	101	3 - 10
Copper	1.2	10	3	> 1000

Nanopowder explosion tests

Material	Pmax (bar g)	dP/dt (bar/s)	Equivalent Kst (bar m/s)	MIE (mJ)
Carbon nanofibre	5.2	62.5	17	Not measured
Carbon nanofibre	6.0	112	30	Not measured
Carbon nanofibre	6.9	591	158	>1000
Carbon nanofibre	5.6	137	37	Not measured
Multi-walled carbon nanotubes	6.4	339	91	>1000

Nanopowder v micron-scale powder

Nanopowder				Micron-scale powder (typical range of data)			
Material	Particle size	P_{max} (barg)	Equivalent K_{St}(bar.m/s)	Material	Particle size	P_{max} (barg)	K_{St} (bar m/s)
Aluminium nanopowder (210 nm)	210 nm	12.5	449	Aluminium	Median <10-100μm	7-12	300-700
Aluminium nanopowder (100 nm)	100 nm	11.2	536				
Iron nanopowder	25 nm	2.9	18	Iron	Median 12μm Median 32μm	5.2 5.1	50 41
Zinc nanopowder	130 nm	5.6	101	Zinc	Median 160μm Median 10μm	0.7 7.3	2 176
Copper nanopowder	25 nm	1.2	3	Copper	Median 25 μm	No ignition	No ignition

