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English summary

The main explosive filling in munitions must have properties that fulfil the insensitive munitions requirements in STANAG 4439. An important property for several of the IM threats is the shock sensitivity of the explosive filling. Accordingly, a Chemring composition MCX-6100 containing NTO/DNAN/RDX (53/32/15) has been tested for shock sensitivity in Intermediate Scale Gap test according to STANAG 4488 Ed 2. MCX-6100 is a melt-cast composition. The density difference between melted and solid material is significant, resulting in challenges to obtain high quality of the fillings. Tested gap test tubes had an average filling density of 96.38 $\pm$ 0.85 % of TMD (Theoretical Maximum Density). X-ray of the tubes showed good filling homogeneity in the bottom with a concentration of the pores and voids in the upper part of the tubes. During testing the tubes were therefore initiated from the bottom.

The obtained result of 58.5 kbar indicates that MCX-6100 has very low shock sensitivity and is a promising candidate for achieving IM requirements.

Sammendrag

Hovedsprengstoffet må ha egenskaper som oppfyller kravet til IM (Insensitive Munitions) gitt i STANAG 4439. En viktig egenskap for å motstå flere av IM-truslene er sjokkfølsomheten til sprengstoffyllingen. Chemring-komposisjonen MCX-6100 med sammensetning NTO/DNAN/RDX (53/32/15) har derfor vært testet for sjokkfølsomhet i Intermediate Scale Gap test i henhold til STANAG 4488 Ed 2. MCX-6100 er en smelt/støp-komposisjon. Forskjellen i tetthet mellom flytende og fast masse er stor, noe som gir store utfordringer i å oppnå god kvalitet/tetthet på støpte fyllinger. For gaptest-rørene som har vært testet har MCX-6100 sprengstoffyllingen i gjennomsnitt en tetthet på 96.38$\pm$ 0.85 % av TMD. Røntgen av rørene viser imidlertid en god homogenitet for nedre halvdel av fyllingene, og at porene og tomrommene er i den øvre delen av rørene. Av den grunn ble rørene under testingen snudd og initiert fra bunnen.

Resultatet for MCX-6100 med en 50 % sannsynlighet for initiering var 58.5 kbar. Dette er en svært lav sjokkfølsomhet og viser at MCX-6100 er en komposisjon med stort potensiale for å oppnå gode IM-egenskaper for systemer hvor den inngår.

Contents

Abbrevations

BAMO	3,3-Bis-azidomethyl oxetane
DNAN	2,4-dinitroanisole
DSTO	Defence Science and Technology Organization
GA	Glycidyl azide
GA/BAMO	Glycidyl azide- (3,3-bis(azidomethyl)oxetane) Copolymers
HMX	Octogen/1,3,5,7-tetranitro-1,3,5,7-tetraazacyclooctane
HWC	Hexogen/Wax/Graphite (94.5/4.5/1)
IM	Insensitive Munitions
IMX-104	NTO/DNAN/RDX (53/31.7/15.3) (3)
MCX	Melt Cast Explosive
MCX-6100	NTO/DNAN/RDX (53/32/15)
NTO	3-Nitro-1,2,4 Triazol 5-one
RDX	hexogen/1,3,5 -trinitro-1,3,5-triazacyclohexane
TMD	Theoretical Maximum Density
TNT	2,4,6-trinitrotoluene
WP	Work Package

1 Introduction

Under the EDA project arrangement No B-0585-GEM2-GC "Formulation and Production of New Energetic Materials" different melt-cast compositions in addition to compositions containing GA/BAMO polymers have been studied. Norway have its main activity in the synthesis of GA/BAMO polymers suitable for coating nitramines for production of press granules, for press filling of munitions units or production of pressed charges.

Norway was the only country that used the energetic binder for explosive charges. Italy and Germany used their polymers as binders for propellants. The compositions we produced have a high content of HMX (94-97 wt%). Their primary application will be as boosters or main fillings for shaped charges.

To broaden the number of different compositions in the generic fragmentation testing in 40 mm shells in WP 4000, Norway included 4 melt cast compositions. These compositions are of interest for Norway as main fillers preferentially for large caliber munitions. Two compositions have TNT and two have DNAN as binder, while the filler is NTO/RDX or NTO/HMX. These compositions have, in addition to fragmentation performance, been characterized for the most important properties as detonation velocity, detonation pressure and critical diameter.

Dinitroanisole (DNAN) is a key IM melt-phase ingredient that is currently applied in several IM melt-pour formulations developed by the U.S. Army and the Australian DSTO (Defence Science and Technology Organization) (1-5). Current interest in DNAN has arisen primarily due to its ability to provide a less sensitive melt-cast medium than TNT and potential for the development of less sensitive melt-cast formulations. Since DNAN is processed essentially the same way as TNT, analogous explosive formulations can easily be transitioned. In addition, DNAN can be demilitarized in the same way as TNT using the same recovery/re-use hardware. Currently DNAN-based formulations are tailored to have TNT or Comp B performance, while having decreased sensitivity.

In this report we have tested one of the study compositions, MCX-6100 with regard to shock sensitivity. MCX-6100 contains DNAN as binder and the filler is NTO/RDX. The nominal content is 32/53/15 (DNAN/NTO/RDX). This composition has NTO/RDX content in the same range as the DNAN based US composition IMX-104 and the TNT based Chemring MCX-6002 composition.

The shock sensitivity was determined by use of the Intermediate Scale Gap Test according to STANAG 4488 (6). The shock sensitivity of a composition is important from two different viewpoints. First, to be able to design a reliable initiation train it's necessary to know the pressure needed for initiation. On the other hand, to be able to protect the munitions against external impact the shock sensitivity is one of the most important properties of an explosive filling. The responses from threats like Bullet Impact, Fragment Impact, Sympathetic Detonation and Shaped

Charge Jet depend upon shock properties of the acceptor. The IM requirements given by STANAG 4439 (7) are easier achieved with main explosive fillings having low shock sensitivity.

2 Experimentally

2.1 Tube filling and casting

The filling of the test tubes was done by Chemring Nobel at Sætre. The tube was placed in a Teflon holder with an alumina sheet covering the end of the tube. At the top of the tube an empty extension of 2-3 cm was given to get sufficient space to fill the tube when the filling goes from liquid to solid during the cooling process. After the composition was melted and heated to 100-102 °C, it was filled into the tube that had been in an incubator at the same temperature over the night. After filling of the composition into the tube the tube was moved to the incubator for 2 hours. The solidification/cooling process of the casted items took place at room temperature.

