FFI-RAPPORT

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Fast heating tube test of MCX-8100

EMTAP 41 Test

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[a]Nammo Raufoss AS

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Summary

The EMTAP 41 fast heating tube test has been carried out during STANAG 4170 qualification of MCX-8100. Seven tubes have been tested and all open up by a burning or degree 1 reaction with no fragmentation. The recovered tubes may be divided into two groups. Four tubes have one longitudinal crack in the center of the body. These reacted after 124±5 seconds at an outer tube surface temperature of 500±33^{o}C. The three remaining tubes, still in one piece, have two or more longitudinal cracks in the body. For these tubes the time to reaction is 154±12 seconds with an outer tube surface temperature of 390±25^{o}C.

MCX-8100 gives a degree 1 or burn reaction for all seven tested tubes in the fast heating test. This shows a mild reaction of the MCX-8100 composition when exposed to the fast heating threat. For munitions filled with MCX-8100 the possibility to achieve IM properties should be good when exposed to thermal threats.

Sammendrag

EMTAP 41 hurtig oppvarmingstest har blitt gjennomført for kvalifisering av komposisjonen MCX-8100. Sju rør er testet, og alle gir en brann eller grad 1 reaksjon. Ingen av rørene fragmenterer i løpet av reaksjonen. Rørene åpnes opp og forblir i et stykke, men kan imidlertid deles i to grupper. Fire rør har en sprekk i lengderetningen, og reagerer etter 124 ± 5 sekunder med en gjennomsnittlig ytre overflatetemperatur på 500 ± 33^{o}C. De resterende tre rørene, fremdeles i ett stykke, har flere sprekker med deler som er i ferd med å bli til fragmenter. Disse rørene reagerer etter 154 ± 12 sekunder med en gjennomsnittlig ytre overflatetemperatur på 390 ± 25^{o}C.

MCX-8100 gir grad 1 reaksjon eller brann for alle sju testede rør i hurtig oppvarmingstest. Utfra dette resultatet kan vi forvente at også ammunisjon med MCX-8100-fylling vil gi en mild reaksjon stilt overfor en branntrussel.

Content

Abbreviations

DNAN	2,4-dinitroanisole
DOSG	Defence Ordnance Safety Group
EMTAP	Energetic Materials Testing and Assessment Policy
HMX	octogen/1,3,5,7-tetranitro-1,3,5,7-tetraazacyclooctane
IM	Insensitive Munitions
MCX	Melt Cast eXplosive
MCX-6002	TNT/NTO/RDX 34/51/15
MCX-6100	DNAN/NTO/RDX 32/53/15
MCX 8001	TNT/NTO/HMX 36/52/12
MCX-8100	DNAN/NTO/HMX 35/53/12
NTO	3-nitro-1.2.4 triazole-5-one
RDX	hexogen/1,3,5-trinitro-1,3,5-triazacyclohexane
STANAG	Standard Agreement
TMD	Theoretical Maximum Density
TNT	2,4,6-trinitrotoluene

1 Introduction

Norway has for some years studied melt-cast compositions for use as main charge fillers in different calibres (1-3). To characterize these compositions both experimental and theoretical studies have been performed. MCX-8100 containing DNAN in addition to NTO and HMX is one of these compositions that have shown good properties as an IM-filler for large calibre munitions (4). Properties as detonation pressure and velocity were determined (5). However, if MCX-8100 shall be applied as main filler the composition needs to be qualified according to STANAG 4170 (6).

One of the properties required to be characterized for qualification is explosive response when ignited (confined and unconfined). STANAG 4491 (7) describes approved or recommended tests or test methods for performing this characterization. From STANAG 4491 Norway selected to use the UK tube tests as test vehicle for this characterization. The two tests we decided to perform were EMTAP 41 and EMTAP 42 (8).

In this report we will report on the EMTAP 41 tube test – fast heating. The qualification of the MCX-8100 composition has been a collaboration between the manufacturer of the composition, Chemring Nobel AS, and the user of the composition, Nammo Raufoss AS. The production of the tube bodies, the end caps and testing has been the responsibility of Nammo Raufoss AS. Manufacturing of the composition and filling it into the test vehicles have been performed by Chemring Nobel AS.

Norway has earlier used tube tests for qualification of DPX-6 (9). However, DPX-6 is a press filled composition. The tubes used for that qualification had a thinner end wall (9 mm) in the end caps and fewer threads. Some tests were performed with that tube design also for the MCX-6100 composition, without success. The high pressure inside the tube when DNAN melts resulted in a hole in the end caps. A response not accepted for a valid test result. In the testing carried out in this report we have used a newer design of the tube vehicle from DOSG UK. The end caps in this design have a wall thickness of 13 mm and in addition the number of threads has been increased. With this newest design neither failure of the end caps nor leakages of explosive filler has been observed.

The explosive response for MCX-8100 when ignited has been characterized by the EMTAP 42 – electrically heated tube test in (12). In this report we have performed the EMTAP 41 tube test – fast heating. No specific requirement has to be fulfilled to pass these tests. However, to fulfil the IM requirements for munitions as 120 mm and 155 mm shells, a mild reaction in the tube tests will increase the possibility. Similar ignition tests, EMTAP 41 and 42, were performed for MCX-6100 in reference 10 and 11.

The filled tubes were X-rayed before testing to study the quality and homogeneity of the fillings. In addition, the densities of the fillings were determined by weighing the tubes before and after being filled with the MCX-8100 composition.

2 Experimentally

2.1 Casting test objects

All test objects were casted by Chemring Nobel AS.

For these test objects the MCX-8100 charge 168001 was used as filler. The empty tubes were stored in a heat cabinet at 100-102^{o}C over the night before filling took place, with the filler holding the same temperature (100-102^{o}C). The filled tubes were then placed in the heat cabinet for 2 hours before cooling at ambient temperature 25^{o}C. During the cooling the top of the tubes were protected by an isolating hat. Pictures of the tubes as received at FFI are shown in Figure 2.1 and Figure 2.2.

Figure 2.1 Tubes No 14 and No 15 as received from Chemring Nobel AS, left picture. Right picture shows the tubes after cleaning and modification of the end surfaces.

The tubes were cleaned and the end surfaces corrected. Figure 2.1, right picture, shows tubes No 14 and 15 after this operation. Figure 2.3 shows tubes No 16 to 20 after cleaning and correction. Figure 2.3 shows that there are some minor cracks in the end surfaces. Before finalizing the tubes for testing the weights were measured and the densities of the fillings determined. The results with regard to filling densities are given in Table 2.1.

Figure 2.2 Picture of tubes No 16 to No 20 as received from Chemring Nobel AS.

Figure 2.3 Picture of tubes No 16 to No 20 after cleaning and modification of the end surfaces.

2.2 Quality of the fillings

2.2.1 Density

Density of the MCX-8100 fillings was measured by weighing the tubes before and after been filled with MCX-8100 CH 168001 composition. The obtained filling densities are given in Table 2.1.

Tube No	Weight Filled Tube (g)	Weight empty tube[1] (g)	Weight of Filling (g)	Filled with MCX-8100 Charge	Filling density $(g/cm^3)^2$	To be tested in
14	2976.87	2636.6	340.27	168001	1.719	FCO
15	2975.22	2635.8	339.42	168001	1.715	FCO
16	2973.87	2635.5	338.37	168001	1.709	FCO
17	2975.97	2634.0	341.97	168001	1.728	FCO
18	2976.20	2637.8	338.40	168001	1.710	FCO
19	2976.37	2637.2	339.17	168001	1.713	FCO
20	2977.72	2639.2	338.52	168001	1.710	FCO

[1]Body+1 end cap. [2]Volume 197.9451 cm^3 calculated from drawing (diameter 3.15 cm, height 25.4 cm).

Table 2.1 Properties of the tubes tested in the EMTAP 42 fast heating tube test..

