Studies on the Effect of Ageing on a range of UK Polymer Bonded Explosives

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Ageing and Insensitive Munitions

- Many cast PBXs have very good IM properties when pristine - low sensitiveness and explosiveness
- Ageing is known to affect the mechanical properties of the polymeric matrix of cast-cured PBXs
- There is a need to establish that the IM capability of cast PBXs is not compromised during service life

UK programmes on ageing of cast PBXs

- Accelerated ageing of cast PBX samples to simulate 20 years service life.
- Mechanical, chemical and hazard testing of aged and control samples
  - What changes?
  - By how much?
  - Does this change compromise IM?
- Environmental trials on PBX-filled munitions

Explosives studied

Composition	Nominal Formulations (%m/m)			
	RDX	Aluminium	HTPB (isocyanate cured)	Plasticiser
ROWANEX 1100	88	--	5	7
ROWANEX 1400	66	22	5	7

- Rowanex 1100 is BAE Systems' explosive of choice for future artillery and general purpose systems
- Rowanex 1400 is an optimised blast explosive

Ageing programme for environmentally conditioned Rowanex 1400 samples

Step	Environmental Conditions
1	31 days at 71°C
2	169 days B3 cycling (diurnal cycle 33-71°C)
3	Transport Vibration (Def. Stan. 00-35; 2hr per axis, 2g sinusoidal sweep)
4	10hr vibration per axis ((Def. Stan; 00-35 -0.4g^2/Hz, 20-2000Hz)
5	Thermal Shock (Def. Stan. 00-35; +70 to -55°C, transfer time 3-5min, 10 cycles)

- Represents nominal 20 year service life
- Radiography indicates no change in frequency of voids between control and aged test pieces

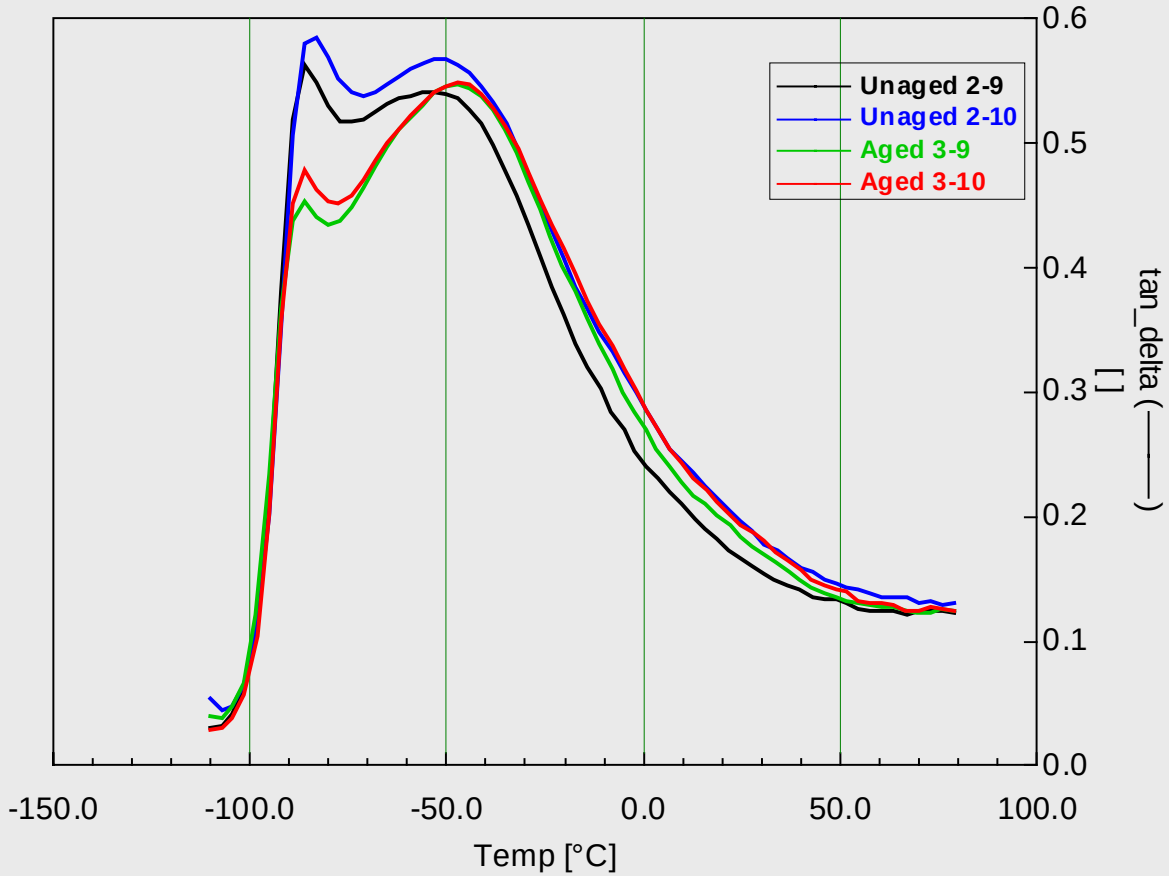
Test Regime for Control and Aged Samples of ROWANEX 1400

