Insensitive Munitions - Development and Qualification of new Melt-Cast Formulations

Abstract No. 18761

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Countermeasures | Sensors & Electronics | Pyrotechnics & Munitions | Energetic Sub-Systems

Background

4 new melt-cast formulations under development and qualification according to STANAG 4170

MCX-6002	NTO / RDX / TNT	51 / 15 / 34
MCX-6100	NTO / RDX / DNAN	53 / 15 / 32
MCX-8001	NTO / HMX / TNT	52 / 12 / 36
MCX-8100	NTO / HMX / DNAN	53 / 12 / 35

The qualification program is a joint effort between Nammo Raufoss, FFI and Chemring Nobel.

Test Program - STANAG 4170

1. Variation of Properties with Age	AOP-7
2. Stability & Thermal Characterization	STANAG 4515/4556
3. Ignition Temperature	STANAG 4515/4491
4. Impact	STANAG 4489
5. Friction	STANAG 4487
6. Compatibility	STANAG 4147
7. Mechanical/Rheological Properties	STANAG 4525/4540/4443
8. Detonation Velocity	AOP-7
9. Critical Diameter	AOP-7
10. Shock	*STANAG 4488*
11. Explosive Response when Ignited	*STANAG 4491*
12. Electrostatic Discharge	*STANAG 4490*

Accelerated Ageing Program

Test	Method	Ageing time at 71 °C (days) 0	30	60	120	180
Tested as flakes:						
• Composition	HPLC	X				X
• DSC, 5 mg and 5 °/min	STANAG 4515	X	X	X	X	X
• Vacuum Thermal Stability 100 °C/48 hours/5 g	STANAG 4556	X	X	X	X	X
• Autoignition 1 g, 2°C/min	MIL-E-81111B	X				X
• BAM Impact Sensitivity	STANAG 4489	X				X
• BAM Friction Sensitivity	STANAG 4487	X				X
Tested as cast samples:						
• Density of samples 2 top and 2 mid samples	Weighing in air/ water	X				X
• Weight loss, 2 pellets, bottom	Weighing	X	X	X	X	X
• Exudation test, 20 hours/65 °C	TL-1376-800	X				

Test results after 180 days @ 71 °C

	Test	Method	Ageing at 71° 180 days, MCX- Δ values between 0 and 180 days:			
			MCX 6002	MCX 6100	MCX 8001	MCX 8100
Tested as flakes	Composition	HPLC				
		NTO	+0.9	+2.2	+1.1	+1.0
		TNT	- 1.4		-0.3	
		DNAN		-1.3		-0.8
		RDX	+0.5	-0.9		
		HMX			-0.8	-0.2
	DSC, 5 mg and 5°/min	STANAG 4515	204 (Δ 2)	206 (Δ 2)	229 (Δ 2)	225 (Δ 3)
	Vacuum Thermal Stability 100°C/48h ml gas/5 gram	STANAG 4556	0.28	0.59	0.22	0.33
	Autoignition 1 g, 2°C/min	MIL-E-81111B	269 / 270 (Δ 1)	270 / 270 (Δ 0)	270 / 273 (Δ 3)	271 / 273 (Δ 2)
	BAM Impact Sensitivity	STANAG 4489	29 / 24 (Δ -5)	26 / 25 (Δ -1)	30 / 24 (Δ -6)	27 / 28 (Δ 1)
	BAM Friction Sensitivity	STANAG 4487	170 / 150 (Δ -20)	194 / 146 (Δ -48)	146 / 162 (Δ 16)	151 / 148 (Δ -3)
Tested as cast charges	Density of samples, 2 top and 2 mid samples. Average values	Weighing in air/water	Δ - 0.019	Δ - 0.023	Δ - 0.012	Δ - 0.009
	Weight loss % 2 pellets	Weighing	0.25 0.18	0.10 0.10	0.14 0.11	0.08 0.09
	20 hours/65°C Cm / Weight loss, %	TL-1376-800	Exudation test 0 / 0.04	0 / 0.02	0 / 0.06	0 / 0.05