Figure 2.1 The figure shows tubes No 11 to No 20 after casting.

Figure 2.2 The figure shows the top of tubes No11 to No15 after cleaning and modification.

Figure 2.1 shows the 10 tubes as received from Chemring. Figure 2.2 shows tubes No 11 to No 15 after having been cleaned and the top adjusted. Figure 2.3 shows the bottom of the tubes No 11 to No 15 after removing the alumina foil and the filling level adjusted.

Figure 2.3 The figure shows the bottom of tubes No 11 to No15 after adjusting the filling level.

Figure 2.4 The figure shows the top of tubes No 16 to No 20 after adjusting the filling level.

Figure 2.4 and 2.5 shows the top and bottom of tubes No 16 to No 20 after cleaning and adjustment of the filling level.

Figure 2.5 The figure shows the bottom of tubes No 16 to No 20 after adjusting the filling level.

2.2 X-ray

All tubes were X-rayed with a 320 kV apparatus at Nammo Raufoss, both at 0^o and 90^o to clarify the position of observed defects. X-ray pictures of all tubes are presented in Figures 2.6 - 2.10. Figure 2.6 shows pictures of tubes No 11 to No 13; the left picture at 0^o and the right picture at 90^o.

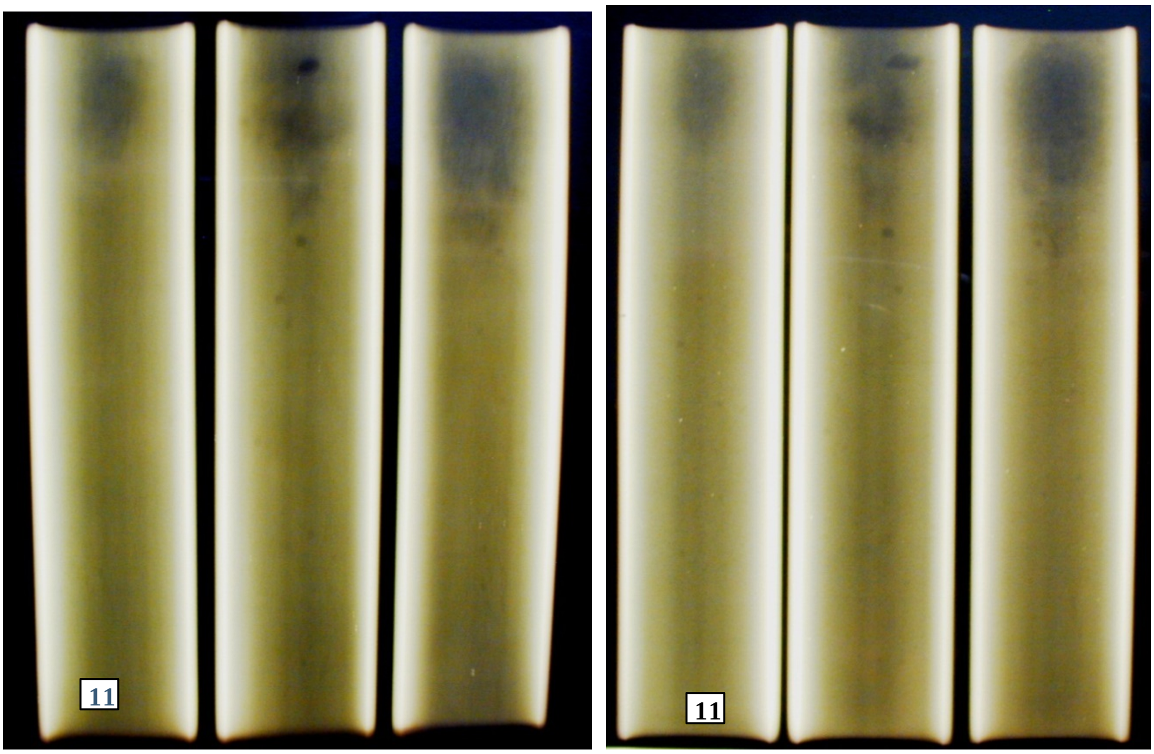

Figure 2.6 X-ray pictures of tubes No 11 to No13: 0^o left and 90^o right

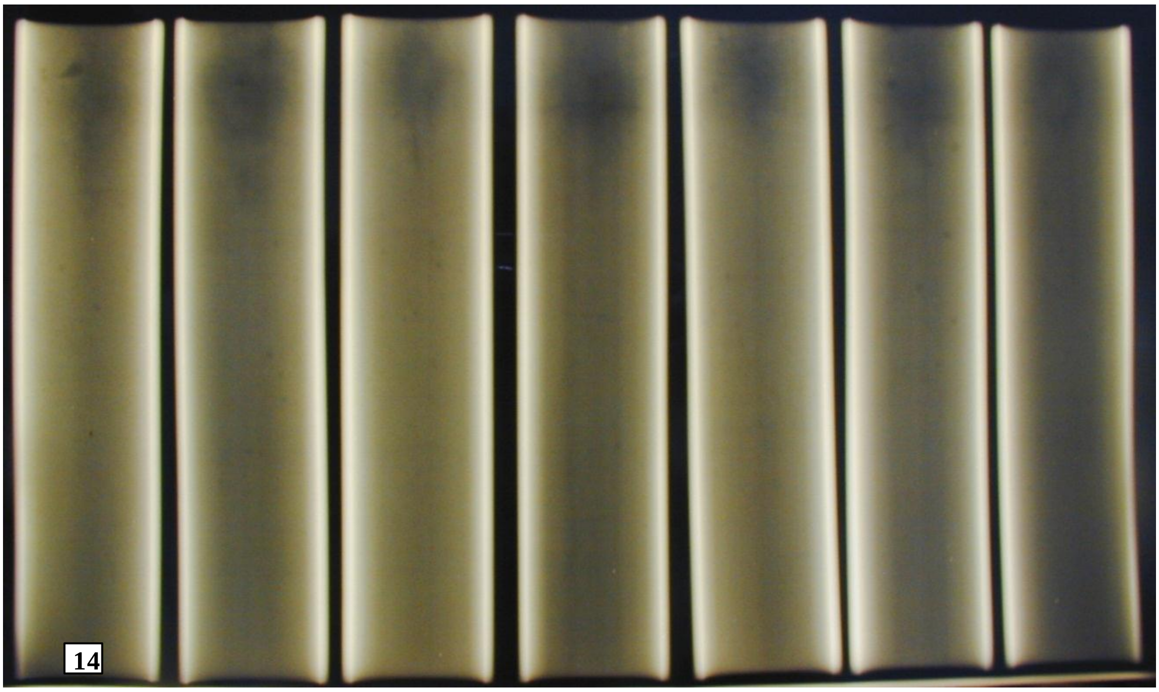

Figure 2.7 The figure shows an X-ray picture of tubes No14 to No 20 at 0°.