The majority of the tubes have visual cracks in the top. However, the densities of the fillings have low variations with an average of 1.715 $\pm$0.006 g/cm^3. TMD for MCX-8100 is 1.7650 g/cm^3. This gives an average filling percentage of 97.2.

2.2.2 X-ray

To inspect the fillings for unexpected defects all tubes were X-rayed. Figures 2.4 and 2.5 show pictures of the X-rayed tubes. All tubes have some pores in addition to areas with lower density in the upper third of the filling. No large empty space is observed. These defects explain the moderate densities of the fillings shown in Table 2.1.

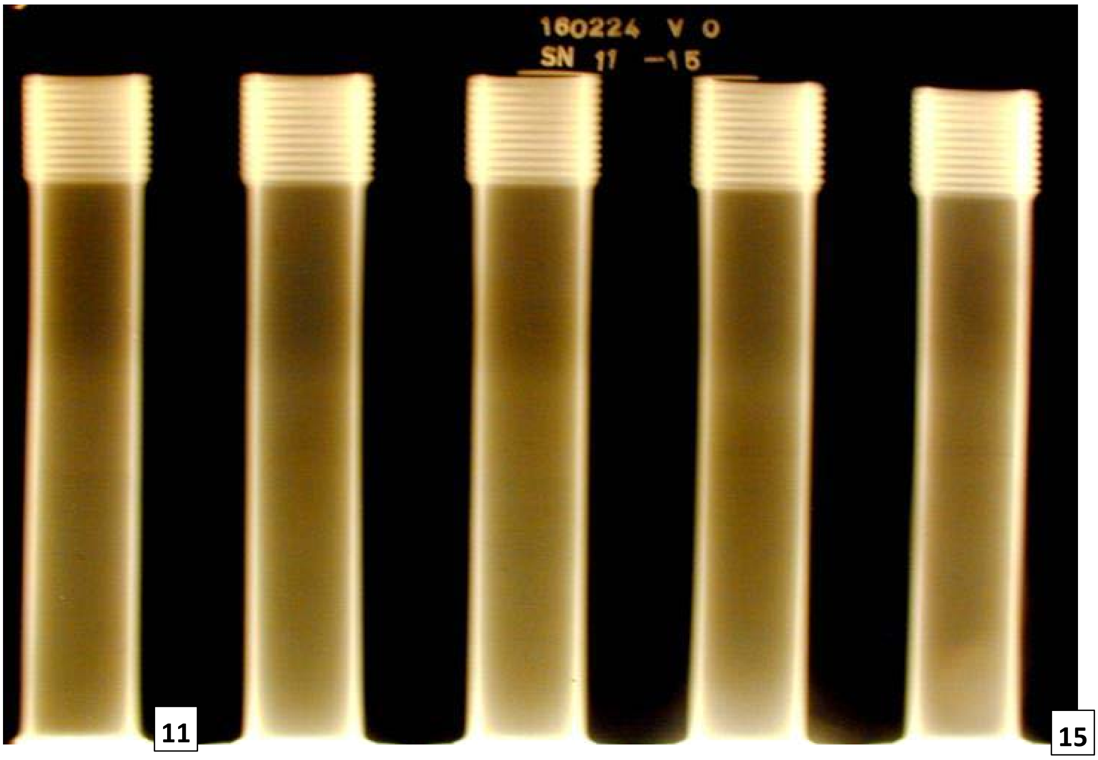


Figure 2.4 X-ray of tubes No 11 to No 15 filled with MCX-8100.

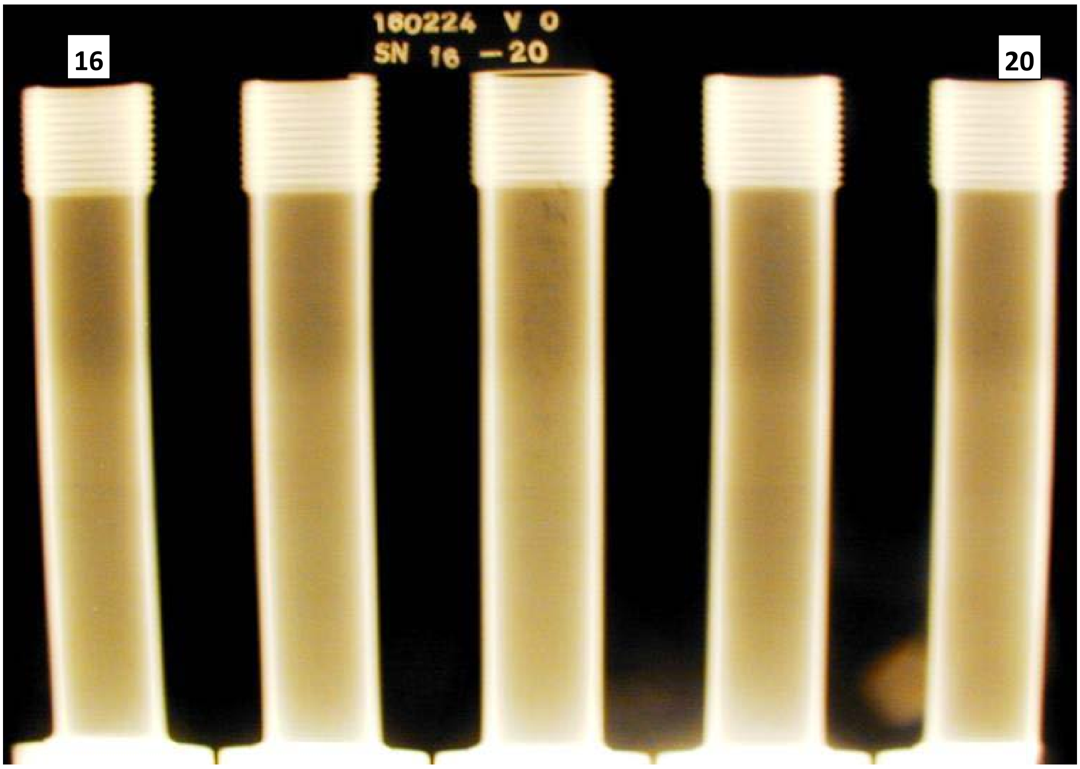


Figure 2.5 X-ray of tubes No 16 to No 20 filled with MCX-8100.

2.3 Tube design

We received the drawings of the tube parts from UK DOSG. Copies of these drawings are given in Appendix A. Our tube has the same dimensions. The only difference is the steel quality. The type of steel Nammo used in the production of the tubes and the end caps is given in Appendix B.

2.4 Test performance

2.4.1 Test setup

The test "Tube Test - Fast Heating (EMTAP test No 41)" was performed according to the description in the DOSG Manual of Tests (8) and STANAG 4491 (7). Figure 2.6 shows a picture of the test area for the testing.

Figure 2.7 shows a picture of how the tube was placed in the pool. In addition it shows how the ignition of the fuel was performed, right side of the pool. Figure 2.8 shows a picture of the position of the two thermocouples used to measure the temperature in the flame and on the tube surface. Appendix C gives distances between tube and fuel surface in addition to the amount/height of kerosene used in each test.

Figure 2.6 Picture of the test area.

Figure 2.7 Test pool and test item seen from the side.

Figure 2.8 Picture of test item with the two thermocouples seen from above.

2.4.2 Instrumentation

Position of the thermocouples: (Figure 2.8)	TC1: On the tube surface. TC2: 10 cm from the tube surface to measure air/flame temperature.

Test equipment

Thermocouples:	Type K 1.5 mm (Inconel) length 10 m.
Compensation cable:	Type K
Tape:	3M363
Data logger:	Agilent 34972 “TEMP-4” MY49004556
Laptop:	Lenovo ThinkPad T520 ID: NO88848
Software:	BenchLink Data Logger 3
Sampling rate:	1 Hz

3 Results

3.1 Test No 8 – Tube No 14

Figure 3.1 shows the temperatures at the tube surface and in the flame 10 cm from the tube surface during the test. The flame surrounds the test item all the time. The event time was manually measured to 2 minutes and 42 seconds, Appendix C. From the temperature measurements in Figure 3.1 we selected the same event time with a tube surface temperature of 409.6^{o}C.

