FFI-RAPPORT

16/02347

Fast heating tube test of MCX-6100

EMTAP 41 Test

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Norwegian Defence Research Establishment (FFI) 24 February 2017

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Keywords
Sprengstoff
Testing

FFI-rapport
FFI-RAPPORT 16/02347

Prosjektnummer
399301

ISBN
P: 978-82-464-2900-7
E: 978-82-464-2901-4

Approved by
Ivar Sollien, *Research Manager*
Jon Skjervold, *Director*

Summary

During STANAG 4170 qualification of the MCX-6100 composition the EMTAP 41 fast heating tube test has been carried out. Two of the seven tested tubes produced three and two fragments respectively during reaction and have thereby a deflagration or degree 2 reaction. Five tubes gave only one fragment by a burn or degree 1 reaction. However, these five tubes may be divided into two groups. Four tubes have one crack in the center of the body. They reacted after 120$\pm$11 seconds with an outer surface temperature of 364$\pm$18^{o}C for three of the tubes. For the fourth tube the surface temperature was 481.5^{o}C. The fifth tube is still in one piece, but has several cracks, and one part of the body is close to being a fragment. This tube reacted after 151 seconds with a surface temperature of 388^{o}C. The tube giving three fragments reacted after 383 seconds with a tube surface temperature of 193.4^{o}C. This deviation may be explained from wind influence during testing.

Achieved results with degree 1 (burn) for five tubes and degree 2 (deflagration) for two tubes are all mild reactions. One can therefore expect that munitions filled with the MCX-6100 composition will have potential to fulfill the IM requirements when the munitions meet a fast heating threat.

Sammendrag

For kvalifisering av komposisjonen MCX-6100 har det blitt gjennomført en EMTAP 41 hurtig oppvarmingstest. Sju rør er testet. Fem av rørene gir en brann eller grad 1-reaksjon, mens to rør gir en deflagrasjon eller grad 2-reaksjon. De to siste rørene gir tre og to fragmenter i løpet av reaksjonen, mens de fem resterende rørene åpnes opp og forblir i ett stykke. Disse fem rørene kan imidlertid deles i to grupper. Fire rør har kun en sprekk i lengderetningen. Denne reaksjonen skjer typisk etter 120 ± 11 sekunder med en ytre overflatetemperatur på 364 ± 18^{o}C for tre av rørene. Det fjerde røret har en overflatetemperatur på 481,5^{o}C. Det resterende røret er fremdeles i ett stykke, men har flere sprekker og en del som er i ferd med å bli til et fragment. For dette røret skjer reaksjonen etter 151 sekunder med en overflatetemperatur på 388^{o}C. Røret som gir tre fragmenter, reagerer først etter 383 sekunder med en overflatetemperatur på kun193,4^{o}C. Avviket kan forklares med vindpåvirkning i testøyeblikket.

Oppnådde resultater med grad 1 (brannreaksjon) for fem rør og grad 2 (deflagrasjon) for to testede rør er alle milde reaksjoner. Det er derfor å forvente at ammunisjon med MCX-6100-fylling vil ha potensial til å tilfredsstille kravet til IM stilt overfor trusselen hurtig oppvarming.

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

For some years Norway has studied melt-cast compositions for use as main charge fillers in different calibres (1-3). Both experimental and theoretical studies to characterize these compositions have been performed. The MCX-6100 composition containing DNAN in addition to NTO and RDX is one of the compositions that have shown good properties as an IM-filler for large calibre munitions (4-6). Properties like shock sensitivity by intermediate scale gap test (7-8) and performance like detonation pressure and velocity have been determined (9). However, if the MCX-6100 composition shall be applied as main filler the composition needs to be qualified according to STANAG 4170 (10).

Of the properties required to be characterized during qualification is explosive response when ignited (confined and unconfined). STANAG 4491 (11) describes approved or recommended tests or test methods to perform this characterization. From STANAG 4491 Norway has selected to use the UK tube tests as test vehicles for this characterization. The two tests we decided to perform were EMTAP 41 and EMTAP 42 (12).

In this report we will report on the EMTAP 41 tube test – fast heating. The qualification of the MCX-6100 composition has been 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 has been performed by Chemring Nobel AS.

Norway has earlier used tube tests for qualification of DPX-6 (13). However, DPX-6 is a press filled composition. The test vehicles used for that qualification had a thinner end wall in the end caps (9 mm) and fewer threads. Some tests were performed with that tube design also with the MCX-6100 composition, without success. The high pressure inside the tube when DNAN melts created hole in the end cap, 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 leakage of explosive filler has been observed.

The explosive response when ignited has been characterized by the EMTAP 42 – electrically heating tube test in (14). In this report we have performed EMTAP 41 tube test – fast heating of the MCX-6100 composition. No specific requirement has to be fulfilled to pass these tests. However, to fulfil the IM requirements for munitions as 155 mm shells, mild reactions in the tube tests will increase the possibility. Similar ignition tests, EMTAP 41 and 42 were performed for the MCX-8100 in reference 15 and 16.