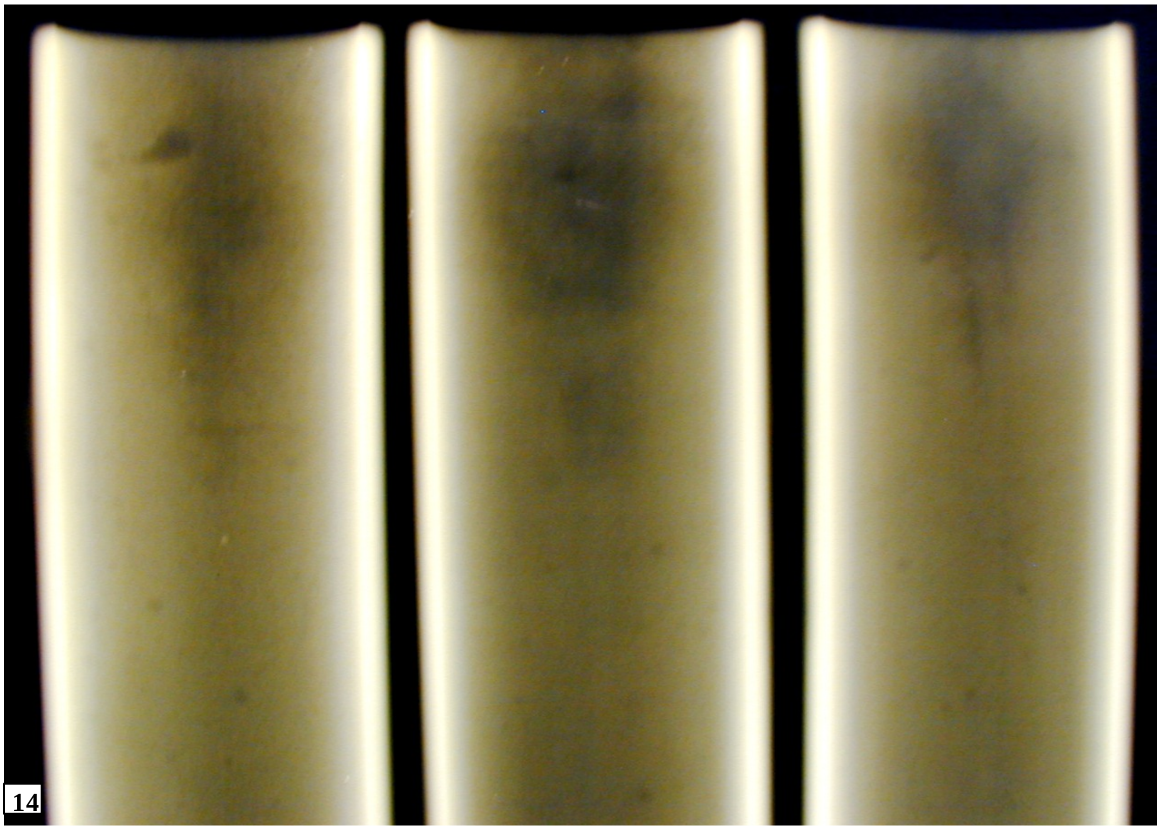

Figure 2.8 The figure shows a magnified X-ray picture of the top of tubes No 14 to No16 at 0°.