Nanopowder v micron-scale powder

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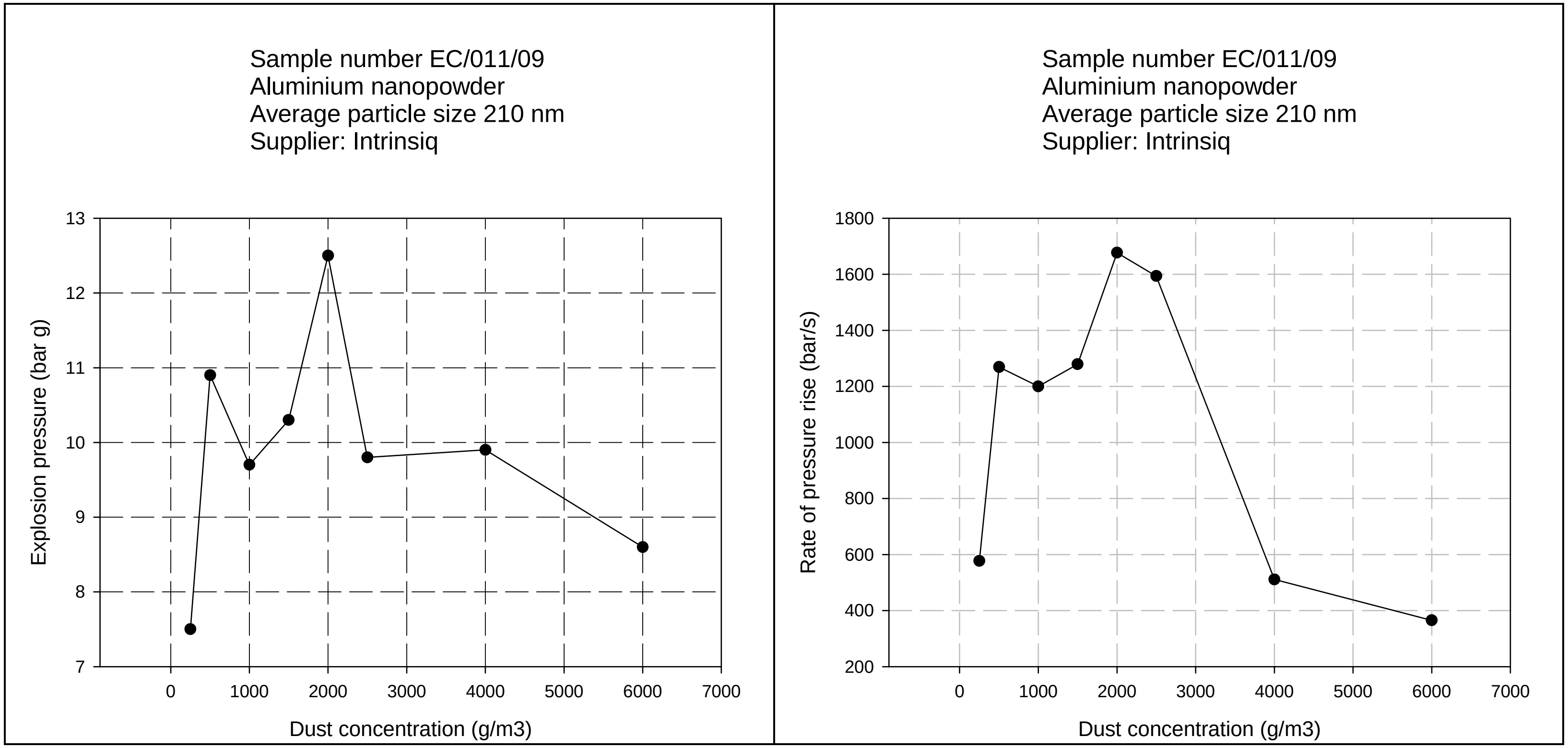
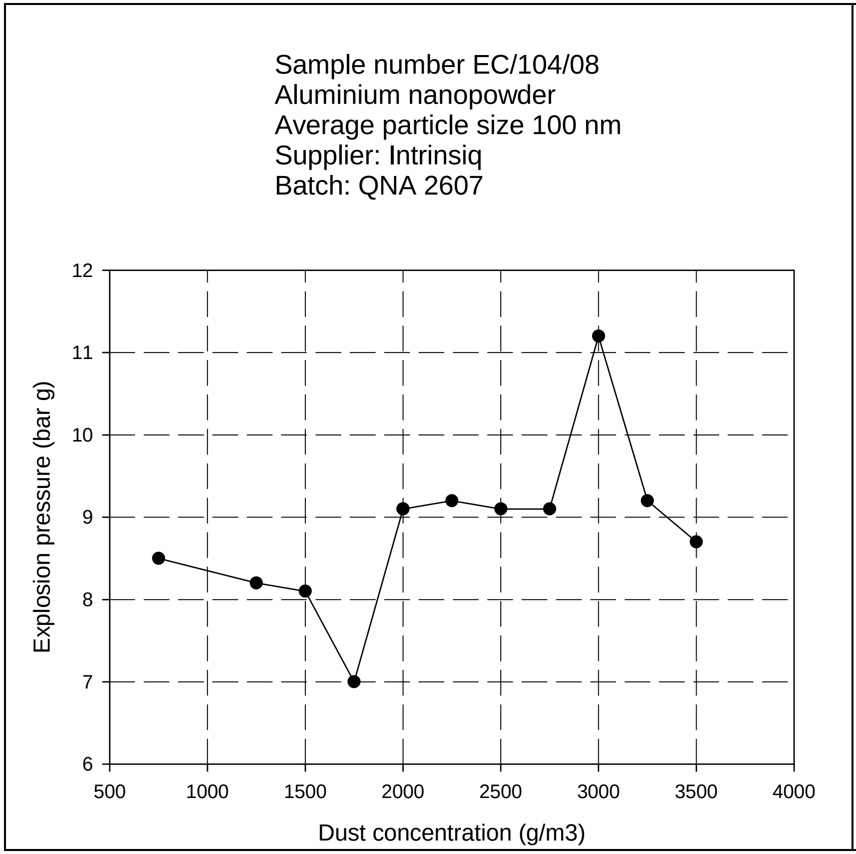
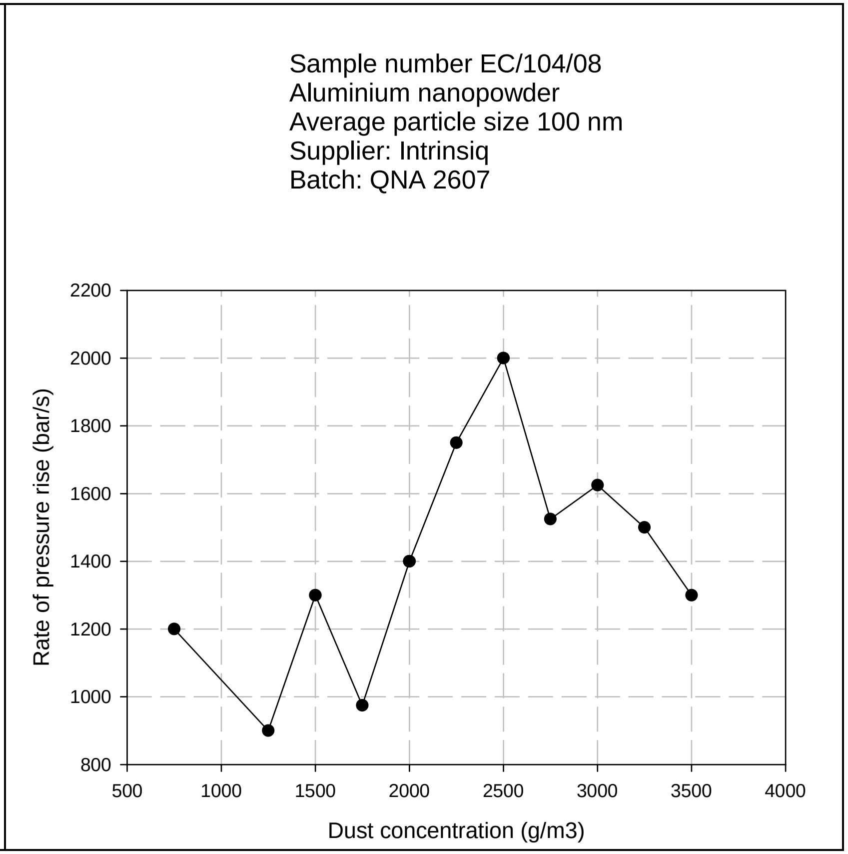
Nanopowder				Micron-scale powder (typical range of data)			
Material	Particle size	P_{max} (barg)	Equivalent K_{St}(bar.m/s)	Material	Particle size	P_{max} (barg)	K_{St} (bar m/s)
Carbon nanofibre EC/42/08	Dia 100-200 nm Length 30-100μm	5.2	17	Carbon	100%<63μm 100%<63μm	8 7.1	151 43
Carbon nanofibre EC/158/07	Dia 80-200 nm Length 0.5-20μm	6.0	30				
Carbon nanofibre EC/116/08	Dia 70-200 nm Length 2-5μm	6.9	158				
Carbon nanofibre EC/117/08	Dia 70-200 nm Length 2-10 μm	5.6	37				
Multi-walled carbon nanotubes EC/153/07	Dia 20-30 nm Length 10-30μm	6.4	91				