The filled tubes were X-rayed before testing to check the quality and homogeneity of the fillings. In addition the densities of the fillings were determined by weighing the tubes before and after filling with the MCX-6100 composition.

2 Experimentally

2.1 Casting test objects

All test objects were casted by Chemring Nobel AS.

For these test objects the MCX-6100 charge 6027/14 was used as filler for three tubes, No 4 to No 6, and charge 6054/15 for tubes No 7 to No 10. The empty tube was stored in a heat cabinet at 100-102^{o}C over the night before filling took place with the filler having the same temperature (100-102^{o}C). The filled tube was then placed in the heat cabinet for 2 hours before cooling at ambient temperature (25^{o}C). During the cooling the top of the tube was protected by an isolating hat. Pictures of the filled tubes as we received them at FFI are shown in Figure 2.1 left picture for tubes No 4 and No 5 and in Figure 2.2 for tubes No 6 to No 10.

Figure 2.1 Pictures of tubes No 4 and No 5 as received from Chemring Nobel AS to the left and after cleaning and modification of the top surface in the center and to the right.

The tubes were cleaned and the end surface corrected. Figure 2.1 shows pictures of tubes No 4 and No 5 after this operation. Figure 2.3 shows pictures of tubes No 6 to No10 after the same treatment. Most of the tubes show some minor cracks in the end surface. Before finalizing the tube for testing the weight were measured and the density of the filling determined. The results with regard to filling densities are given in Table 2.1.

Figure 2.2 Picture of tubes No 6 to No 10 as received from Chemring Nobel AS.

Figure 2.3 Pictures of tubes No 6 to No 10 after cleaning and modification of the end surface.

2.2 Quality of the fillings

2.2.1 Density

The density of the MCX-6100 fillings was measured by weighing of empty and filled tubes.

Tube No	Weight Filled Tube (g)	Weight empty tube (g)[1]	Weight of Filling (g)	Filled with MCX-6100 Charge	Filling density $(g/cm^3)^2$	To be tested in
4	2968.22	2628.7	339.52	6027/14	1.715	FCO
5	2970.72	2631.2	339.52	6027/14	1.715	FCO
6	2972.57	2634.0	338.57	6027/14	1.710	FCO
7	2976.26	2636.7	339.56	6054/15	1.715	FCO
8	2976.10	2636.4	339.70	6054/15	1.716	FCO
9	2971.96	2633.6	338.36	6054/15	1.709	FCO
10	2974.24	2636.5	337.74	6054/15	1.706	FCO

[1]Body+1 end cap. [2]Volume 197.9451 cm^3 calculated from drawing specification of diameter 31.5 mm and height 254 mm.

Table 2.1 Properties of the tubes tested in the EMTAP 41 fast heating tube test.

In the top most tubes have minor visual cracks. However, the densities of the fillings have low variation with an average of 1.712 $\pm$0.004 g/cm^3. TMD for MCX-6100 is 1.7629 g/cm^3. This gives an average filling percentage of 97.1.