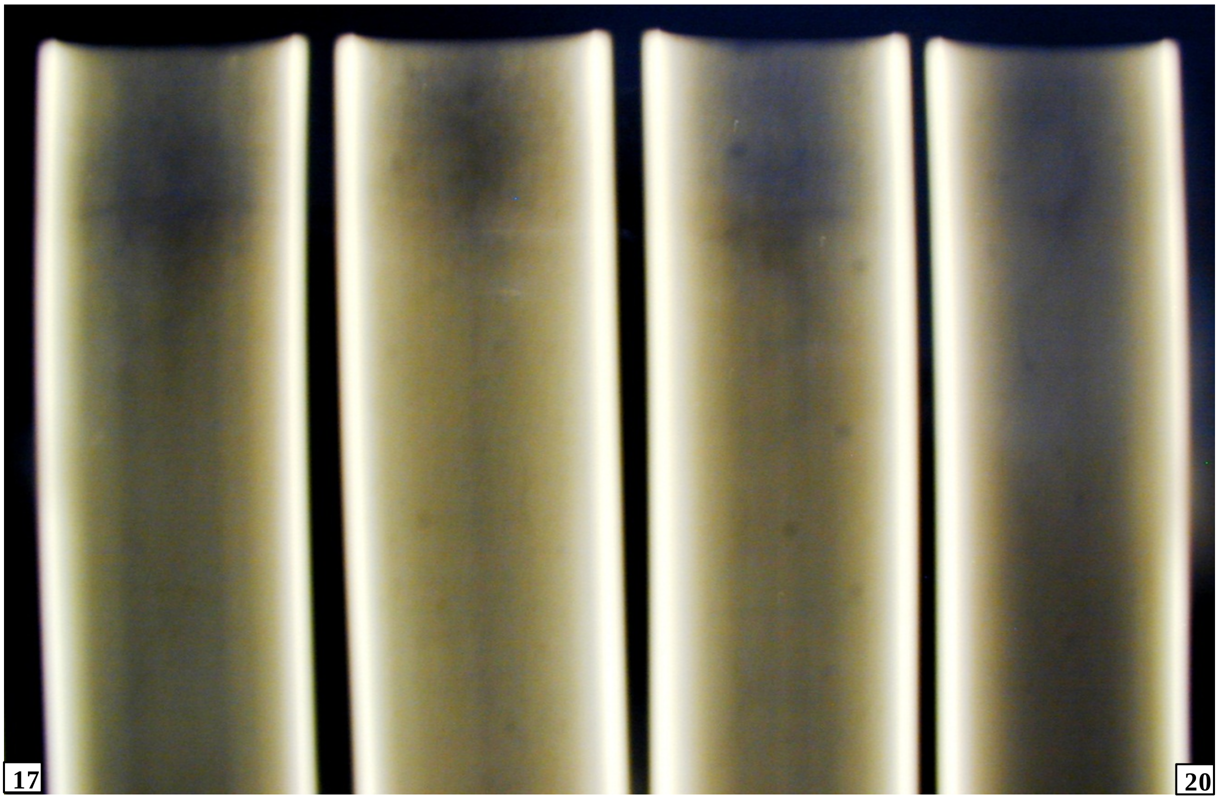

Figure 2.9 The figure shows a magnified picture of the top of tubes No 17 to No 20 at 0^o.

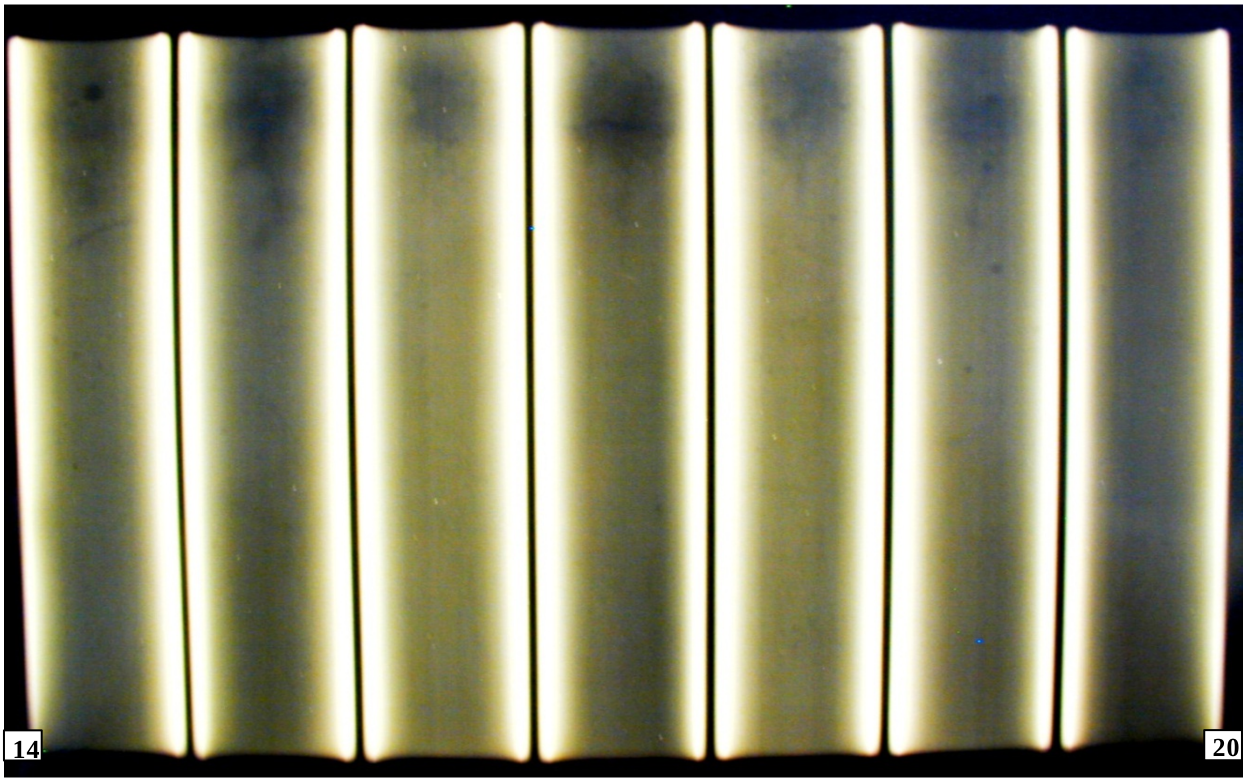

Figure 2.10 X-ray of tubes No 14 to No 20 after being turned 90^o.

The X-ray pictures explain the moderate density obtained for the fillings, see table 3.1. As seen from the X-ray pictures there are more or less dark areas at the top of all tubes. However, all tubes have few defects in the lower 10 cm, and it was decided to fire them by initiation from the bottom.

2.3 Intermediate Scale Gap Test

We have used the Intermediate Scale Gap Test described in STANAG 4488 (6) for determination of the shock sensitivity with one exception. The ethyl acetate cards we used had a thickness of 0.254 mm instead of 0.19+0.002/-0.001 mm as recommended in the STANAG.

As booster explosive we used HWC containing RDX/Wax/Graphite (94.5/4.5/1). The booster was pressed with 7.2 tons pressure and a dwell time of 60 seconds. The control report for the booster explosive is given in Appendix A. Initiation was performed with a detonator No 8. Figure 2.11 shows the test conditions for the firings.

Figure 2.11 The picture shows the test setup for firing of the gap test tubes filled with MCX-6100 composition.

2.4 Pressure determination for HWC-donor

To determine the donor pressure we fired pellets used as donor towards Plate Dent ST-52 witness plate with thickness 70 mm. Figure 2.12 shows a picture of the set up, and Figure 2.13 shows a picture of the witness plate after firing. The depth in the witness plate was measured to 7.09 mm. From the calibration given in (8) we obtain a pressure of 255 kbar or 25.5 GPa. Reference (9) gives another equation for calculation of the detonation pressure: $P_{CJ} = 3.2455*h + 0.4274$ where h is the dent depth. For our firing this equation gives a pressure of 23.44 GPa.