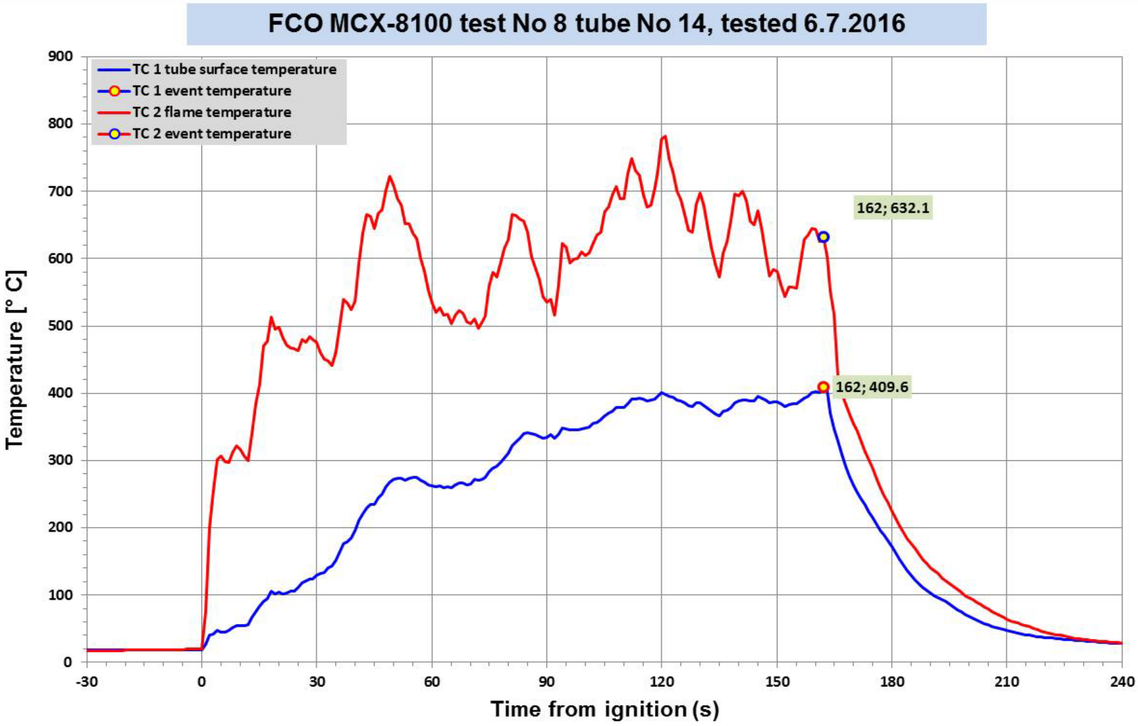


Figure 3.1 Temperatures in the flame and on the tube surface for tube No 14 filled with MCX-8100 CH 168001.

After the test was finished the test item was recovered, Figure 3.2. The weight of the recovered item was 3694.68 g. The weight of the empty tube was 3687.6 g. The difference in weight is due to soot and combustion deposits in and on the recovered tube. We could not observe unreacted filler in the tube.

Figure 3.2 Pictures of the recovered tube after testing.

3.2 Test No 9 - Tube No 15

The next tube tested was tube No 15. For this tube the flame temperature after ignition was more or less constant between 800-900°C until a reaction occurred. The time to reaction was, as Figure 3.3 shows, 125 seconds with a temperature on the tube surface of 457.0°C and in the flame of 908.1°C. Manually registered time to event was also 2 minutes and 5 seconds.

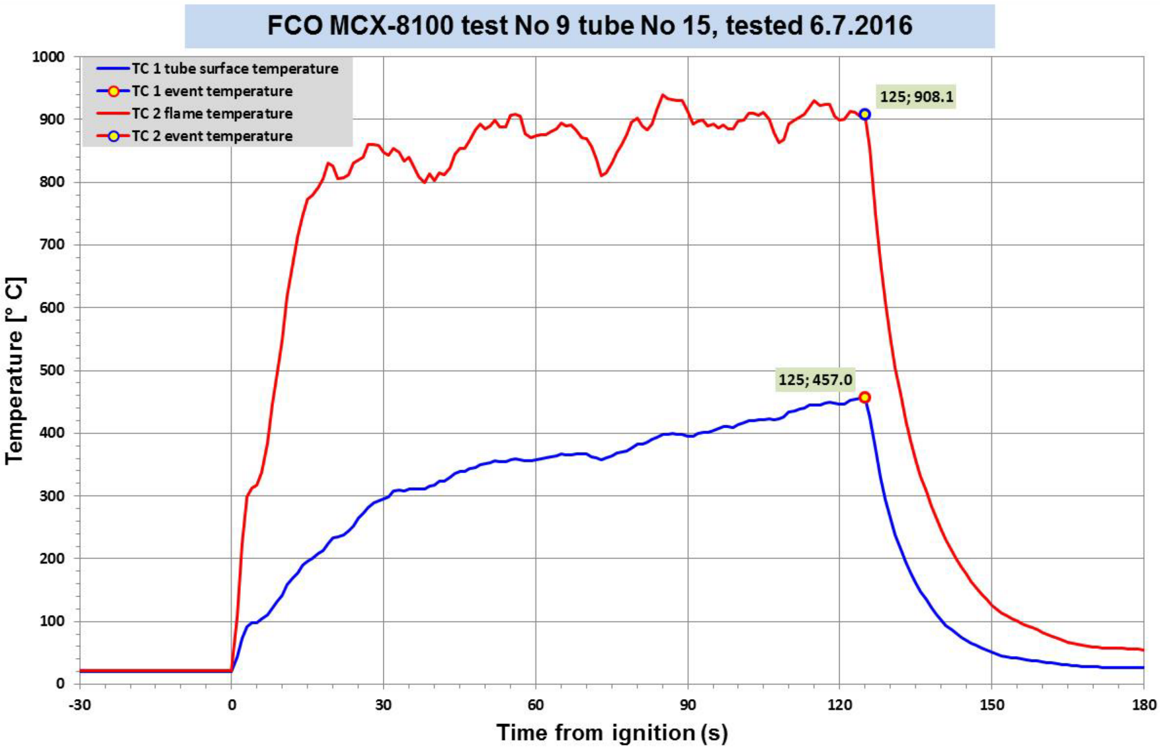


Figure 3.3 Temperatures in the flame and on the tube surface for tube No 15 filled with MCX-8100 CH 168001.

Figure 3.4 Pictures of the recovered tube after testing.

Figure 3.4 shows the recovered tube. The weight of the recovered tube was 3689.02 g. The empty tube has a weight of 3686.8 g. The difference in weight comes from soot and combustion deposits. No rest of the filling was observed.

3.3 Test No 10 - Tube No 16

In test No 10 tube No 16 was tested. Figure 3.5 shows the temperature registrations on the two applied thermocouples. The event time is the same as the manually measured, 1 minute and 56 seconds. The temperature on the surface of the tube was 520.1^{o}C at the event time.

Figure 3.6 shows the recovered tube with a weight of 3697.45 g. The weight of the empty tube was 3686.5 g. The extra weight of the recovered tube compared to the empty tube consists of soot and combustion deposits. No unreacted filler was observed in the tube.