Aluminum sample EC/11/08 – 2 litre sphere test results

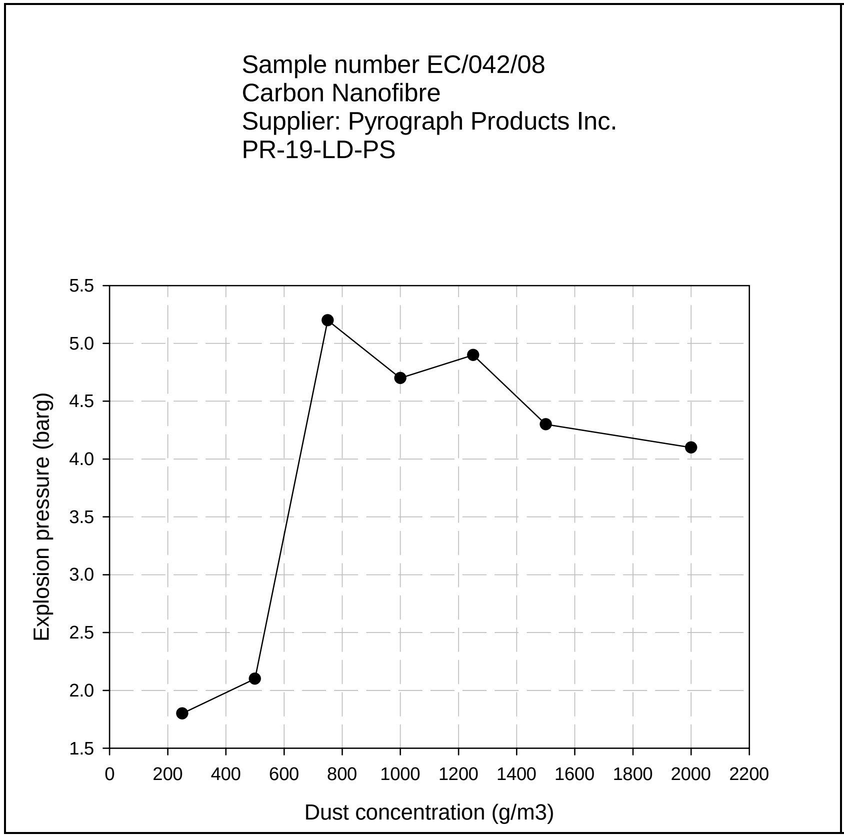


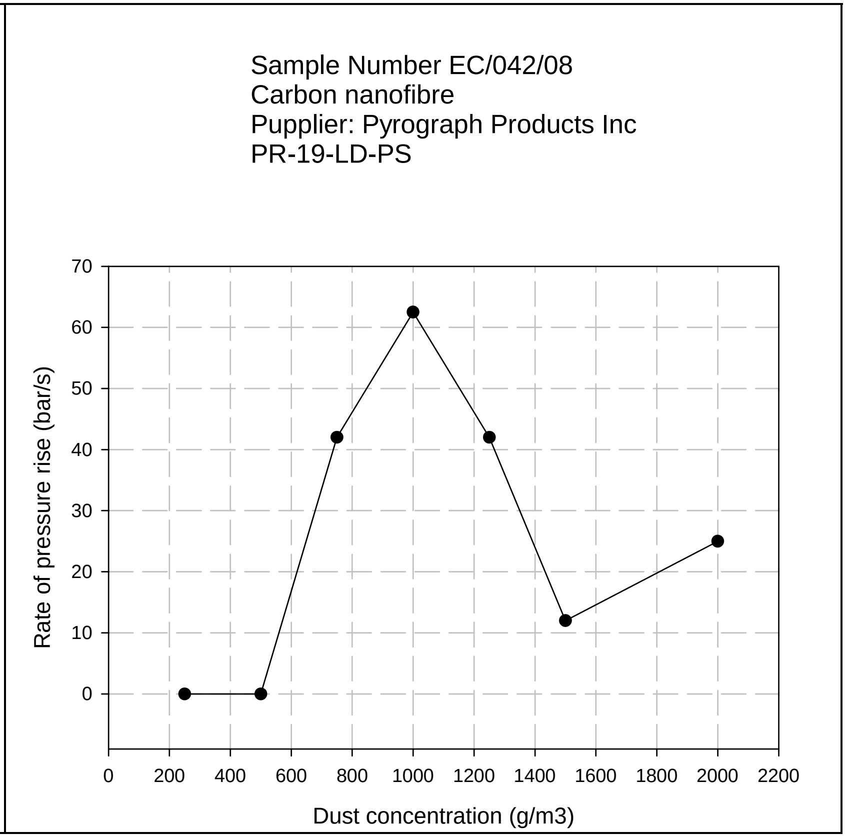
Aluminum sample EC/11/08 – 2 litre sphere test results