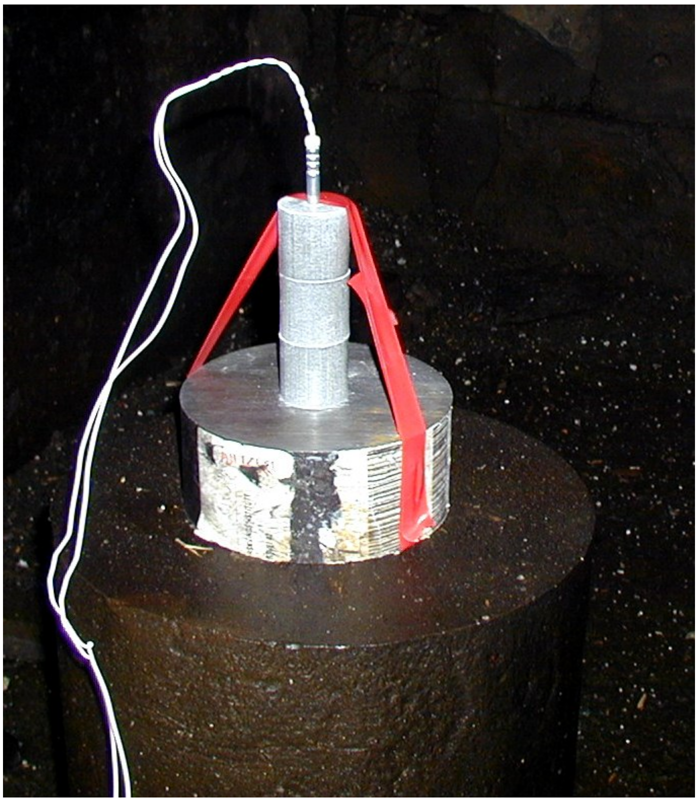

Figure 2.12 The picture shows test setup for HWC booster pressure determination.

Figure 2.13 The plate dent witness plate for HWC booster.

3 Results

3.1 Filling quality

All tubes were cleaned before filling followed by measurements of volume and weight. After filling the tubes were cleaned for spilled explosive during filling. The filling level both at the bottom and top were adjusted to give a plan end surface, see Figure 2.2-2.5. After these operations the filled tubes were weighed and the weight of the filling calculated. Table 3.1 gives all measured properties in addition to the calculated filling densities.

Tube No	Weight (g)	Inner diameter Top (mm)	Inner diameter Bottom (mm)	Average Inner Radius (mm)	Height (mm)	Volume (cm^3)	Weight Tube + Filling (g)	Weight of Filling (g)	Density (g/cm^3)
11	876.85	39.68	39.70	19.8450	199.95	2.474	1299.75	422.90	1.709
12	872.73	39.64	39.69	19.8325	200.65	2.479	1293.66	420.93	1.698
13	885.38	39.59	39.60	19.7975	200.75	2.472	1299.43	414.05	1.675
14	905.64	39.33	39.37	19.6750	200.04	2.433	1316.14	410.50	1.687
15	876.81	39.69	39.63	19.8300	199.76	2.468	1295.37	418.56	1.696
16	901.51	39.40	39.34	19.6850	200.35	2.439	1321.65	420.14	1.723
17	873.17	39.75	39.87	19.9050	200.22	2.492	1294.18	421.01	1.689
18	907.76	39.33	39.28	19.6525	200.06	2.427	1320.69	412.93	1.701
19	903.33	39.51	39.48	19.7475	200.65	2.458	1318.38	415.05	1.688
20	881.02	39.61	39.68	19.8225	200.29	2.472	1306.22	425.20	1.720
Average density of filling									**1.699±0.015**

Table 3.1 Properties of the 10 gap test tubes filled with MCX-6100 composition.

The average density of the fillings of 1.699±0.015 g/cm^3 is equivalent to 96.38±0.85 %TMD.

3.2 Firing of gap test tubes

The first tube to be tested was tube No 11 and we used a barrier of 120 cards between donor and acceptor. Initiation was from the bottom. Figure 3.1 shows the test item before firing and the witness plate and the rests of the tube after firing. The response was no detonation. Most of the explosive was recovered and the tube nearly complete.

Firing No 2 was with tube No 12. The barrier thickness was reduced to 105 cards. Figure 3.2 shows the test item before testing and the recovered parts after firing. The witness plate was undamaged and the entire explosive consumed. The tube was fragmented into large fragments and approximately 7 cm of the tube intact. The response was no reaction but the reaction was much closer to a detonation than for the first firing with a barrier thickness of 120 cards.

Figure 3.1 Firing No 1, tube No 11, barrier thickness 120 cards. Response: No reaction.

Figure 3.2 Firing No 2, tube No 12, barrier thickness 105 cards. Response: No reaction.

For the third firing we reduced the barrier thickness with 10 more cards to 95 cards. Figure 3.3 shows the test item before firing and the witness plate after firing. The witness plate has a hole indicating that the response is full detonation.

Figure 3.3 Firing No 3, tube No 13, barrier thickness 95 cards. Response: Detonation.

Figure 3.4 Firing No 4, tube No 14, barrier thickness 100 cards. Response: No reaction.

For firing No 4 with tube No 14 the barrier thickness was increased with 5 cards to 100 cards. Figure 3.4 shows a picture of the test item before firing and the recovered parts after firing. The witness plate was undamaged and half of the tube was intact. The other part of the tube was fragmented into large fragments and in addition some unreacted explosive was recovered. The response for firing No 4 was no reaction.

Firing No 5 of tube No 15 was performed with a barrier thickness of 95 cards. Figure 3.5 shows the test item before firing and the witness plate after firing. The witness plate got a hole indicating a detonation response for the acceptor.