2.2.2 X-ray

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

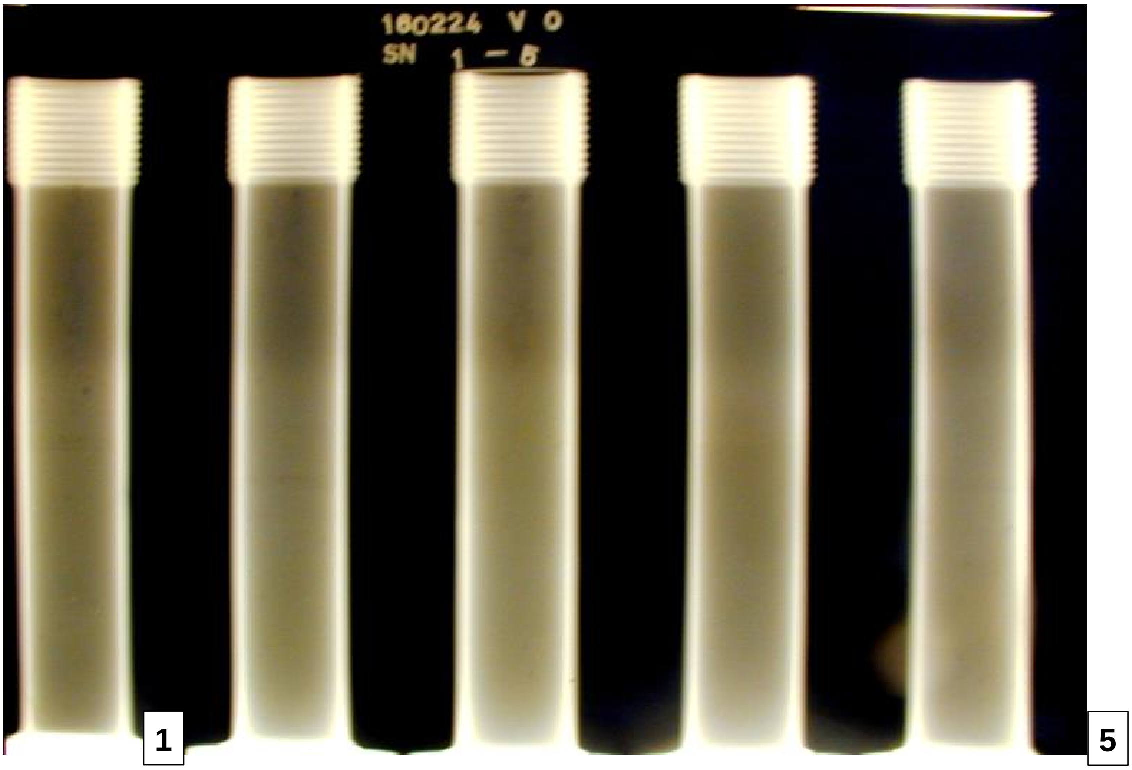


Figure 2.4 X-ray of tubes No 1 to No 5 filled with MCX-6100.

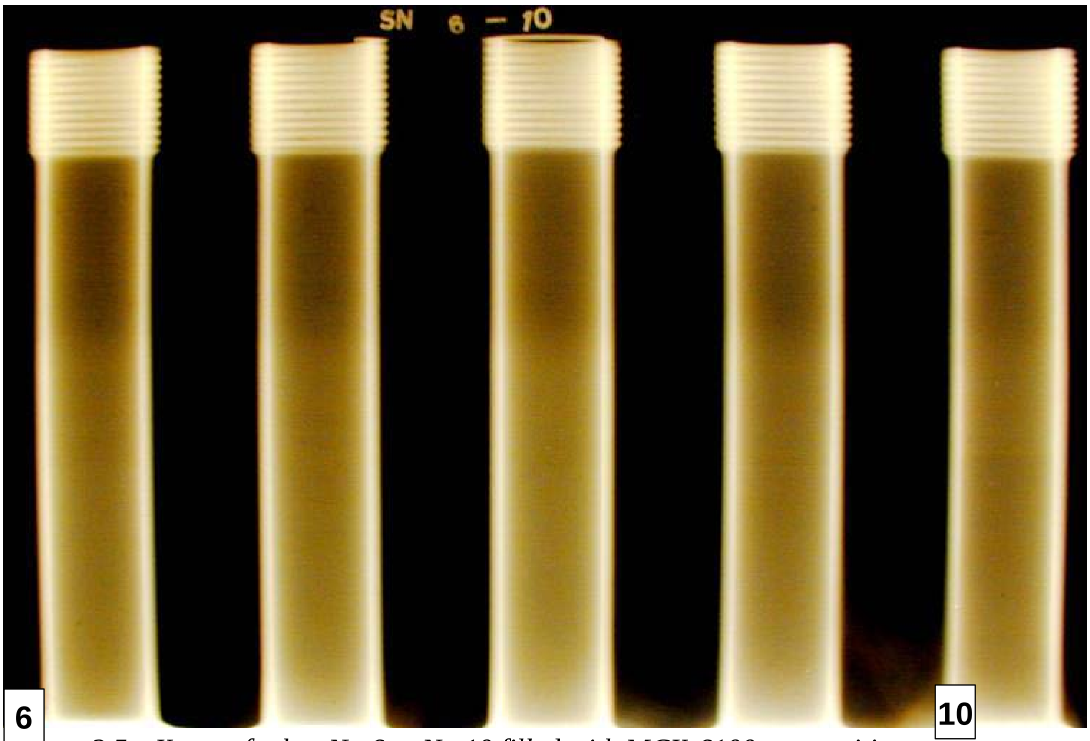


Figure 2.5 X-ray of tubes No 6 to No 10 filled with MCX-6100 composition.

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 the description in the DOSG Manual of Tests (12) and STANAG 4491 (11). 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, at the right side of the pool. Figure 2.8 shows a picture of the position of the two thermocouples used to measure the temperatures 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   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 1 – Tube No 4

Figure 3.1 shows the temperatures at the tube surface and in the flame during the test. Due to wind the flame did not surround the test item all the time. The event time was manually measured to 6 minutes and 22 seconds, Appendix C. From the temperature measurements shown in Figure 3.1 an event time one second slower (383 seconds) was selected. The temperature at the tube surface was 206.3°C slightly higher than the flame temperature of 193.4°C. The rapid tube surface temperature increase after the reaction may be due to heat from burning of the filler.