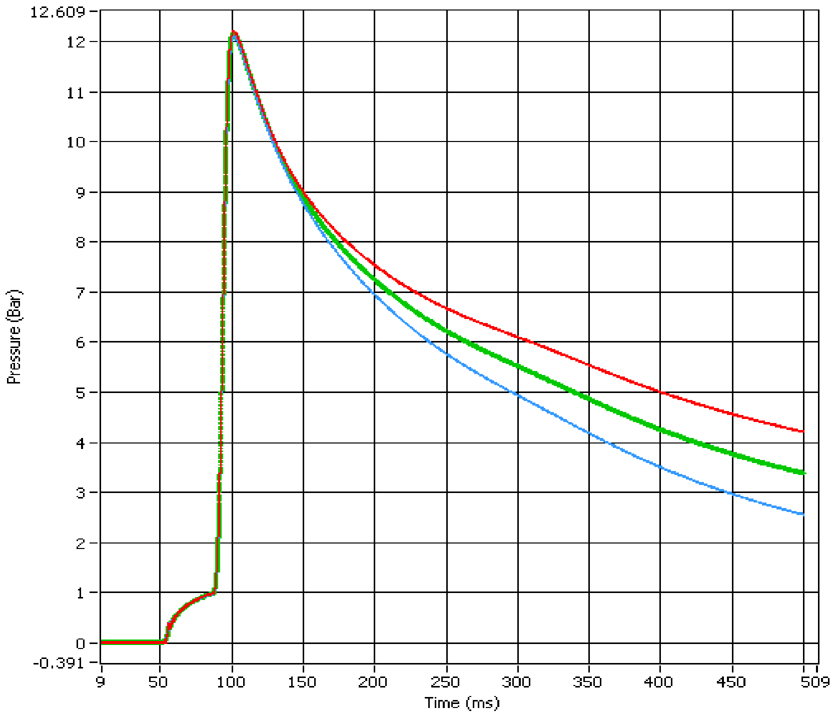


Carbon nanofibre sample EC/042/08 – 2 litre sphere test results



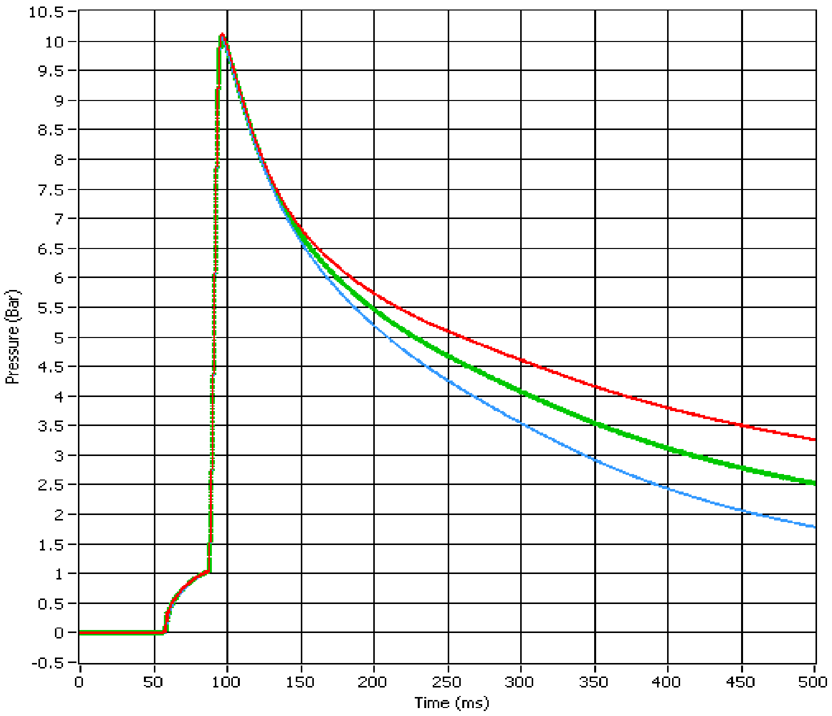


Aluminium sample EC/104/08 – 2 litre sphere test results



aluminium nanopowder EC/104/08