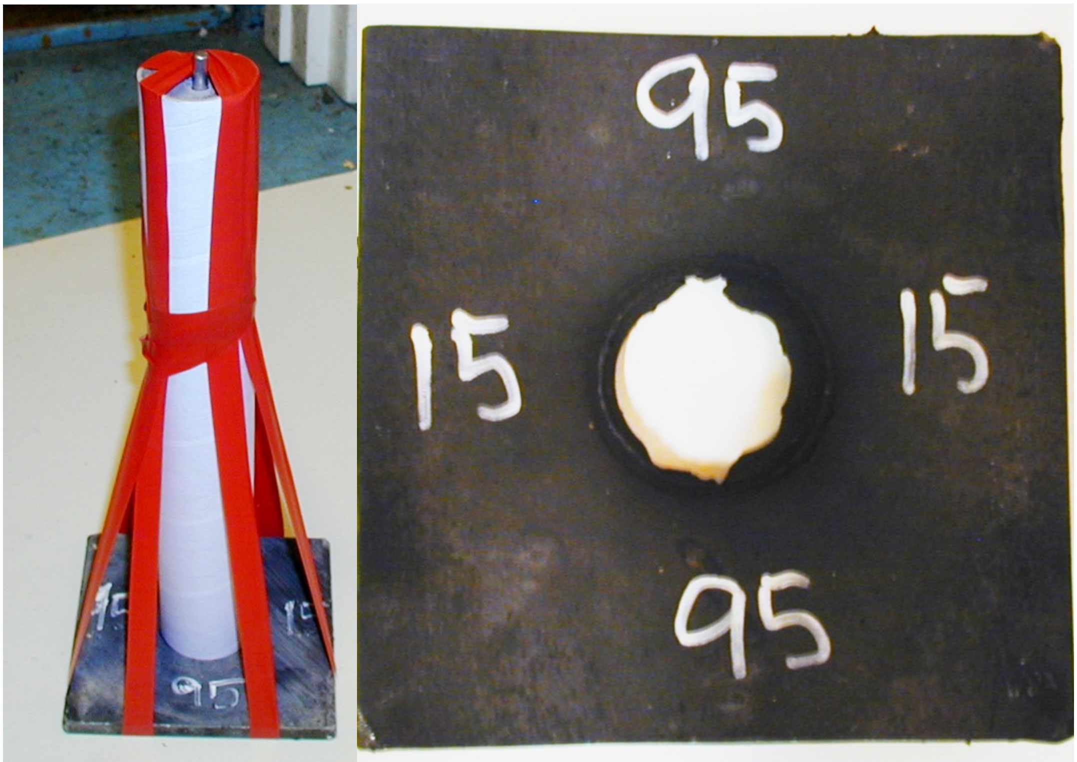

Figure 3.5 Firing No 5, tube No 15, barrier thickness 95 cards. Response: Detonation.

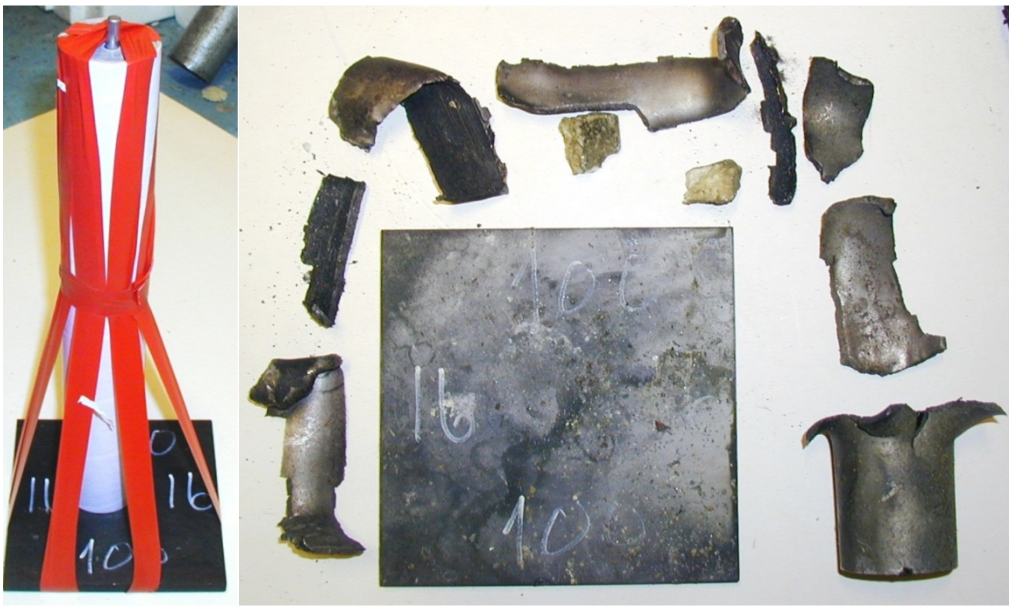

Figure 3.6 Firing No 6, tube No 16, barrier thickness 100 cards. Response: No reaction.

Firing No 6 with tube 16 had a barrier thickness of 100 cards. Figure 3.6 shows pictures of the test item before firing and the recovered witness plate and tube remnants. The witness plate is undamaged indicating no reaction response. The tube remnants including the recovered unconsumed explosive are close to what we obtained from firing No 4, indicating the same degree of reaction.

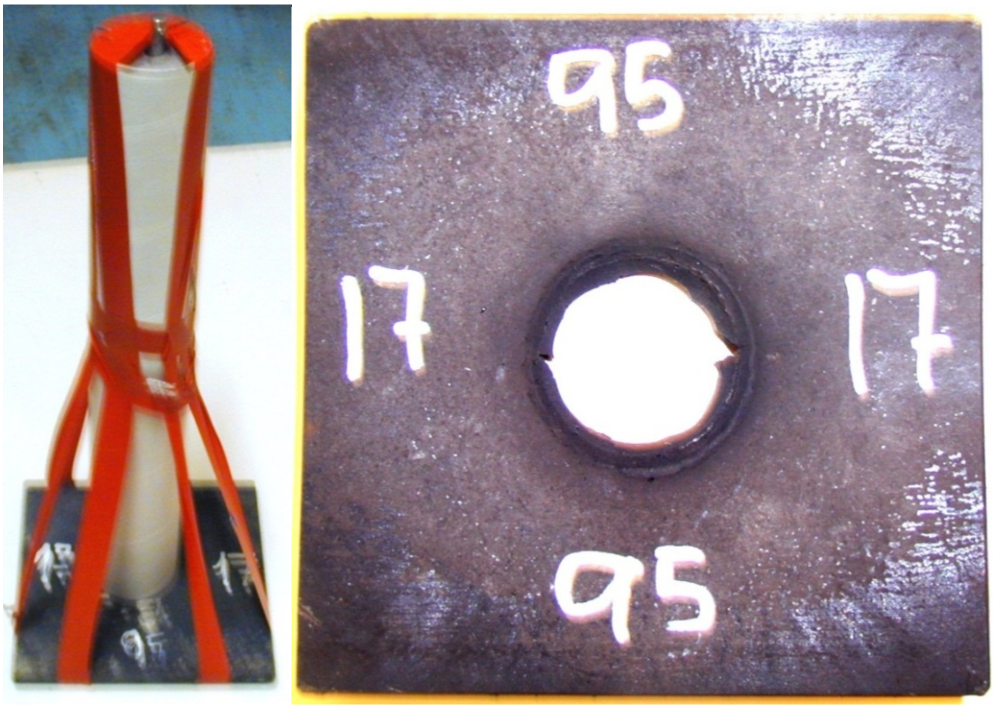

Figure 3.7 Firing No 7, tube No 17, barrier thickness 95 cards. Response: Detonation.