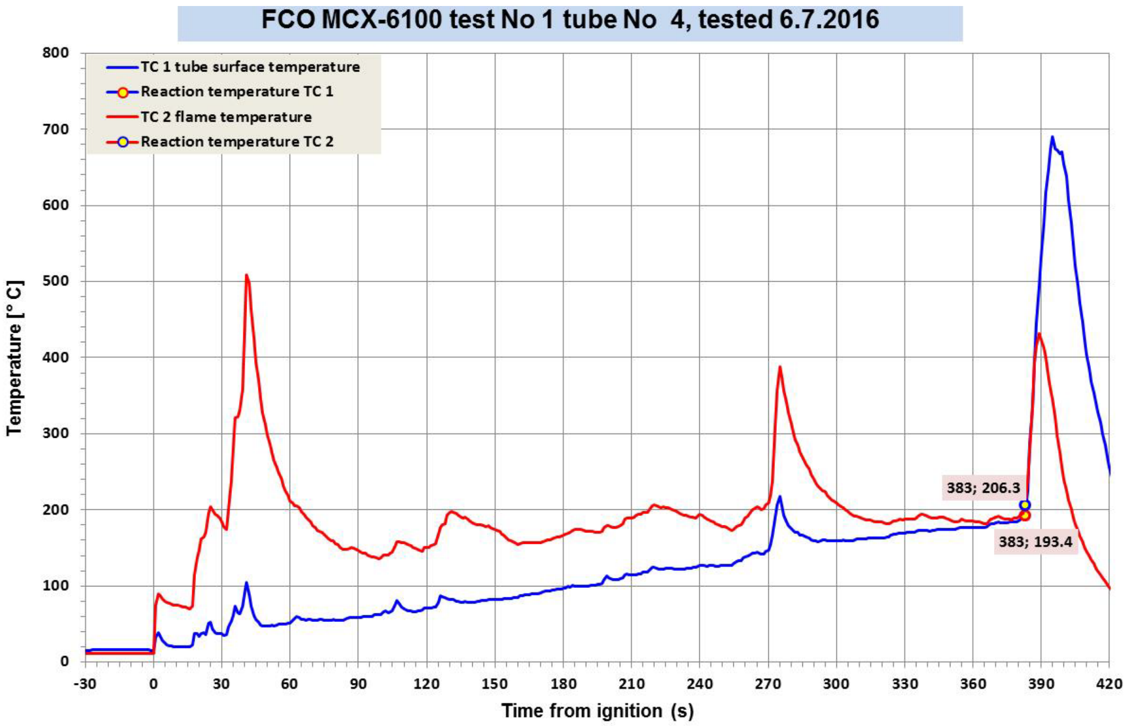


Figure 3.1 Temperatures in the flame and on the tube surface for tube No 4 filled with MCX-6100 CH 6027/14.

After the test was finished 3 fragments of the test item were recovered, Figure 3.2. Total weight of recovered fragments was 3459.76 g. The largest fragment had a weight of 3246.24 g. The weights of the two other body fragments were 102.53 g and 110.97 g respectively. The weight of the empty tube was 3679.7 g. 219.94 g of steel was not recovered. From Figure 3.2 it looks like the number of missing fragments may be one or two.

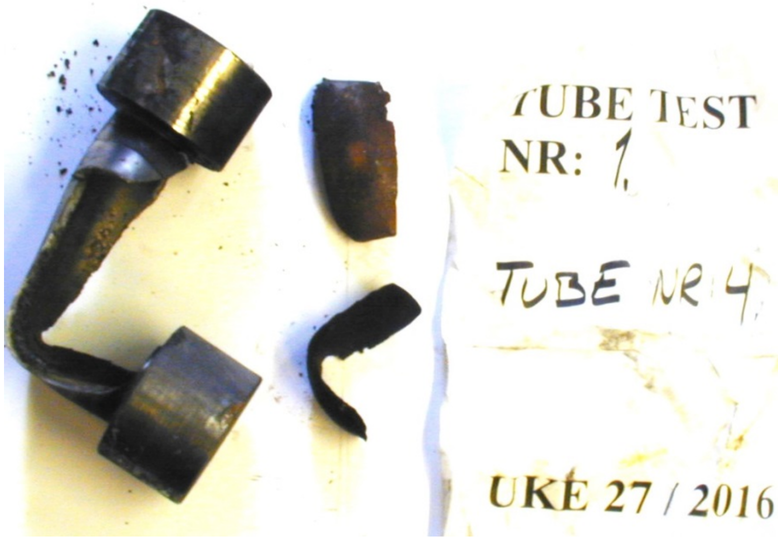


Figure 3.2 Picture of the recovered tube and fragments after test completion.

3.2 Test No 2 - Tube No 5

The next tube to be tested was tube No 5. For this tube the flame temperature after ignition was more or less constant until a reaction occurred. The event time was, as Figure 3.3 shows, 136 seconds with a temperature on the tube surface of 383.8^{o}C and in the flame of 745.8^{o}C. Manually measured time to event was 137 seconds, Appendix C.

Figure 3.4 shows the recovered tube. The weight of the recovered tube was 3687.16 g. The empty tube had a weight of 3682.2 g. The increased weight comes from soot and combustion deposits. No rest of the MCX-6100 filling was observed.