Dust concentration 3000 g/m^3



aluminium nanopowder EC/104/08

Dust concentration 2500 g/m^3

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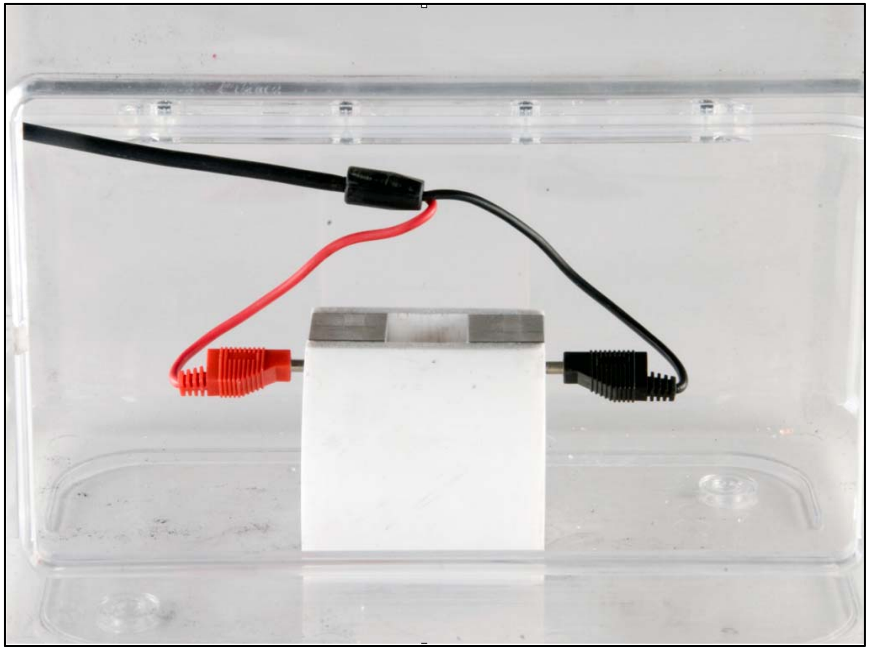
Nanopowder explosion test apparatus