Test or Method	Specification or Reference
Antioxidant level	STANAG 4581
Sol / Gel	QinetiQ/FST/LP033918 / STANAG 4581
Moisture content	Memo dated 30/03/2004
Dynamic mechanical analysis	STANAG 4540
Surface hardness	From guidelines given in BS 903-A26:1995, ISO 48:1994 and BS 903-A57:1997, ISO 7619:1997, LP043948.
Tensile testing	STANAG 4506
Heat flow calorimeter	STANAG 4582
Tube test - internal ignition version	EMTAP No.35
Tube test -Fuel fire version	EMTAP No.41
Tube test -Electrically heated version	EMTAP No.42
Large scale gap test	EMTAP No.22
Additional Non-standard Tests	
Test method	**Additional Diagnostics or Tests**
Dynamic mechanical analysis	Ultrasonic analysis, SEM
Chemical Analysis	GC-MS, Thermal Analysis (DSC, TGA), IR Spectroscopy
Instrumented Gap Test	

Chemical and mechanical test results for environmentally conditioned samples

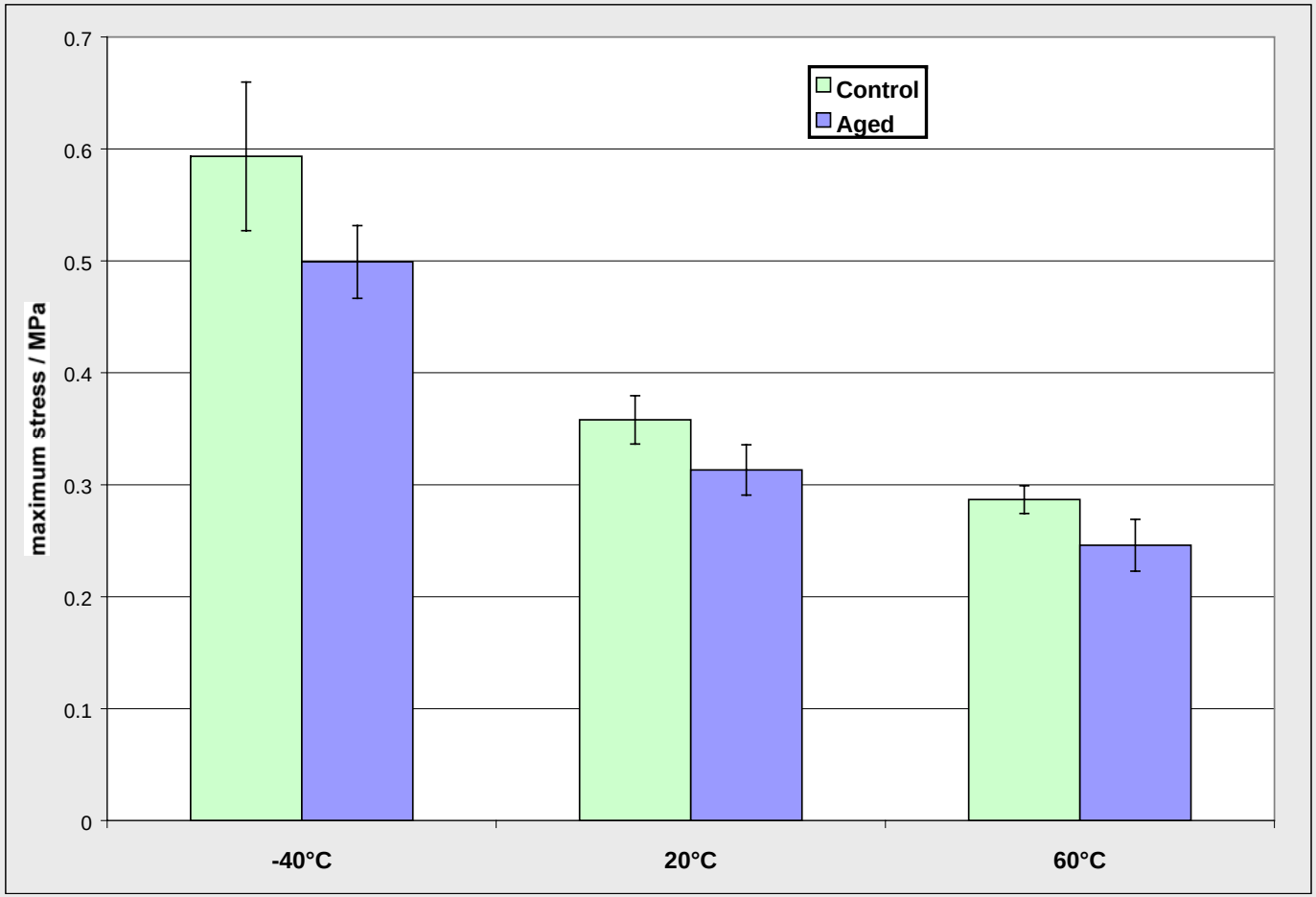
Test	Notes	Conclusions
Soluble Fraction	Results distribution greater for aged samples	
Antioxidant Levels	Slight Reduction on Ageing	
Moisture content	Karl Fischer method and weight loss on vacuum heating	No Significant Changes
Shore A Surface Hardness		No Significant Changes