Compatibility

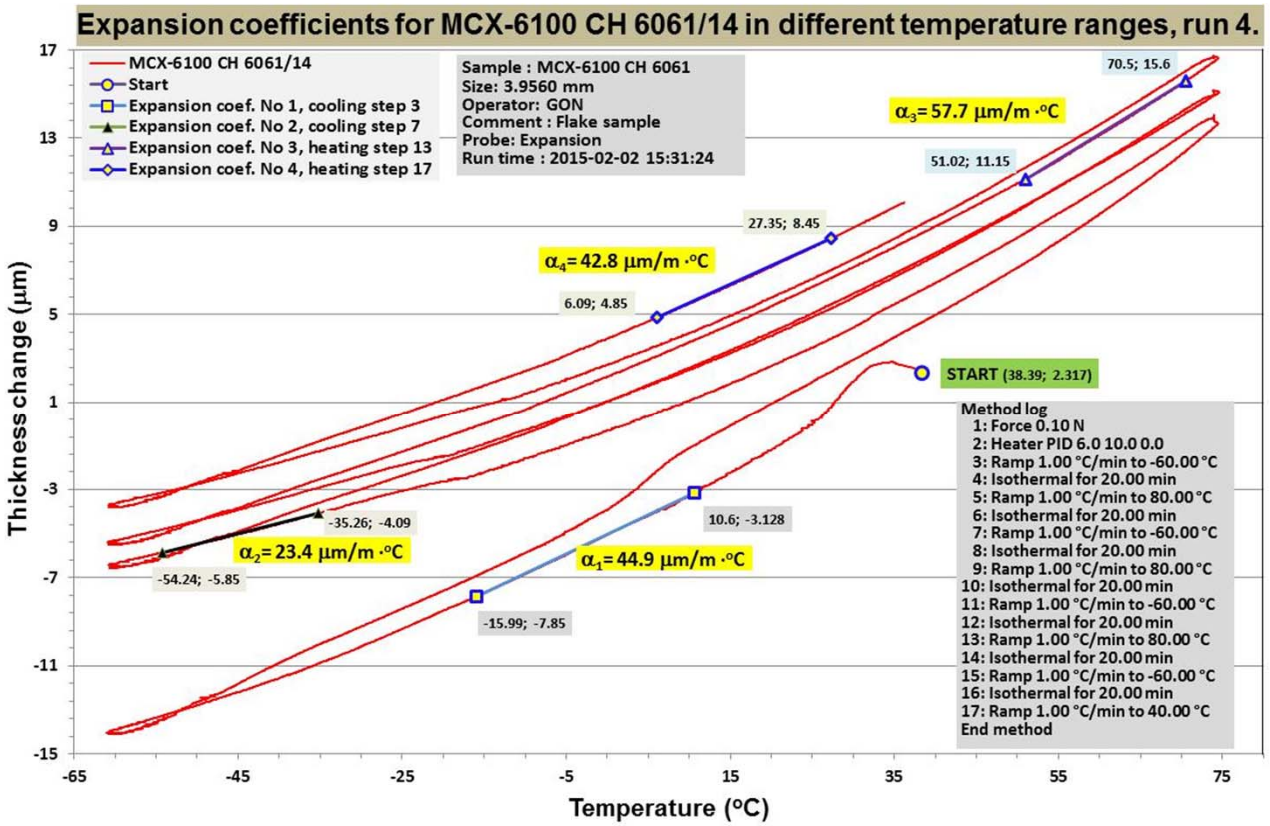
- The compatibility with contact materials should be tested according to STANAG 4147

- Compatibility with packaging material (Plastic bag) tested for two compositions
  - MCX-6002 / Plastic bag: 0,10 ml/g
  - MCX-6100 / Plastic bag: 0,12 ml/g
  - No compatibility problems expected

- The compatibility towards other materials should be tested by the user

Linear Thermal Expansion

- The Coefficient of linear thermal expansion determined by TMA
- All four compositions tested
- Temperature cycling between -60 °C and +70 °C, from 2 to 5 cycles
- Temperature cycling shows irreversible growth
- Typical examples for the four formulations are shown below



Expansion coefficient No (α_n)	Temperature range (°C)	Cycle No	Temperature mode	Expansion coefficient (mm/mm•°C
1	10.60 – -15.99	3	Cooling	44.9
2	-35.26 – -54.24	7	Cooling	23.4
3	51.02 – 70.50	13	Heating	57.7
4	6.09 – 27.35	17	Heating	42.8