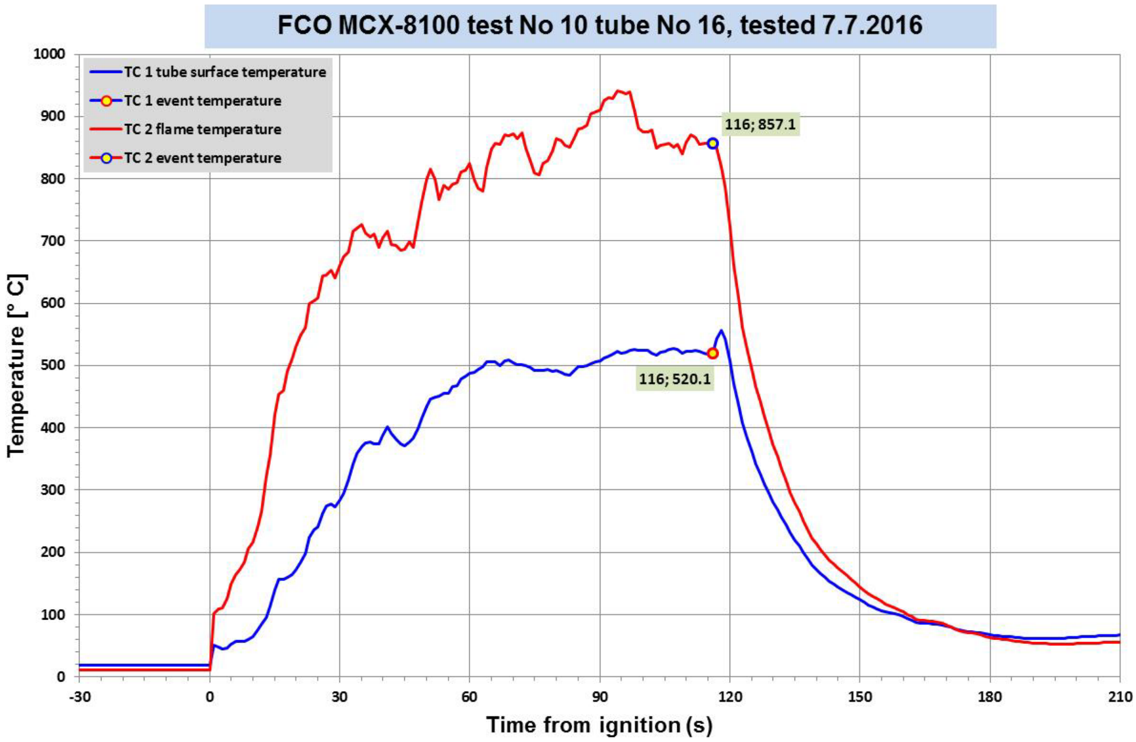


Figure 3.5 Temperatures in the flame and on the tube surface for tube No 16 filled with MCX-8100 CH 168001.

Figure 3.6 Pictures of the recovered tube after testing.

3.4 Test No 11 - Tube No 17

The next tube we tested was tube No 17. Figure 3.7 shows registrations of the temperatures in the flame and on the tube surface. The time to event was 163 seconds and the temperature at the surface was measured to 406.5^{o}C. The manually measured event time was 2 minutes and 43 seconds. The longer time to reaction for this tube is due to slower temperature increase on the tube surface compared to what we observed for tubes No 15 and No 16. The event temperature for this tube is comparable with the time for tube No 14, 162 seconds. The difference in event time, as Figure 3.8 shows, gives a slightly different opening of the tube. The tube has more than one longitudinal crack as also obtained for tube No 16 .The weight of the recovered tube was 3687.51g. The weight of the empty tube was 3685.0 g. Added weight to the recovered tube comes from soot and combustion deposits. No unreacted filler rests were observed in the tube.

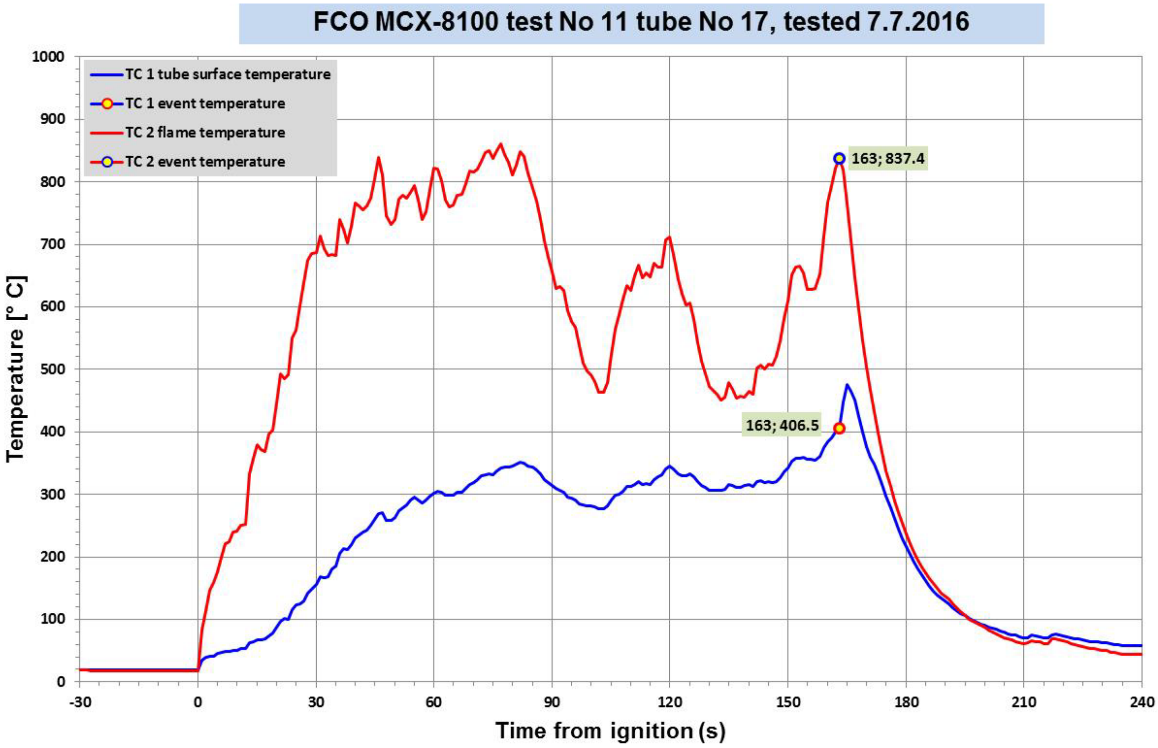


Figure 3.7 Temperatures in the flame and on the tube surface for tube No 17 filled with MCX-8100 CH 168001.

Figure 3.8 Pictures of the recovered tube after testing.

3.5 Test No 12 - Tube No 18

The next tube we tested was tube No 18. Figure 3.9 shows registrations of the temperatures in the flame and on the tube surface. The time to event was 126 seconds with a tube surface temperature of 480.4°C. The manually measured event time was 2 minutes and 5 seconds. The time to reaction for this tube is comparable to what we observed for tubes No 15 and No16. This gives, as Figure 3.10 shows, a similar tube opening as for tube No 15 and No 16 with only one longitudinal crack. The weight of the recovered tube was 3690.65 g. The weight of the empty tube was 3688.8 g. Added weight of the recovered tube comes from soot and combustion deposits. No unreacted filler rests were observed in the tube.