Dynamic Mechanical Analysis (DMA)



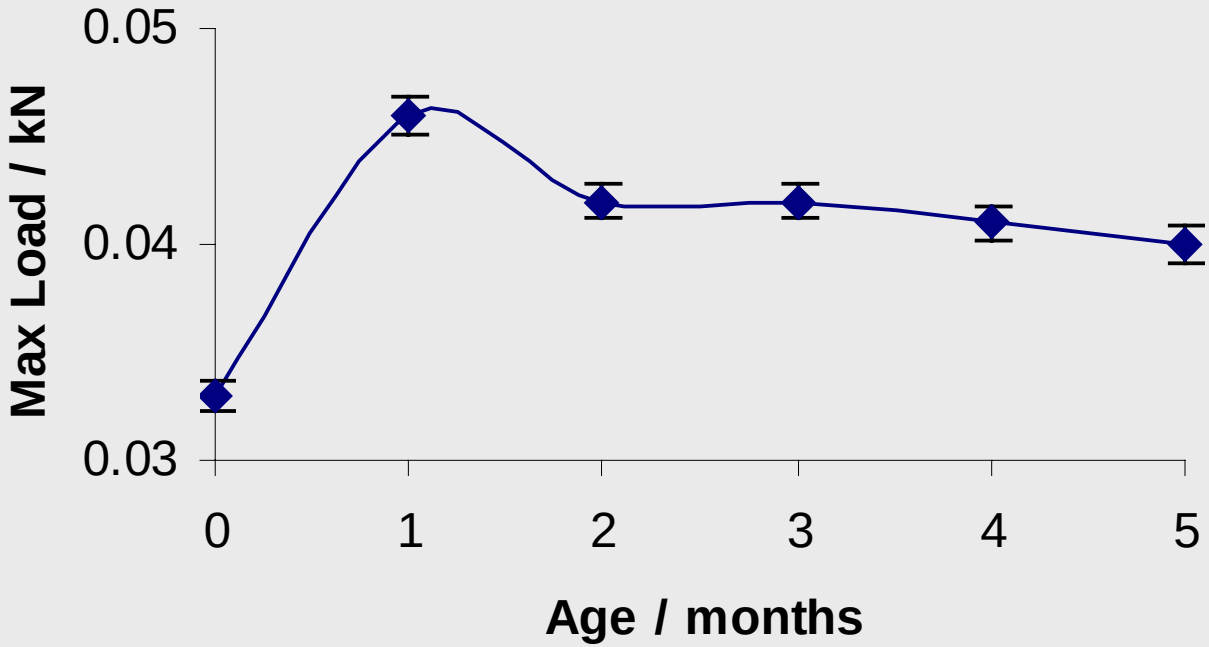
- Small increase in modulus between about -80 and -50^{o}C
- Glass transition temperature remains unchanged at -95^{o}C.