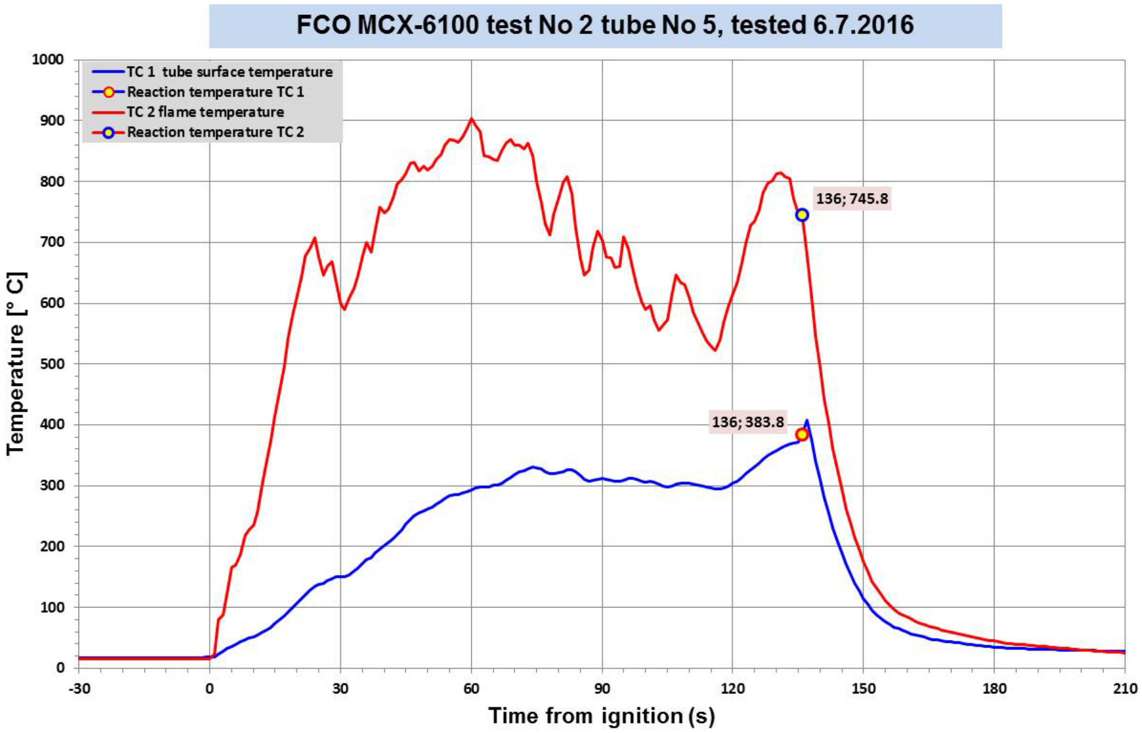


Figure 3.3 Temperatures in the flame and on the tube surface for tube No 5 filled with MCX-6100 CH 6027/14.

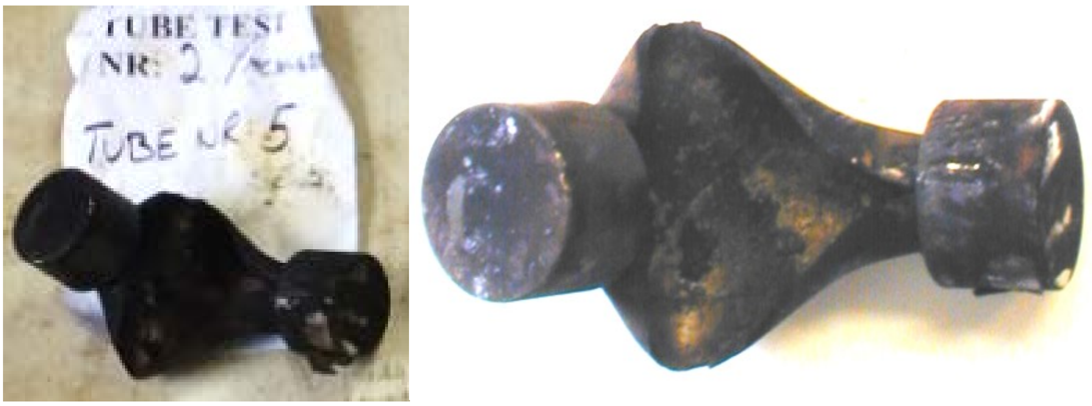


Figure 3.4 Pictures of the recovered tube after testing.

3.3 Test No 3 - Tube No 6

The next tube to be tested was tube No 6. Also for this test there were some wind disturbances, so the way the flame surrounded the tube varied, Figure 3.5. However a reaction took place after 197 seconds with a tube surface temperature of 416.1°C and a flame temperature 10 cm from the tube surface of 843.1°C.