Figure 3.8 Firing No 8, tube No 18, barrier thickness 100 cards. Response: No reaction.

Firing No 7 with tube No 17 had a barrier thickness of 95 cards. Figure 3.7 shows pictures of the test item before firing and of the witness plate after firing. From the hole in the witness plate the response is a detonation reaction. Firing No 8 with tube No18 had a barrier thickness of 100 cards. Figure 3.8 shows the test item before testing and the recovered witness plate and the remnants of the tube. The witness plate is intact and the acceptor response is no reaction.

Figure 3.9 Firing No 9, tube No 19, barrier thickness 95 cards. Response: Detonation.


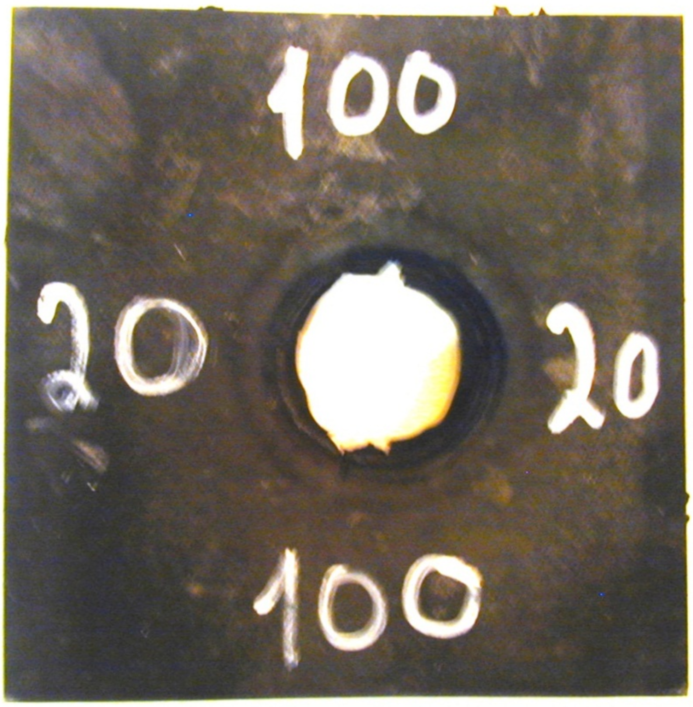

Figure 3.10 Firing No 10, tube No 20, barrier thickness 100 cards. Response: Detonation.

Firing No 9 with tube No19 had a barrier thickness of 95 cards. Figure 3.9 shows pictures of the test item before firing and the witness plate after firing. The hole in the witness plate gives a detonation response. Firing No 10 with tube No 20 had a barrier thickness of 100 cards between the donor and the acceptor. Figure 3.10 shows pictures of the test item before firing and the witness plate after firing. The hole in the witness plate indicates that detonation of the acceptor took place.

3.3 Summary of gap test results

Table 3.2 summarizes the conditions and the results of all the firings of gap test tubes filled with MCX-6100 composition. In Figure 3.11 the same information is given as a diagram.

Firing No	Tube No	Number of cards	Thickness (mm)	Response
1	11	120	30.48	No reaction
2	12	105	26.67	No reaction
3	13	95	24.13	Detonation
4	14	100	25.40	No reaction
5	15	95	24.13	Detonation
6	16	100	25.40	No reaction
7	17	95	24.13	Detonation
8	18	100	25.40	No reaction
9	19	95	24.13	Detonation
10	20	100	25.40	Detonation

Table 3.2 The table gives a summary of the responses for the tested gap tubes filled with MCX-6100 composition.