Tensile Test results, Comparison of Maximum Stress Level



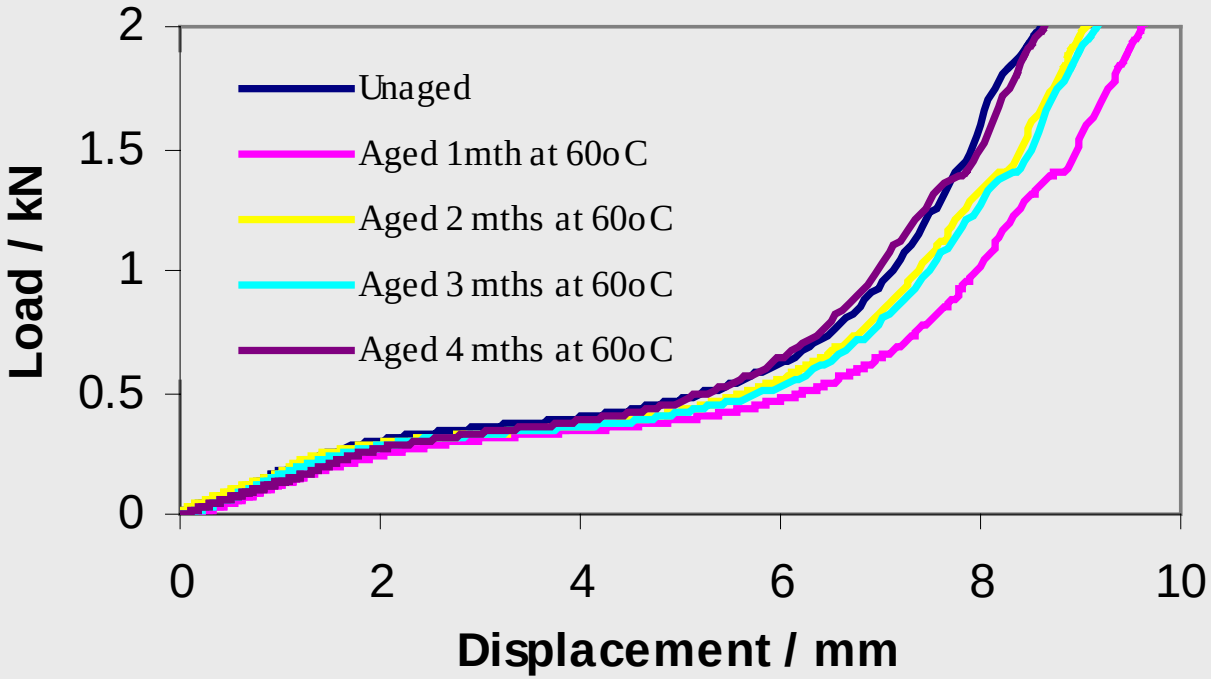
- Relatively small changes at low and ambient temperature
- Reduced maximum stress and modulus, increased strain capability

Max load before failure at 60°C



- Significant increase in the strength of the PBX over the first month of ageing, presumably due to the continuing cross-linking reaction.
- Elasticity also increases on ageing