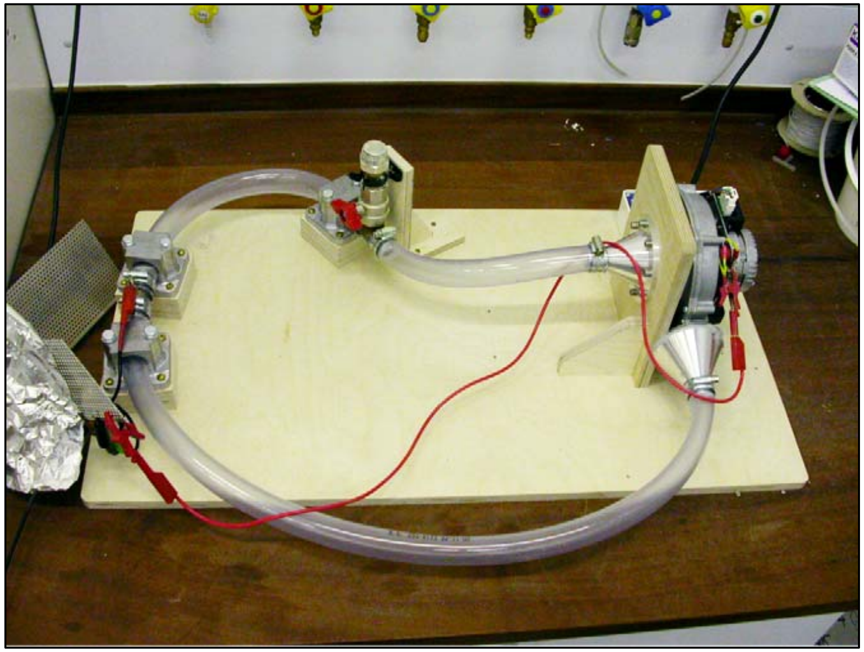
Aluminium nanopowder explosion

Electrostatic Charging



Resistivity test cell

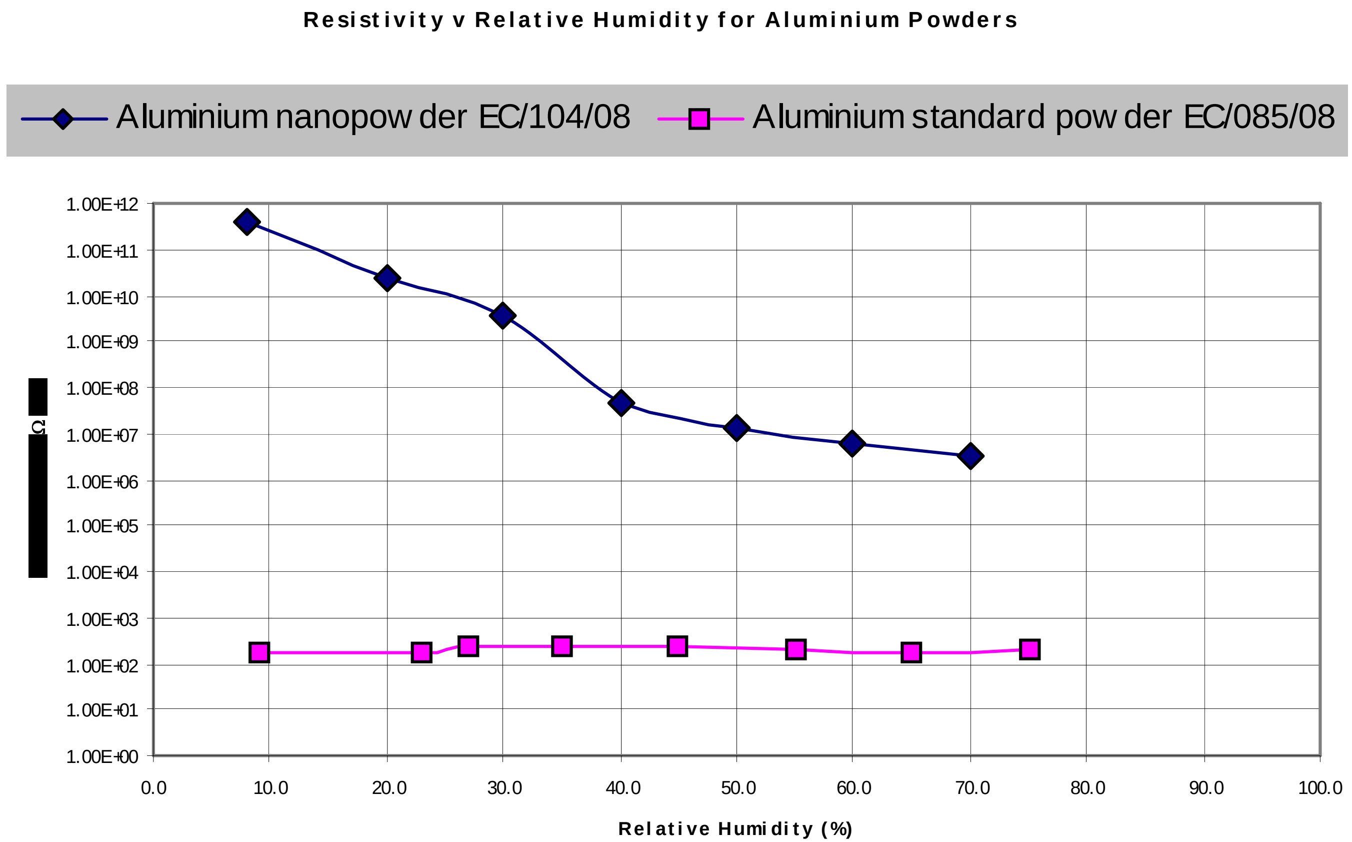
ρ= 0.001 Rs [H × W/L]