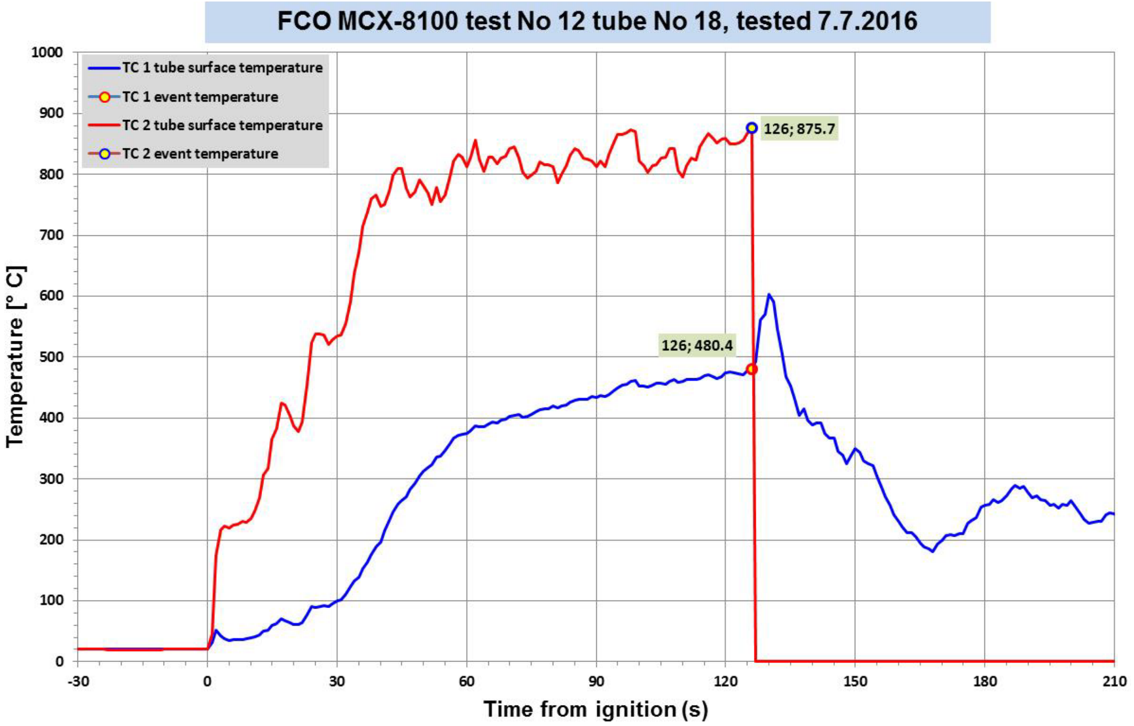


Figure 3.9 Temperatures in the flame and on the tube surface for tube No 18 filled with MCX-8100 CH 168001.

Figure 3.10 Pictures of the recovered tube after testing.

3.6 Test No 13 - Tube No 19

The next tube we tested was tube No 19. Figure 3.11 shows registrations of the temperatures in the flame and on the tube surface. The time to event was 128 seconds with a tube surface temperature of 541.0°C. The manually measured event time was 2 minutes and 8 seconds. The time to reaction for this tube is comparable to what we observed for tubes No 15, No 16 and No18. This gives, as Figure 3.12 shows, a similar tube opening as for tube No 15, No 16 and No 18. The weight of the recovered tube was 3691.04 g and with unreacted filler 3710.28 g. The weight of the empty tube was 3688.2 g. Added weight (2.8 g) to the recovered tube comes from soot and combustion deposits. 19.24 g unreacted filler was observed in the tube, the picture in the center of Figure 3.12.

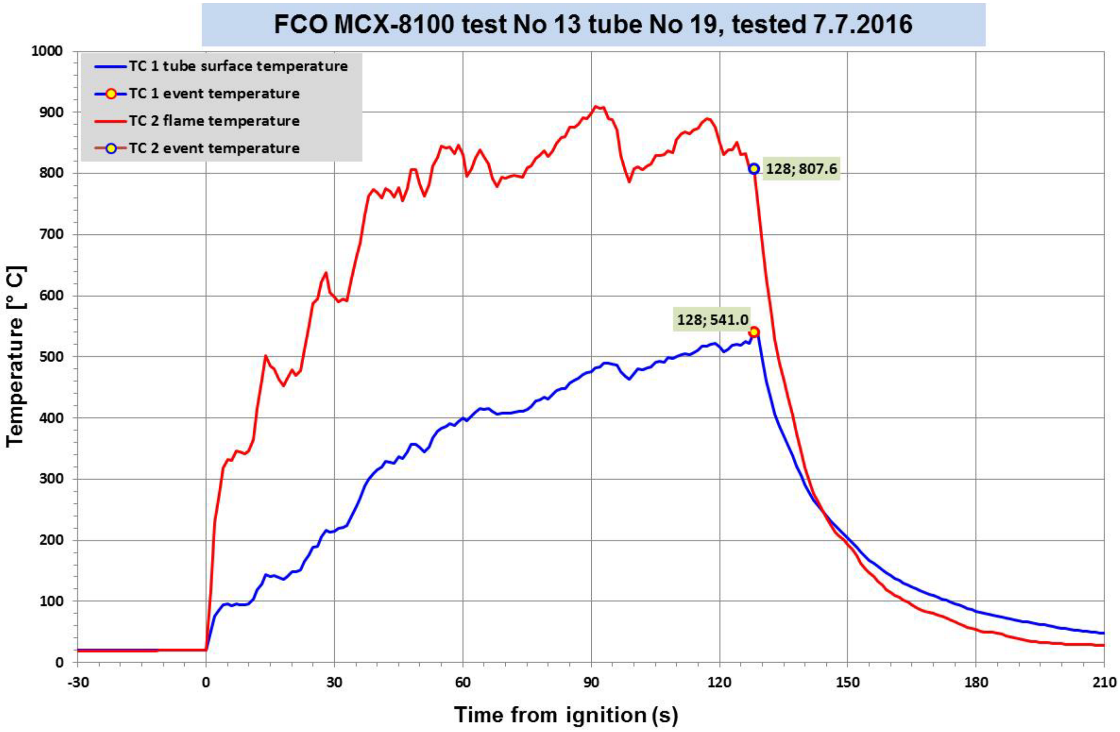


Figure 3.11 Temperatures in the flame and on the tube surface for tube No 19 filled with MCX-8100 CH 168001.

Figure 3.12 Pictures of the recovered tube after testing.

3.7 Test No 14 - Tube No 20

The last tube tested with the MCX 8100 filler was tube No 20. Figure 3.13 shows registrations of the temperatures in the flame and on the tube surface. The time to event was 136 seconds with a temperature on the tube surface of 353.4^{o}C. The manually measured event time was 2 minutes and 16 seconds. The time to reaction for this tube is slightly shorter than for tubes No 14 and 17. However Figure 3.14 shows a similar opening of the tube as for tube No 14 and No 17 with more than one longitudinal crack. One large fragment is nearly released. The weight of the recovered tube was 3701.83 g. The weight of the empty tube was 3690.2 g. Added weight of the recovered tube comes from soot and combustion deposits. No unreacted rests of the filler was observed in the tube.

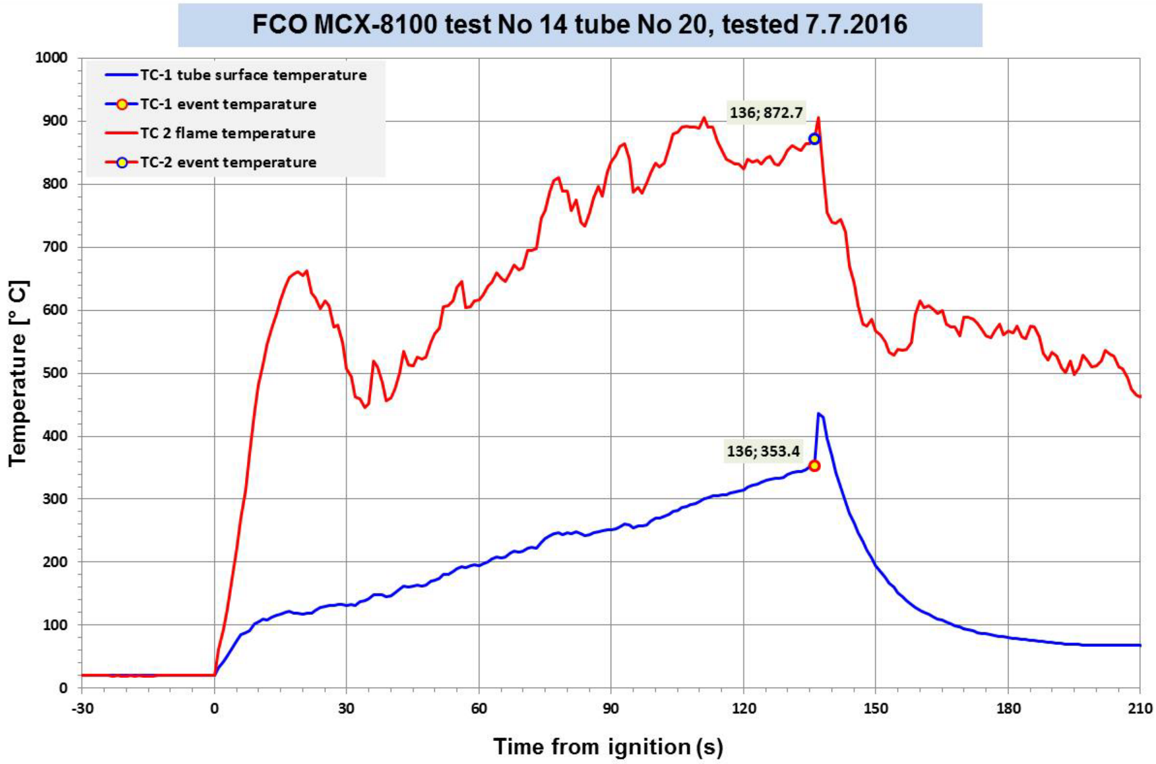


Figure 3.13 Temperatures in the flame and on the tube surface for tube No 20 filled with MCX-8100 CH 168001.