Compression Testing

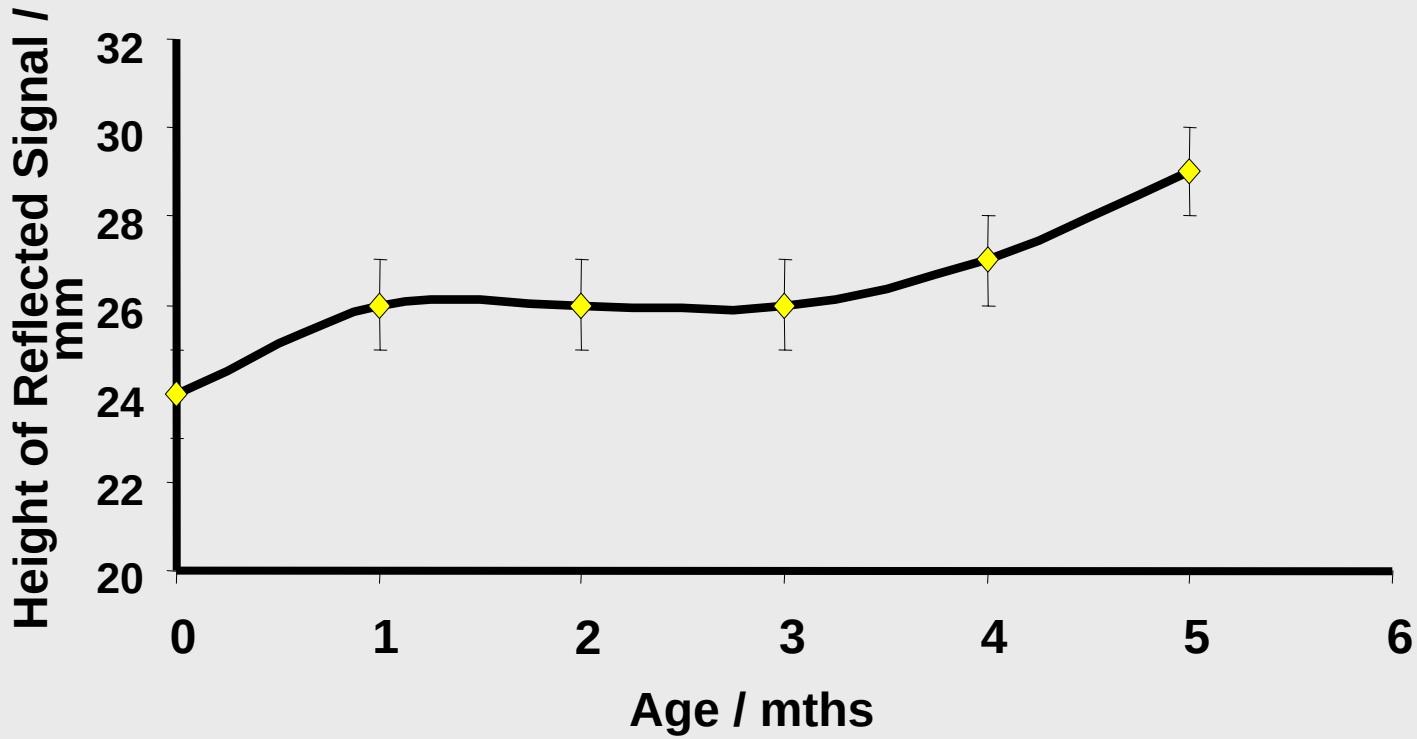


- Little variation in the load required to cause plastic deformation as the material ages.
- Homogeneity of filler dispersion within the matrix would account for the slight variations in compression resistance.