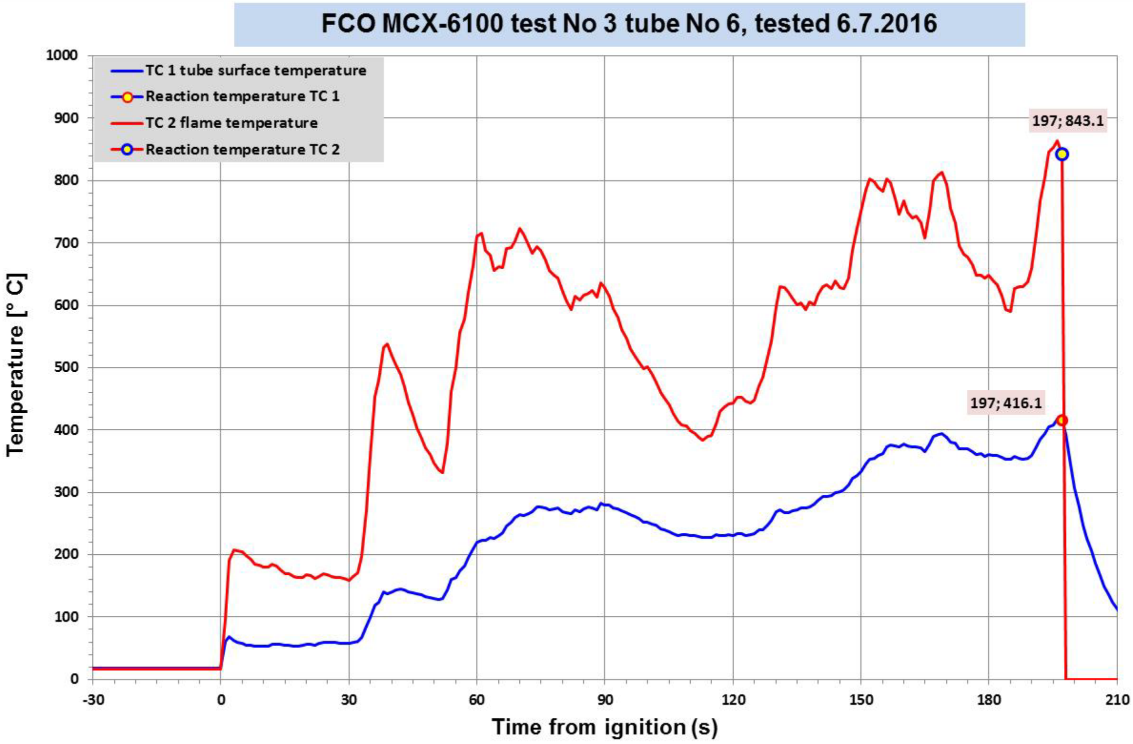


Figure 3.5 Temperatures in the flame and on the tube surface for tube No 6 filled with MCX-6100 CH 6027/14.

As Figure 3.6 shows the test item produced two fragments. The largest fragment weighed 3539.25 g including 40 g unconsumed MCX-6100 filler, see Figure 3.6. The second fragment had a weight of 187.68 g. The empty tube had a weight of 3685 g. Recovered mass was 3726.99 g. No steel fragments were missing.

Figure 3.6 Pictures of the recovered tube after testing. Right picture shows recovered unreacted filler MCX-6100.

3.4 Test No 4 - Tube No 7

The next tube to be tested was tube No 7 containing MCX-6100 CH 6054/15. Figure 3.7 shows a fast increase of the flame temperature after ignition and that it stays high until a reaction occur. The time to event is 118 seconds and the tube surface temperature is 481.5°C. Manually measured event time was 1 minute and 56 seconds; Appendix C. Figure 3.8 shows the recovered tube. The weight of the recovered tube was 3694.7 g. The weight of the empty tube was 3687.7g. No unreacted filler was observed, only soot and combustion deposits.