Figure 3.14 Pictures of the recovered tube after testing.

3.8 Summary of the test results

In the test description (8) the guidance below is given to interpret the results:

For all tests, the relative *explosiveness* of the composition under the test conditions is assessed from the degree of fragmentation of the tube body, not end caps.

Degree 0 No reaction
Degree 1 Burning
Degree 2 Deflagration, 2-9 fragments of tube body
Degree 3 Explosion 10 to < 100 fragments
Degree 4 Detonation >100 fragments

NB: End cap fragments not counted

By using the above guidance we obtain the results given in Table 3.1 and Table 3.2 for MCX-8100 CH 168001.

All tubes tested gave mild reactions. However, for the three tubes (No 14, No 17 and No 20) having the lowest temperature influence, we observe the time to event to increase, and a different tube opening, with more than one longitudinal crack during the reaction. When the time to reaction increases, the reaction increases in severity. However, all 7 tubes remain in one piece, and we get only a degree 1 burning reaction. This reaction occurs after approximately 2 minutes. In one tube, tube No 19 rests of the filler were recovered. The tubes with the shortest time to reaction (124±5 seconds) (No 15, No 16, No 18 and No 19) open up with only one longitudinal crack. For these tubes the average surface temperature at the event time was 500± 33°C. For the 3 remaining tubes the average event time was 154±12 seconds with an outer tube surface temperature of 390±25°C.

Round No	Vehicle No	Temperature (°C)		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

**Recovered ≈20 g MCX-8100*

Table 3.1 Summary of the results for the EMTAP test No 41 tube test fast heating of MCX-8100 CH 168001.

Round No	Vehicle No	Time Date	Filling Density (g/cm^3)	Recovered fragment			% Filling Recovered	Degree of Reaction	Time to Event (s)	Comments
				Total No	Body No	%Wt				
8	14	060716	1.719	1	1	100	0	1	162	
9	15	060716	1.715	1	1	100	0	1	125	
10	16	070716	1.709	1	1	100	0	1	116	
11	17	070716	1.728	1	1	100	0	1	163	
12	18	070716	1.710	1	1	100	0	1	126	
13	19	070716	1.713	1	1	100	5	1	128	
14	20	070716	1.710	1	1	100	0	1	136	

Table 3.2 Summary of the results for the EMTAP test No 41 tube test fast heating of MCX-8100 CH 168001.

The time to event is slightly longer and the temperature on the tube surface is higher for MCX-8100 than for MCX-6100 in the EMTAP 41 tube test (10). The tube surface temperature for the equal responding tubes is $500 \pm 33^{o}C$ for MCX-8100 compared to $364 \pm 11^{o}C$ for MCX-6100. This difference may partly be explained by the difference between RDX in MCX-6100 and the HMX in MCX-8100. RDX has a lower decomposition temperature than HMX.

Appendix

A Tube drawings

A.1 The body and the end cap

We received the following drawings of the tube test vehicle from UK DOSG.

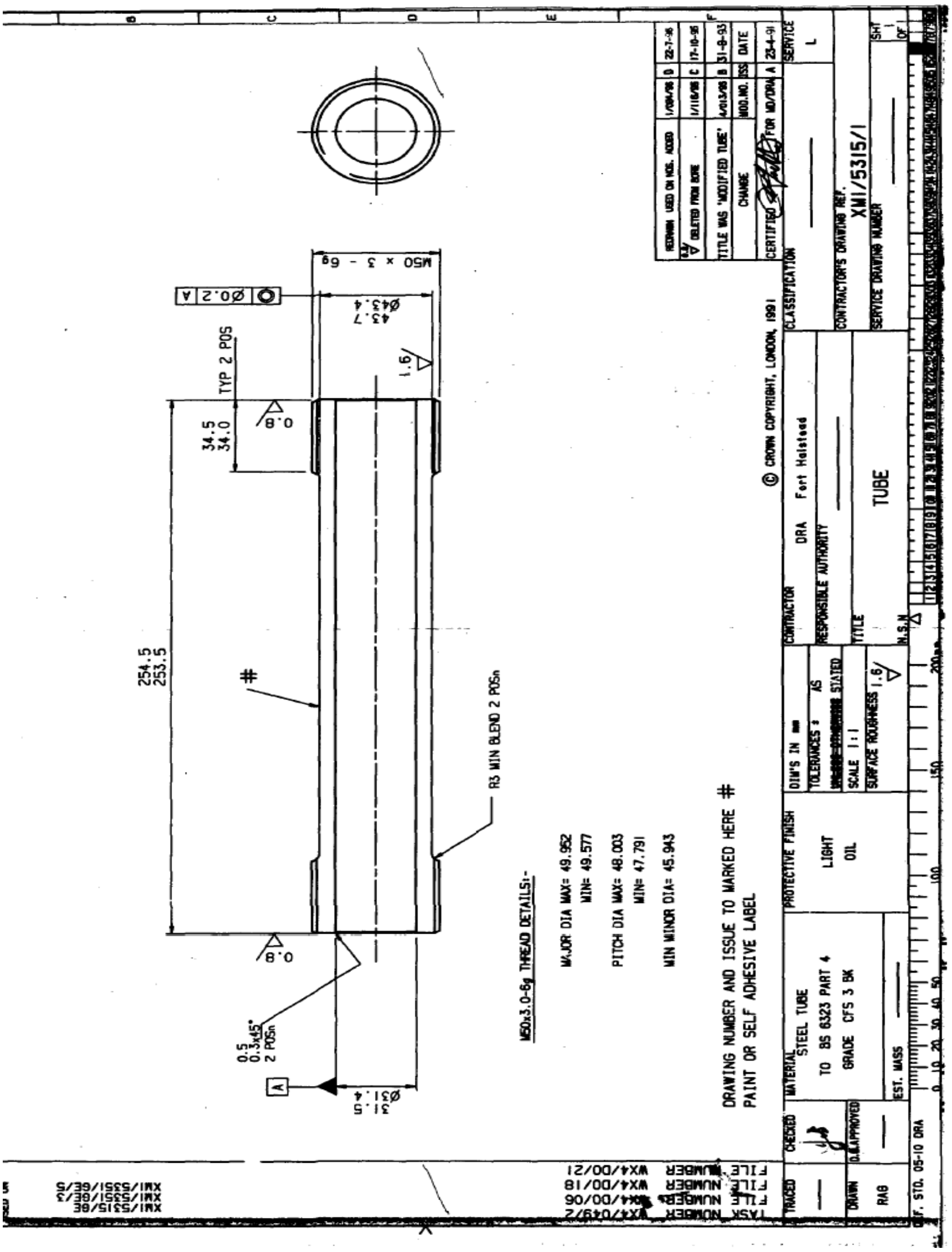


Figure A.1 Drawing of the tube body.