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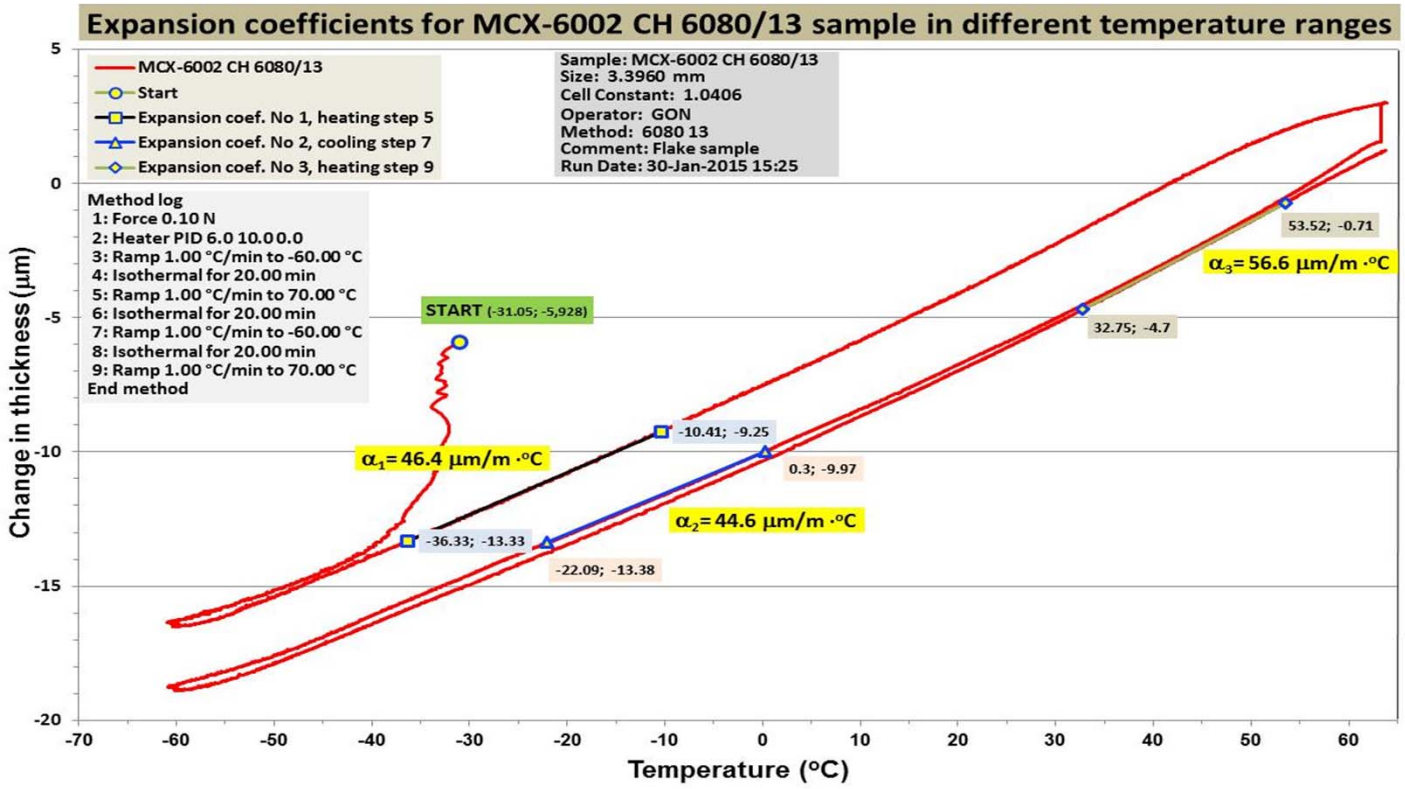
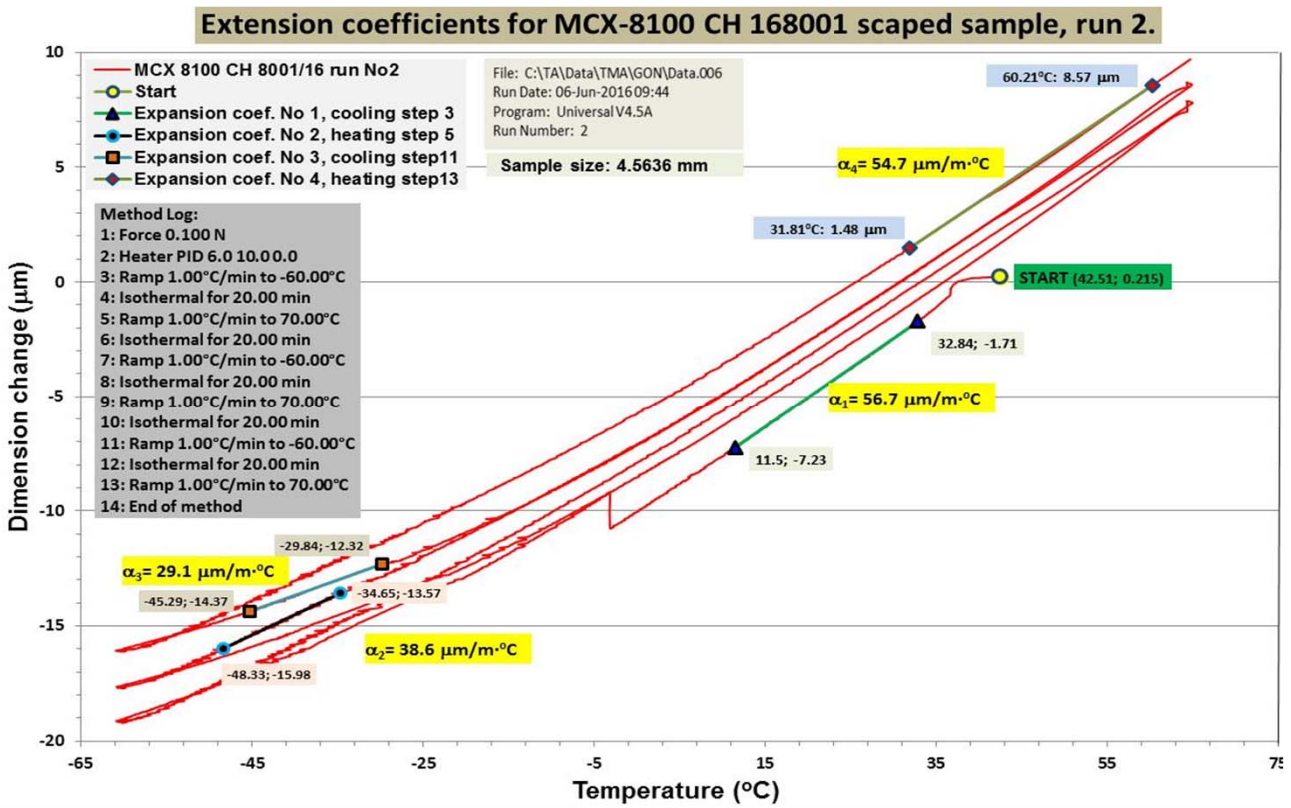