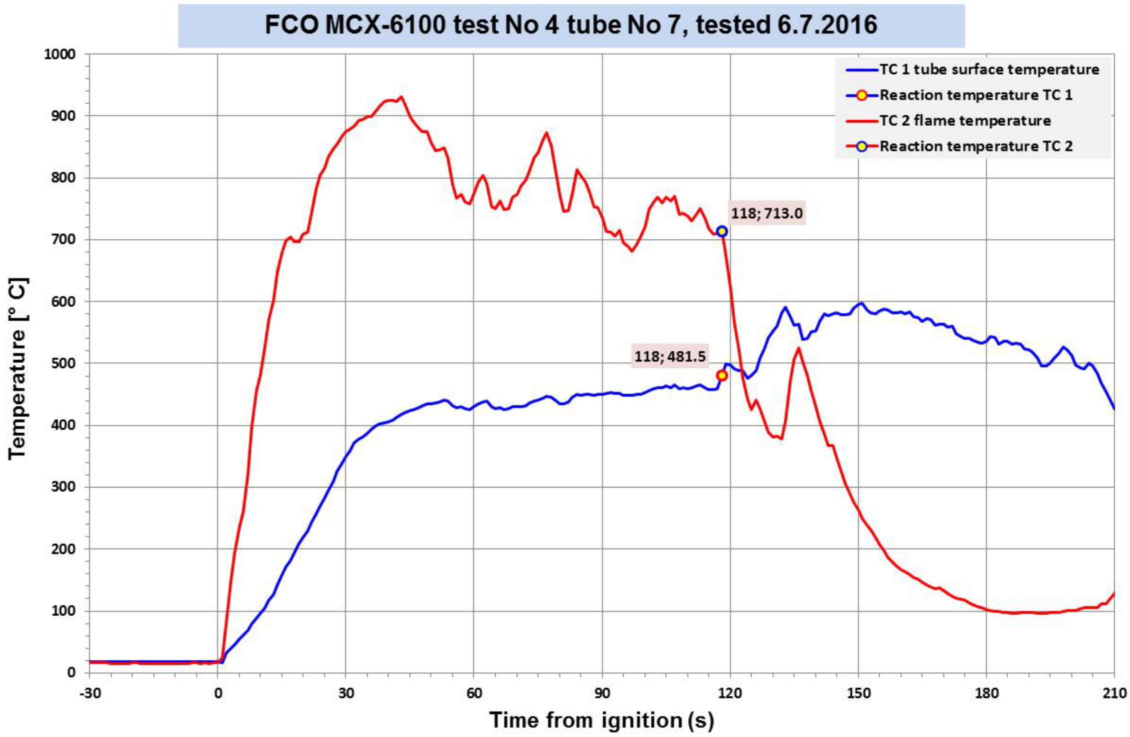


Figure 3.7 Temperatures in the flame and on the tube surface for tube No 7 filled with MCX-6100 CH 6054/15.

Figure 3.8 Pictures of the recovered tube after testing.

3.5 Test No 5 - Tube No 8

In test No 5 tube No 8 was tested. The temperature in the flame surrounding the tube was at a stable high level as the temperature registered on the tube surface, Figure 3.9. A reaction took place after 106 seconds with a tube surface temperature of 339.6°C. The manually measured event time was 1 minute and 44 seconds. The recovered tube is shown in Figure 3.10. The weight of the recovered test item was 3695.97 g. The weight of the empty tube was 3687.7 g. The added weight comes from soot and combustion deposits. No unreacted filler was observed.

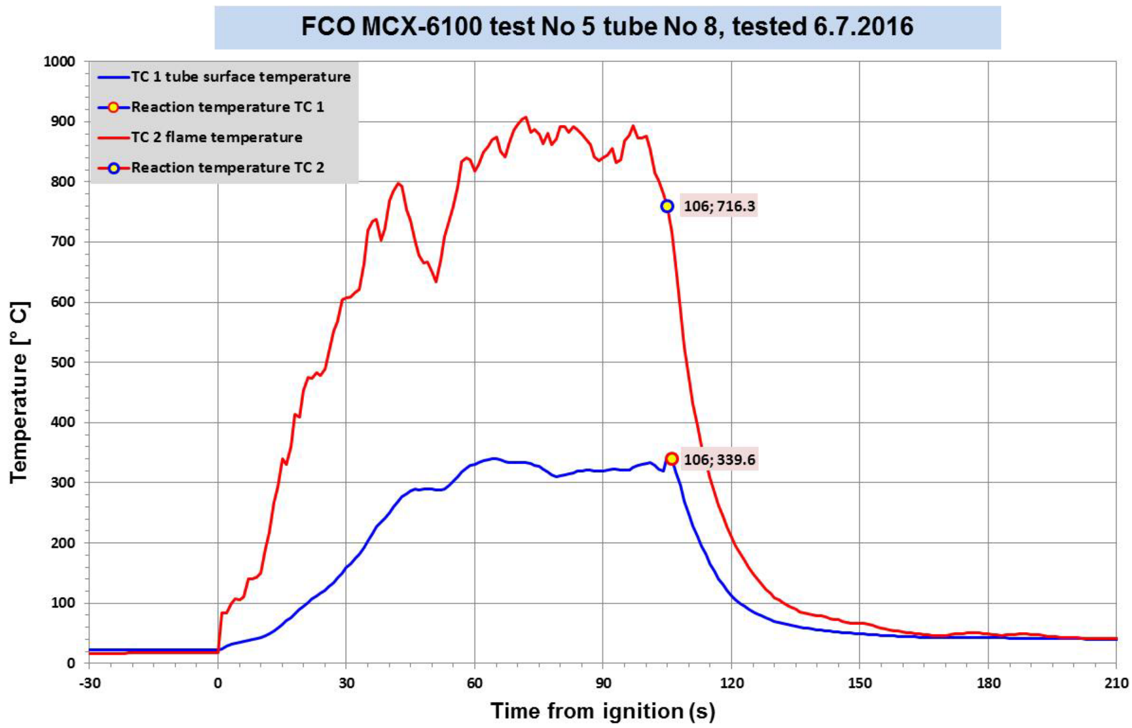


Figure 3.9 Temperatures in the flame and on the tube surface for tube No 8 filled with MCX-6100 CH 6054/15.