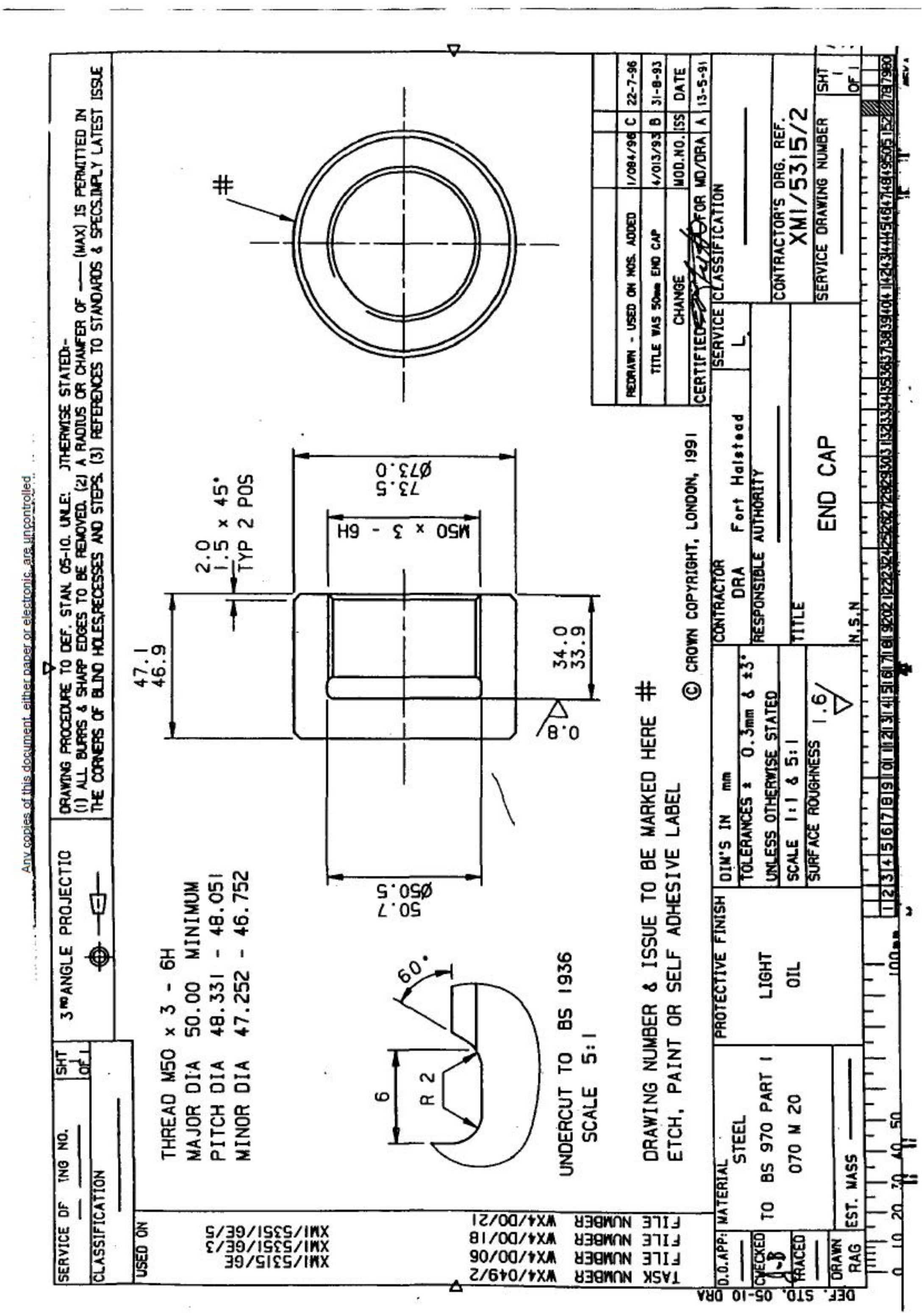


Figure A.2 Drawing of the end cap with thread dimensions.

B Nammo tube design

B.1 Material applied

Not all materials specified in the drawings from UK were available in Norway. To replace these, similar materials were selected, and the specifications of these are given in Figure B-1.

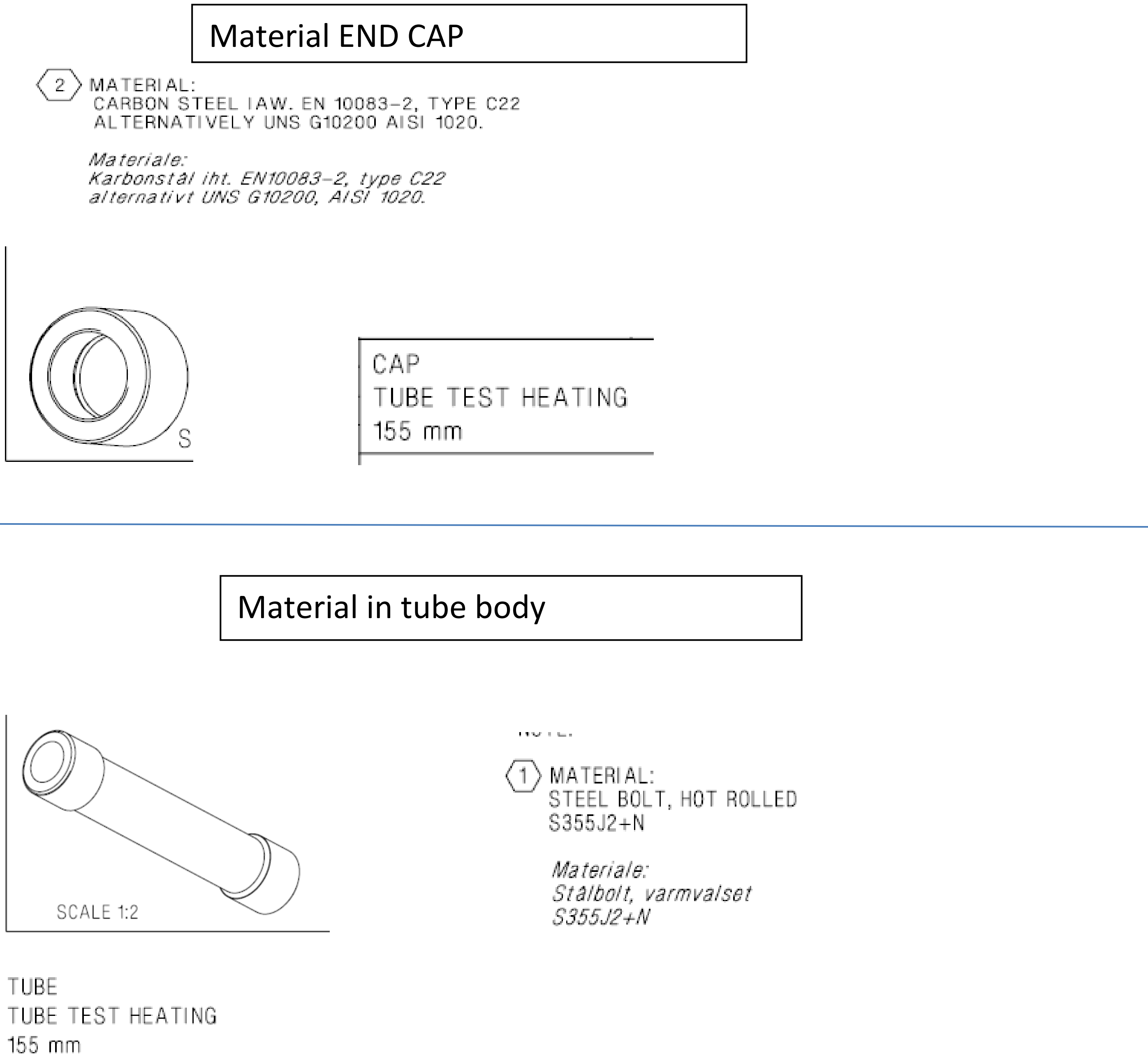
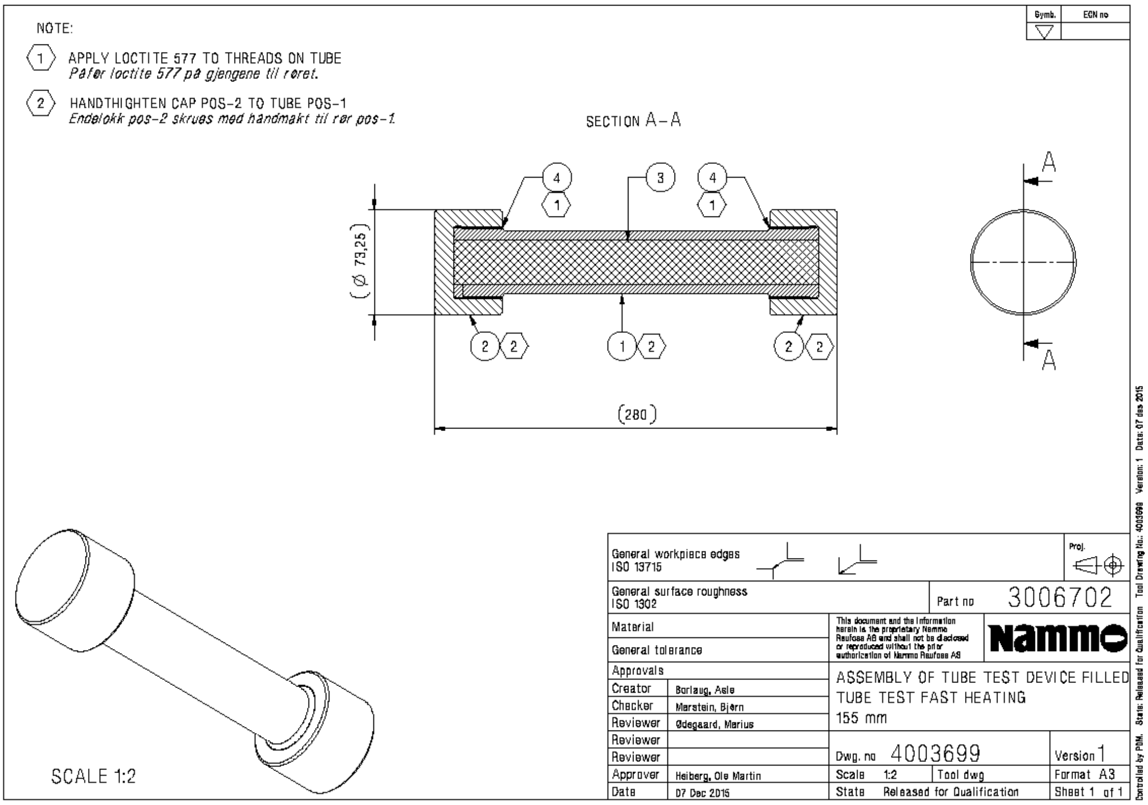