Acoustic Analysis

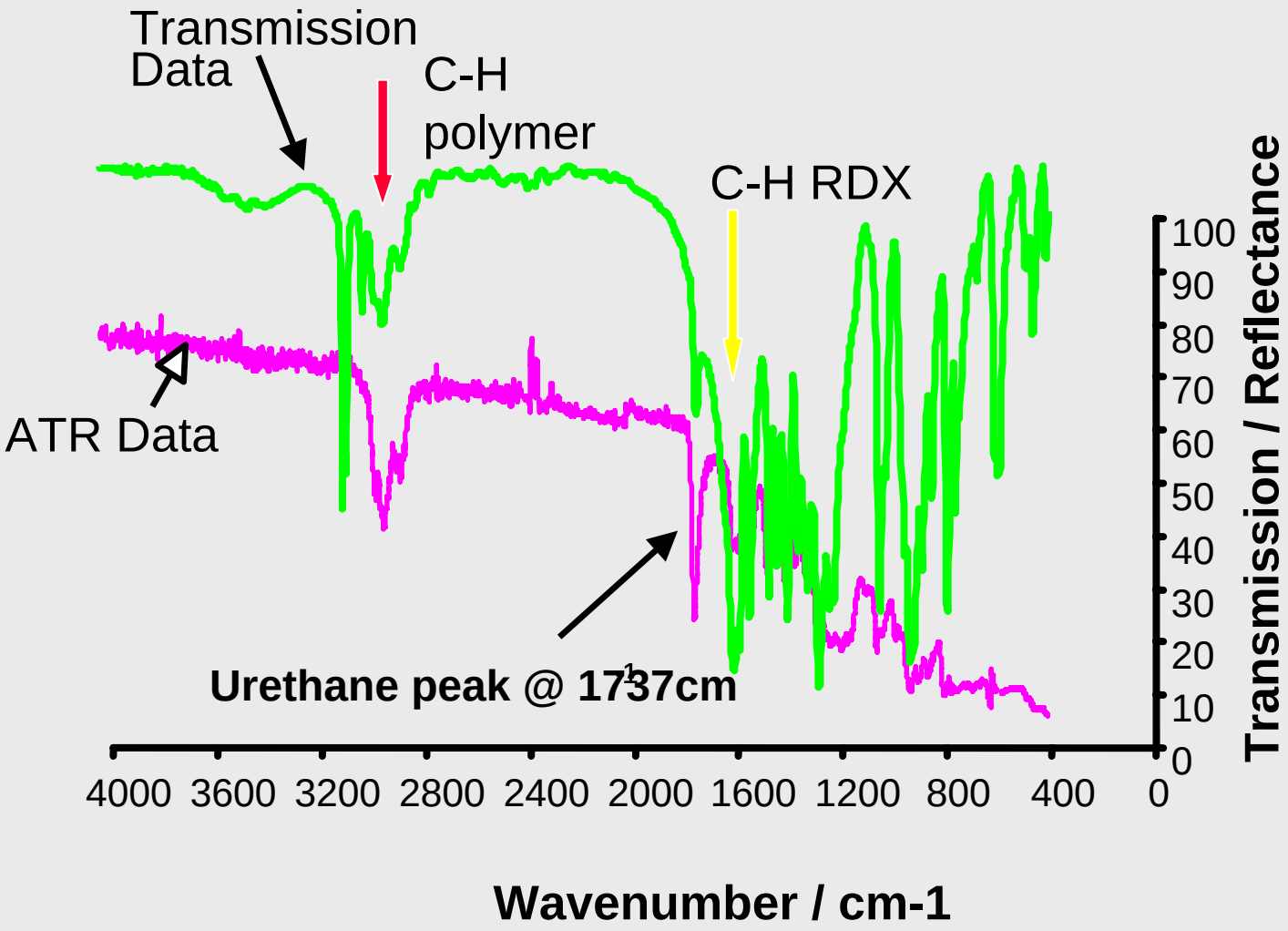
Velocity of Sound = $1666ms^{-1}$

- has remained constant for the samples tested