Charge test apparatus

I = C x dV/dt

Resistivity



Resistivity

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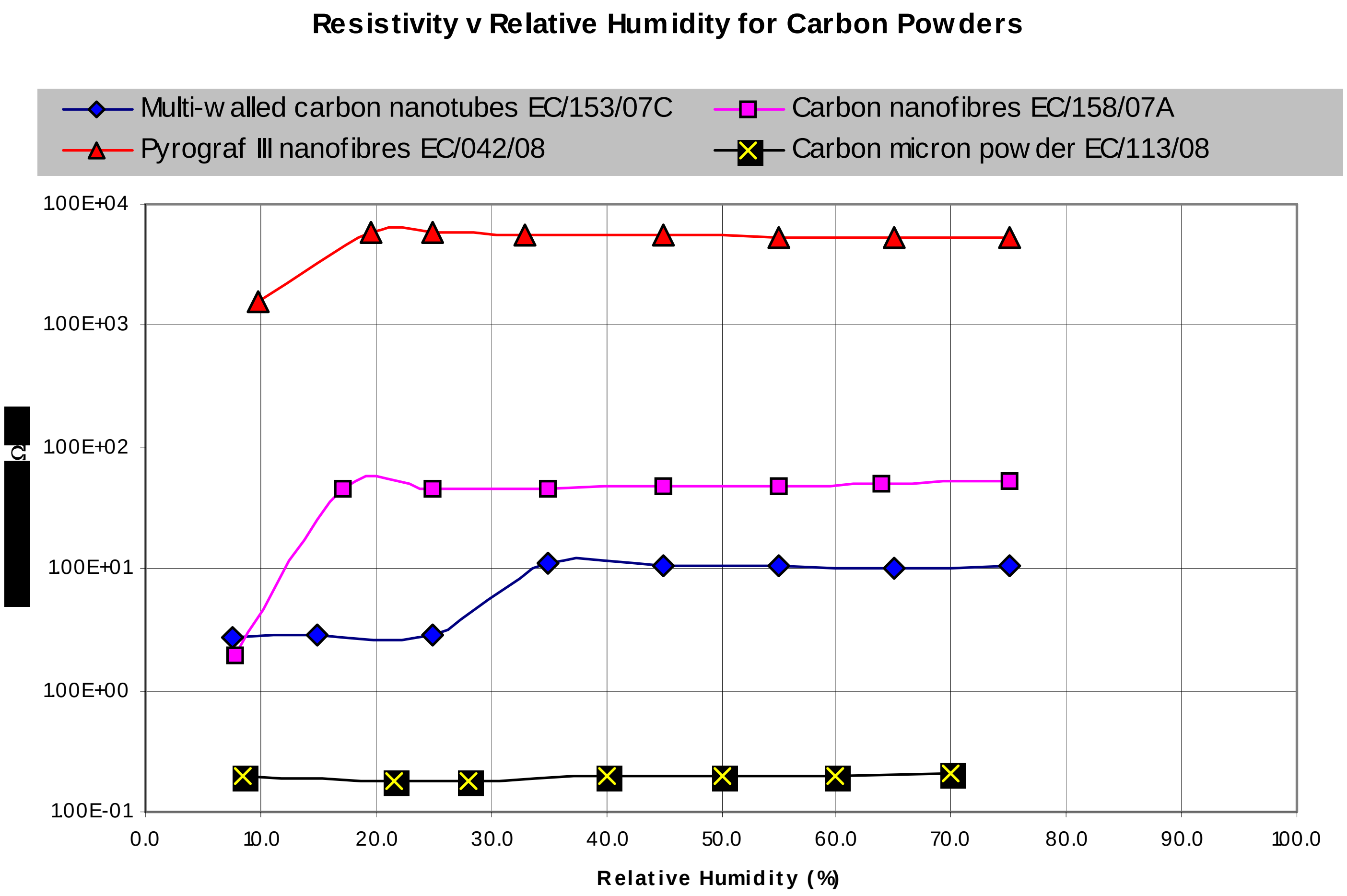

Charge – Carbon Nanofibres

- All the powders produced charge,
- Some materials developed negative and some developed positive charge.
- Generally, the charge developed by nanopowders was comparable with the micron-scale powders.

Rate of change of voltage (V/s)	Capacitance (F)	Current (A)
-1.16E-02	1.05E-06	-1.22E-08

Ambient environmental conditions:
Humidity: 65.3%RH
Temperature: 17.8ºC

Conclusions

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- Special equipment has been developed to measure the explosion characteristics and electrostatic properties of nanopowders
- Explosion characteristics measured to-date are broadly comparable with micron-scale powders
- MIE – zinc and iron more ignitable than micron-scale powders
- Electrostatics – resistivity and charging tests – increasing relative humidity resulted in decrease in resistivity.
- Resistivity generally greater than micron-scale powders