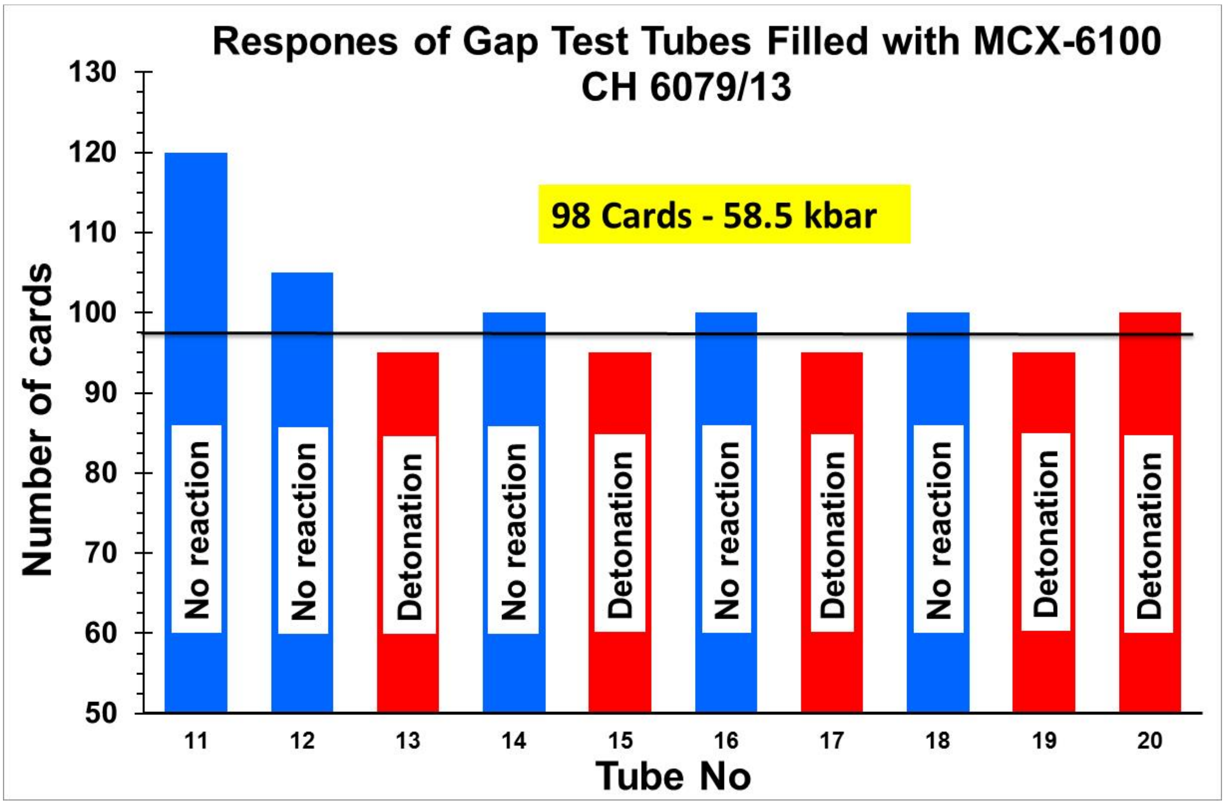

Figure 3.11 Responses for tested gap test tubes filled with MCX-6100 composition.

Figure 3.11 shows that the responses for all firings with the same barrier thickness except for tube No 10 are reproducible. 50% probability for detonation occurs with 98 cards or a barrier thickness of 24.9 mm. According to Figure B.1 in Appendix B a 24.9 mm thick barrier corresponds to a pressure of **58.5 kbar.** This result was expected compared to the result for IMX-104 given in the literature (1,4). It is significantly better than 40.4 kbar for the equal TNT composition MCX-6002 tested in (10).

The no optimal density of the fillings doesn't seem to influence the shock sensitivity when we initiate the acceptor from the bottom. The results seem to be reproducible by this test setup. However sedimentation due to density differences of the ingredients may result in a higher content of NTO in the bottom of the tested tubes.

4 Summary

Melt-cast composition MCX-6100 has been filled into Intermediate Scale Gap Test tubes. The quality of the casted fillings was investigated by X-ray and density measurements. 10 tubes have been tested with different distances between donor and acceptor to determine the 50% probability for obtaining a detonation transition response. For MCX-6100 this limit has been found to be 58.5 kbar.

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Appendix A Control report HWC

KONTROLLRAPPORT B
etter EN 10204 - 3.1

Chemring Nobel

Kjøper/Mottaker FFI Postboks 25 2007 Kjeller	Bestillingsnummer V/ Gunnar Nevstad Bestillingsdato 16.01.14	Rapportnummer 045 Kontrolldato 27.01.14
Produsent Dyno Nobel ASA N-3476 Sætre NORWAY	Produksjonsdato 23.01.14	Offentlig oppdragsnummer
Lot nummer DDP14A0068-0002	Mengde 10 kg	
Sprengstofftype **RDX/VOKS/GRAFITT, 94,5/4,5/1**	Leveringsbetingelser/Teknisk underlag For testing	

Analyseresultater for loten

	Sammensetning			Fuktighet og flyktige bestanddeler	Surhet	
	RDX	Voks	Grafitt			
KRAV	94,5 ± 0,5 %	4,5 ± 0,5 %	1,0 ± 0,2 %	≤ 0,1%	≤ 0,02 %	
RESULTAT 03/14	94,4	4,7	0,9	0,0	0,00	0,0
	Uløste partikler på USS No. 60	Vacuum stabilitet	Volumvekt	Kornfordeling %, USS No.		
				> 12	> 18	< 100
KRAV	Ingen	≤ 1,2 ml/g	0,86 - 0,93g/ml	0	≤ 2	≤ 1
RESULTAT 03/14	ingen	0,1	0,89	0	0	1

Kjersti K Bergh[?] Kvalitetssjef

Chemring Nobel AS
High Energy Materials
Manager QA

Figure A.1 Control report of the HWC used as donor explosive.

Appendix B Relation between barrier thickness and pressure

STANAG 4488 gives the relation between barrier thickness and pressure for HWC donors with density ϕ=1.60 g/cm^3. The number of cards is different from what we have used since our card is thicker than those in Figure B.1.

ANNEX B to
STANAG 4488
(Edition 2)

TABLE 2. INTERMEDIATE SCALE GAP TEST CALIBRATION DATA
RDX/WAX/GRAPHITE DONOR

# OF CARDS	BARRIER THICKNESS (mm)	PRESSURE (kbar)	# OF CARDS	BARRIER THICKNESS (mm)	PRESSUR E (kbar)
10	1.90	185.4	230	43.70	22.8
20	3.80	168.6	235	44.65	21.7
30	5.70	153.2	240	45.60	20.7
40	7.60	139.3	245	46.55	19.7
50	9.50	126.7	250	47.50	18.8
60	11.40	115.1	255	48.45	18.0
70	13.30	104.7	260	49.40	17.1
80	15.20	95.2	265	50.35	16.3
90	17.10	86.5	270	51.30	15.6
100	19.00	78.7	275	52.25	14.8
105	19.95	75.0	280	53.20	14.1
110	20.90	71.5	285	54.15	13.5
115	21.85	68.2	290	55.10	12.9
120	22.80	65.0	295	56.05	12.3
125	23.75	62.0	300	57.00	11.7
130	24.70	59.1	305	57.95	11.1
135	25.65	56.4	310	58.90	10.6
140	26.60	53.7	315	59.85	10.1
145	27.55	51.2	320	60.80	9.7
150	28.50	48.8	325	61.75	9.2
155	29.45	46.6	330	62.70	8.8
160	30.40	44.4	335	63.65	8.4
165	31.35	42.3	340	64.60	8.0
170	32.30	40.4	345	65.55	7.6
175	33.25	38.5	350	66.50	7.2
180	34.20	36.7	355	67.45	6.9
185	35.15	35.0	360	68.40	6.6
190	36.10	33.4	365	69.35	6.3
195	37.05	31.8	370	70.30	6.0
200	38.00	30.3	375	71.25	5.7
205	38.95	28.9	380	72.20	5.4
210	39.90	27.6	385	73.15	5.2
215	40.85	26.3	390	74.10	5.0
220	41.80	25.1	395	75.05	4.7
225	42.75	23.9	400	76.00	4.5

Figure B.1 The table shows the relation between barrier thickness and pressure for HWC donor.