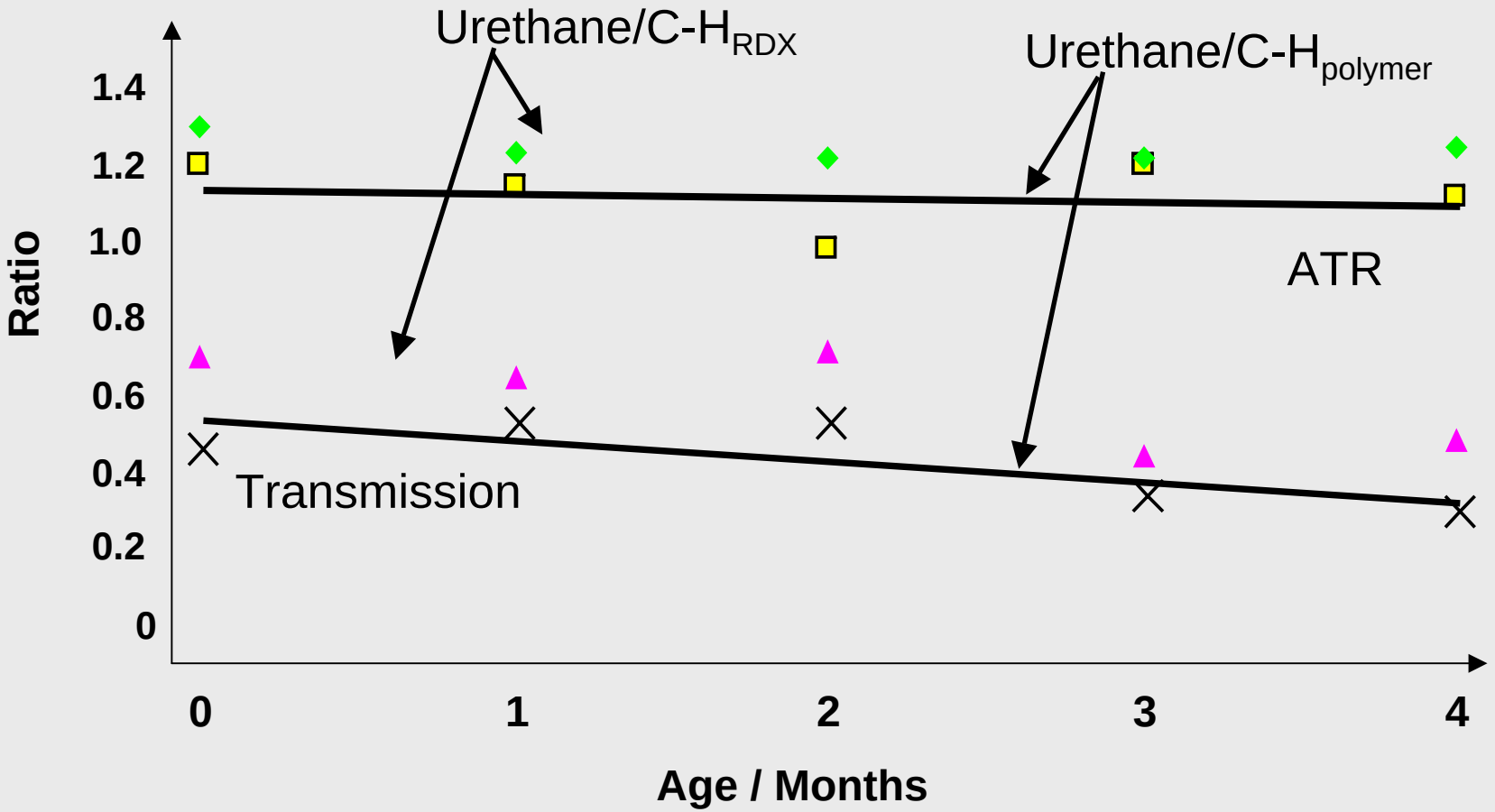


Signal attenuation is reduced with age. Less energy lost to elastic polymer as X-linking increases