Expansion coefficient No (α_n)	Temperature range (°C)	Cycle No	Temperature mode	Expansion coefficient (mm/mm•°C
1	-36.33 – -10.41	5	Heating	46.4
2	0.30 – -22.09	7	Cooling	44.6
3	32.75 – 53.52	9	Heating	56.6



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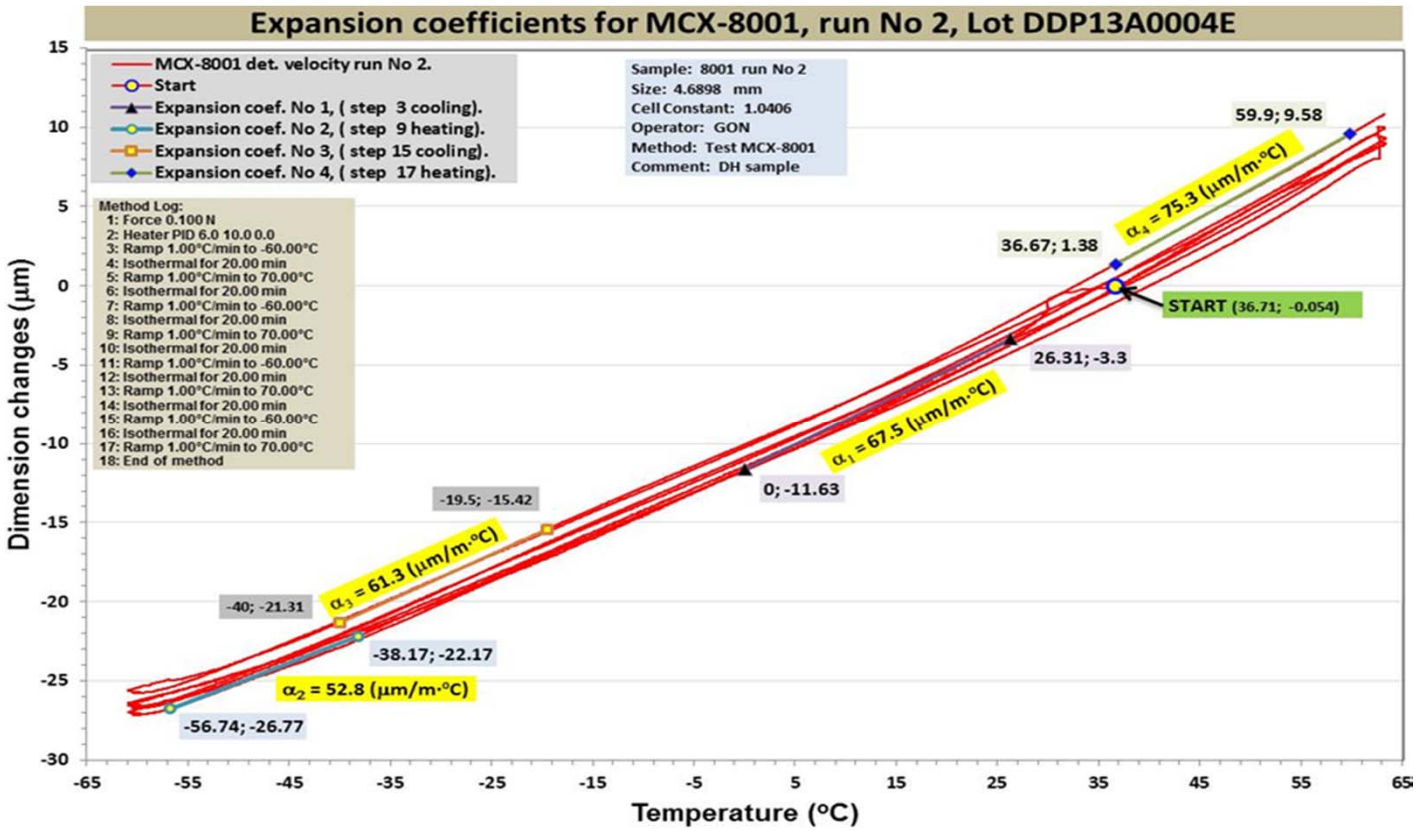

Expansion coefficient No (α_n)	Temperature range (°C)	Cycle No	Temperature mode	Expansion coefficient (mm/mm•°C
1	26.31 – 0.0	3	Cooling	75.3
2	-56.74 – -38.17	9	Heating	61.3
3	-19.5 – 40.0	15	Cooling	52.8
4	36.67 – 59.9	17	Heating	75.3

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Fast cook-off (EMTAP test no. 41)

- Testing according to DOSG Manual of tests and STANAG 4491
- Testing completed for MCX-6100 and MCX-8100
- Test set-up with two thermocouples shown below

Fast Cook-off

- The pictures below shows the two reaction types obtained for MCX-6100 and MCX-8100:
  - Reaction type 1 (Deflagration, 1 fragment) to the right
  - Reaction type 2 (Explosion, 2-9 fragments) to the left
- MCX-6100, tube 4 and 6 gave reaction type 2, probably caused by wind.

Fast Cook-off MCX-6100

FCO MCX-6100

Test No	Tube No	Temperature (oC)		Distance to Kerosene (mm)	Height Kerosene (mm)	Time to event (s)	Number of fragments	Weight of recovered fragments (g)	Degree of reaction
		Tube Surface	Flame						
1	4	193.4	206.3	300	40	383	3	3459.76	2
2	5	383.8	745.8	300	35	136	1	3687.16	1
3	6	416.0	843.1	300	25	197	2	3726.99	2
4	7	481.5	713.0	300	30	118	1	3694.70	1
5	8	339.6	716.3	300	30	106	1	3695.97	1
6	9	388.0	833.7	300	30	151	1	3693.78	1
7	10	369.5	791.9	300	30	118	1	3690.41	1