Figure B.1 Information about selected materials used in the production of tube bodies and end caps.



PARTSLIST REPORT

Nammo		Part no.:	3006702		Ver.:	1.11	State:	Released for Qualification		
		Part name:	ASSEMBLY OF TUBE TEST DEVICE				Level:	0		
		Page:	1 of 1				Date:	01 Sep 2016		
Pos.no.	Part no.	Ver.	State	Part name	Qty.	Unit	Ref.dwg.no.	Ver.	State	
	3006702	1.11	Released for Qualification	ASSEMBLY OF TUBE TEST DEVICE			4003699	1.10	Released for Qualification	
1	3006701	1.3	Released for Qualification	TUBE	1	each	4003698	1.11	Released for Qualification	
2	3006693	1.3	Released for Qualification	CAP	2	each	4003690	1.8	Released for Qualification	
3	769119	1.1	Released	EXPLOSIVE MCX-6100	1	as needed				
4	142244	1.3	Released	Glue, Loctite 577, 250 ml	1	as needed				

Figure B.2 Nammo drawings for the tube tests test vehicle production.

C Test report Nammo Test Center

Nammo Test Center	TEST-REPORT	Report no.: KJN-055-16 Rec.no 2016-07-28-OMH-TC

Test : 155mm tube test stanag 4491

Cust:		**Inspection Instruction:**	
Item :		**Projectnr:**	P370042-10
Part :		**Date of test:**	06.07.2016
Lot no. :		**Place :**	Brennplass

Setup: We made a pan of 2mm steel 600x600mm and filled it with kerosine

Test No.	Tube No.	temp	Distance tube-kerosine	Kerosine mm	Time of reaction	Fragments	Remarks
1	4	see table	300 mm	40 mm	6 min 22 sec	4	MCX 6100
2	5	see table	300 mm	35 mm	2 min 17 sec	1	MCX 6100
3	6	see table	300 mm	25 mm	3 min 17 sec	2	MCX 6100
4	7	see table	300 mm	30 mm	1 min 56 sec	1	MCX 6100
5	8	see table	300 mm	30 mm	1 min 44 sec	1	MCX 6100
6	9	see table	300 mm	30 mm	2 min 31 sec	1	MCX 6100
7	10	see table	300 mm	30 mm	1 min 58 sec	1	MCX 6100
8	14	see table	300 mm	30 mm	2 min 42 sec	1	MCX 8100
9	15	see table	300 mm	30 mm	2 min 5 sec	1	MCX 8100
10	16	see table	300 mm	30 mm	1 min 56 sec	1	MCX 8100
11	17	see table	300 mm	30 mm	2 min 43 sec	1	MCX 8100
12	18	see table	300 mm	30 mm	2 min 5 sec	1	MCX 8100
13	19	see table	300 mm	30 mm	2 min 8 sec	1	MCX 8100
14	20	see table	300 mm	30 mm	2 min 16 sec	1	MCX 8100

AUT / Knut Nybakke
Test Manager.

Present: Ole Martin Heiberg
Marius Ødegård

Figure C.1 Summary report Nammo Test Center of EMTAP-41 of MCX-6100 and MCX-8100.

References

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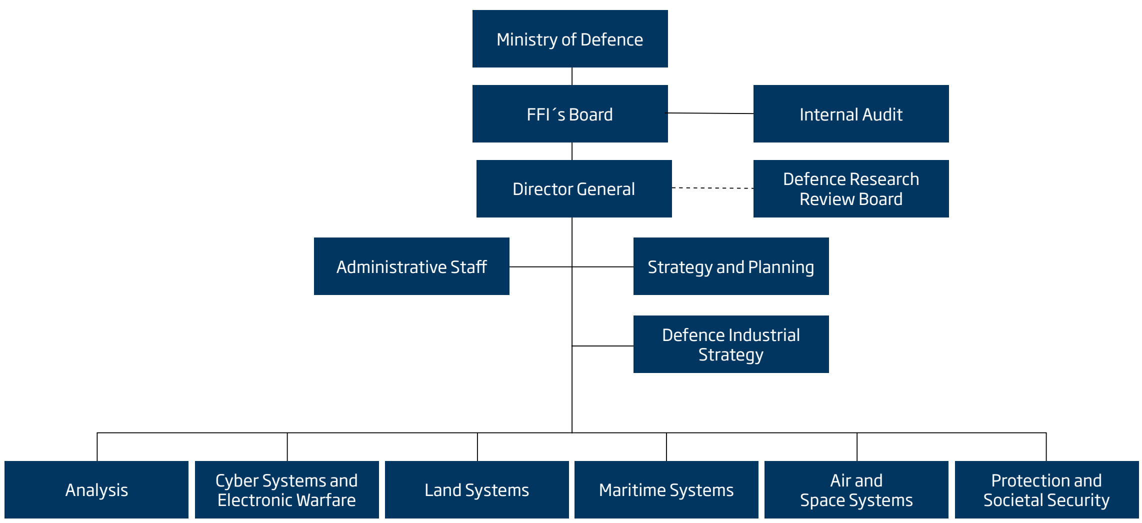

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