ATR/IR Transmission



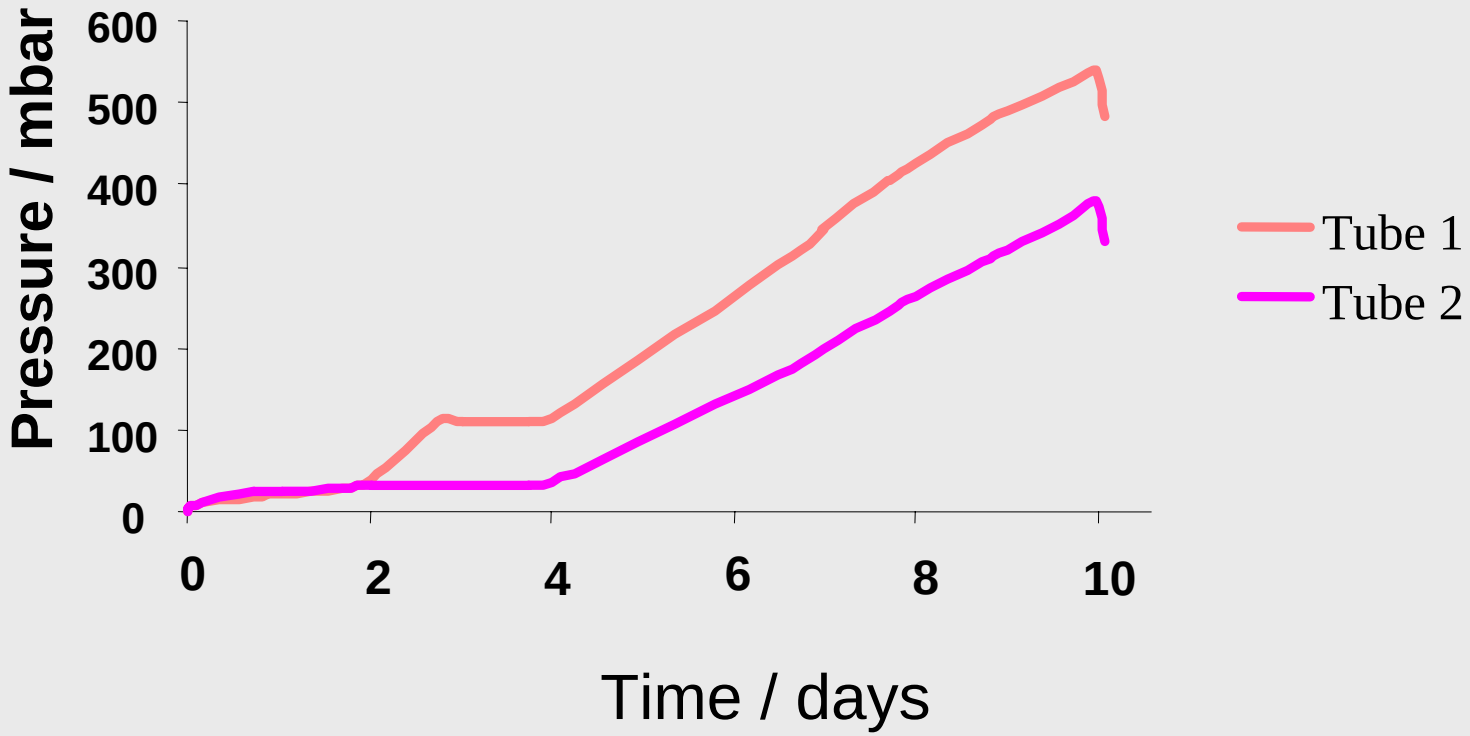
IR Peak Ratios



- Intensity of urethane peaks is reduced with age
- Can be explained by the formation of allophanate groups?

Vacuum Stability

- Carried out in accordance with STANAG 4147
- Samples heated at 80°C for 10 days



Large Scale Gap Test

Sample	Median gap (mm Perspex)	Median Gap (Gpa)
Control	33.5	4.38
Aged	33.9	4.29

LX-14	54.4	1.70
Rowanex 1100	44.8	2.50

Tube Test - Internal Ignition

- Control
  - 8 no ignition
  - 2 burned, no burst
- Aged
  - 3 no ignition
  - 4 burned, no burst
  - 3 burst, no fragmentation

Tube Test - Fuel Fire

- Control
  - 4 burst, no fragments
  - 6 deflagration, maximum 4 fragments
- Aged
  - 3 burst, no fragments
  - 7 deflagration, maximum 4 fragments

Conclusions for Rowanex 1400

- Chemical and physical properties change with age
- These changes are not sufficient to compromise IM capability
- Values measured can be used as bounds for intelligent surveillance programmes

Environmental Trials on PBX-filled Munitions

- BAE Systems has carried out risk reduction programmes on a range of ROWANEX 1100 filled projectiles, in readiness for anticipated UK MOD orders for IM compliant ammunition systems:
  - L15 155mm
  - L31 105mm HE
  - 4.5” IA/IM Naval Ammunition

155mm L15 Projectiles

- Bounce to Defence Standard 00/35, Test M11, duration 6 x 5 minutes
- Modified AOP-34 vibration regime (AS90), 205minutes duration low frequency at axial and traverse, and 44 minutes duration high frequency at axial and traverse
- 2.1m drop to Defence Standard 00/35, Test M5, two drops per shell
- All At –46°C

155mm L15 Projectiles

155mm L15 Cold Bounce

155mm L15 Cold Drop

No evidence of cracking, exudation or dusting

105mm L31 Projectiles

- Sixty shell conditioned; thirty at –46°C and thirty at +63°C
  - 2.1m drop to Defence Standard 00/35, Test M5, two drops per shell
  - Loose cargo bounce to STANAG 4370, AECTP-400 Method 406, duration 2 x 10 minutes
  - 7 days B3 Diurnal Cycling to STANAG 2895
- All fired without incident at pressures up to 400MPa

4.5” IA/IM Naval Ammunition

- 15 rounds were conditioned at –18° and +49°C packed in N36 containers/N6 crate
  - Logistic vibration to Defence Standard 00-35, Test M1 for 6 hours
  - Restrained cargo shock to Defence Standard 00-35, Test M3
  - Multiple free fall to Defence Standard 00-35, Test M5; two from 1.5m while cold and one from 2.1m while hot
  - Horizontal impact to Defence Standard 00-35, Test M5
  - B2 Diurnal cycling for 91 days (equivalent to 3 years service) and 231 days (equivalent to 10 years service)
  - C1 Diurnal cycling for 14 days
  - Free fall to Defence Standard 00-35, Test M5, either 1m, 1.5m or 2.1m
  - Ship vibration to AECTP Edition 1, Method 401
  - Underwater shock to Defence Standard 00-35, Test M3
  - Free fall to Defence Standard 00-35, Test M5, 0.5m

4.5” IA/IM gun firings

- After completion of the three year environmental regime five rounds were fitted with L106 fuzes and gun-fired without incident.
- After completion of the ten year environmental regime five rounds were filled with NC23 fuzes and gun-fired without incident.

Conclusions for Rowanex 1100

- Extensive accelerated ageing has failed to induce any apparent failure in Rowanex 1100 filled shell
- Aged shell proven to be safe for gun launch
- Although mechanical properties undoubtedly change with time, there is no reason to suspect that this could compromise the excellent IM characteristics of the formulation

Questions?