Fast Cook-off MCX-8100

FCO MCX-8100

Test No	Tube No	Temperature (oC)		Distance to Kerosene (mm)	Height Kerosene (mm)	Time to event (s)	Number of fragments	Weight of recovered fragments (g)	Degree of reaction
		Tube Surface	Flame						
8	14	409.6	632.1	300	40	162	1	3694.68	1
9	15	457.0	908.1	300	35	125	1	3689.07	1
10	16	520.1	857.1	300	25	116	1	3697.45	1
11	17	406.5	837.4	300	30	163	1	3687.51	1
12	18	480.4	875.7	300	30	126	1	3690.65	1
13	19	541.0	807.6	300	30	128	1	3691.04*	1
14	20	354.3	872.7	300	30	136	1	3701.83	1

Slow Cook-off (EMTAP Test No. 41)

- Testing according to DOSG Manual of tests and STANAG 4491
- Slow Cook-off testing just started, only MCX-6100 and MCX-8100 tested, and only one test each at 300 °C/hour.
- Both gave a grade 1 reaction (deflagration).
- Further SCO testing is ongoing.

Detonation Pressure and Velocity

Detonation pressures for the DNAN compositions are approx. 40 kbar lower than expected from the CHEETAH calculations.

DNAN-based compositions have a VoD approx. 400 m/s lower than expected from the CHEETAH calculations.

Formulation	Composition	VoD, m/s	Pdet (kbar)	Cheetah (kbar)
MCX-6002	NTO/TNT/RDX	7816	247	257-262
MCX-8001	NTO/TNT/HMX	7694	246	256-261
MCX-6001	NTO/DNAN RDX	7199	190	230
MCX-8100	NTO/DNAN/HMX	7068	208	248

Critical Diameter

- Two different methods:
  1) cast conical charges (MCX-6100)
  2) test items were glued together from cylindrical charges (MCX-6002, MCX-8001 and MCX-8100).

Formulation	Crit. Dia., mm
MCX-6002	10,0
MCX-8001	<11
MCX-6100	19,7
MCX-8100	*20 / 16*

Left an instrumented test item
Middle normal test setup
Right recovered witness plates

Shock Sensitivity testing

- Both Intermediate scale gap.test (ISGT) and small scale gap-test (BICT gap test) are used
- Critical diameter is an issue for DNAN-based compositions
- Only MCX-6100 and MCX-6002 tested so far
- The testing of MCX-8100 and 8001 is ongoing

	ISGT kbar	BICT mm	% TMD
MCX-6002		10/12	96
MCX-6002	40		98
MCX-6100	58,5 / 60,8		98
MCX-6100	36,5		95

NTO-based melt-cast compositions

	MCX-8100 NTO / DNAN/ HMX 53 / 35 / 12	MCX-6100 NTO/ DNAN/ RDX 53 / 32 / 15	MCX-8001 NTO/ TNT/ HMX 52 / 36 / 12	MCX-6002 NTO/ TNT/ RDX 51 / 34 / 15	Comp B TNT/RDX 40/60
Full scale prod	X	X	X	X	X
	Deg. Of Reaction / No. of fragments	Deg. Of Reaction / No. of fragments			
FCO	1 / 1 (7)	1 / 1 (5) 2 / 2 (1) 2 / 3 (1)			
SCO	1 / 1 (1)	1 / 1 (1)			
Viscosity, °C	7 sec / 96	5-8 sec / 96	6-9 sec / 85	11 sec / 85	3-5 sec.
Det.Vel. m/s (meas.)	7068	7199	7694	7816	7800
Det. Pres. kbar	208	193	246	247	
Crit. Dia. mm	20	19-20	<11	10	4
ISGT, Kbar		58.5 / 60.8		40	26

Summary

- Accelerated ageing testing completed.
- Tested NTO + TNT versus DNAN and RDX versus HMX
- Detonation velocity and detonation pressure completed.
- Tube tests for MCX-6100 started (FCO / SCO)
- MCX-6002 has performance like Comp B but with improved IM properties.
- All four formulations can be processed in standard melt-cast production equipment

Acknowledgement

Considerable contributions to the program from

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- Gaute Jensen, Nammo Raufoss