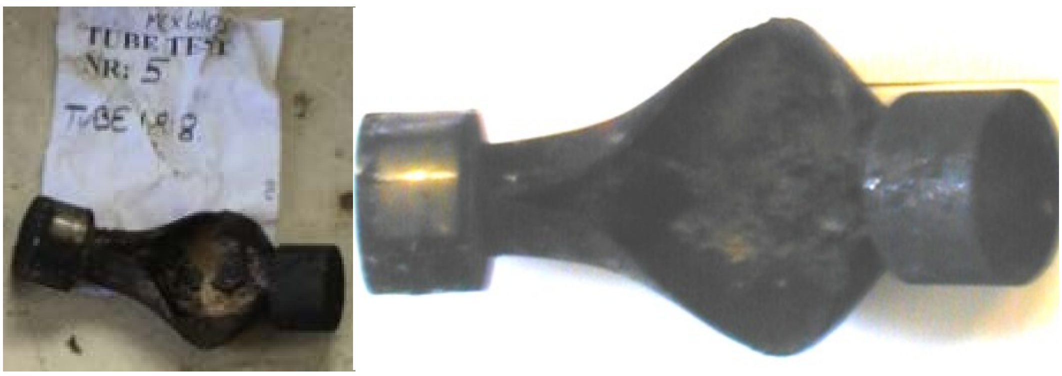


Figure 3.10 Pictures of the recovered tube after testing.

3.6 Test No 6 - Tube No 9

The next tested tube was tube No 9. Figure 3.11 shows temperatures on the tube surface and in the surrounding flame. Both temperature measurements show a bit slow increase. However, a reaction took place after 151 seconds with a tube surface temperature of 388°C and a flame temperature of 833.7°C. The manually measured event time was 2 minutes and 31 seconds. Figure 3.12 shows the recovered tube with slightly more severe damages than the previous tested tube No 8. The tube remains in one piece, but is close to lose one fragment. The weight of recovered tube was 3693.78 g. The weight of the empty tube was 3684.6 g. The recovered tube contained no unreacted filler, only soot and combustion deposits.

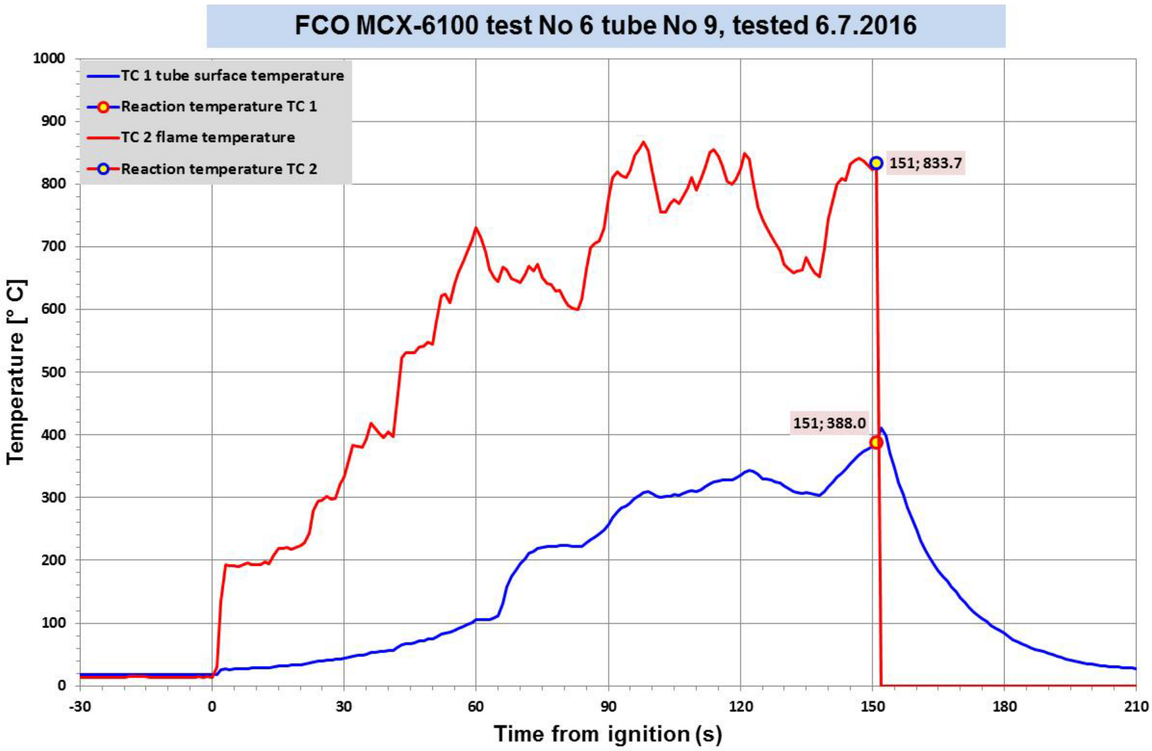


Figure 3.11 Temperatures in the flame and on the tube surface for tube No 9 filled with MCX-6100 CH 6054/15.

Figure 3.12 Picture of the recovered tube after testing.

3.7 Test No 7 - Tube No 10

The last tube we tested was tube No 10. Figure 3.13 shows the temperatures at the tube surface and in the surrounding flame. For both positions it takes some time to reach the maximum. The tube reacted after 118 seconds with a tube surface temperature of 369.5^{o}C.

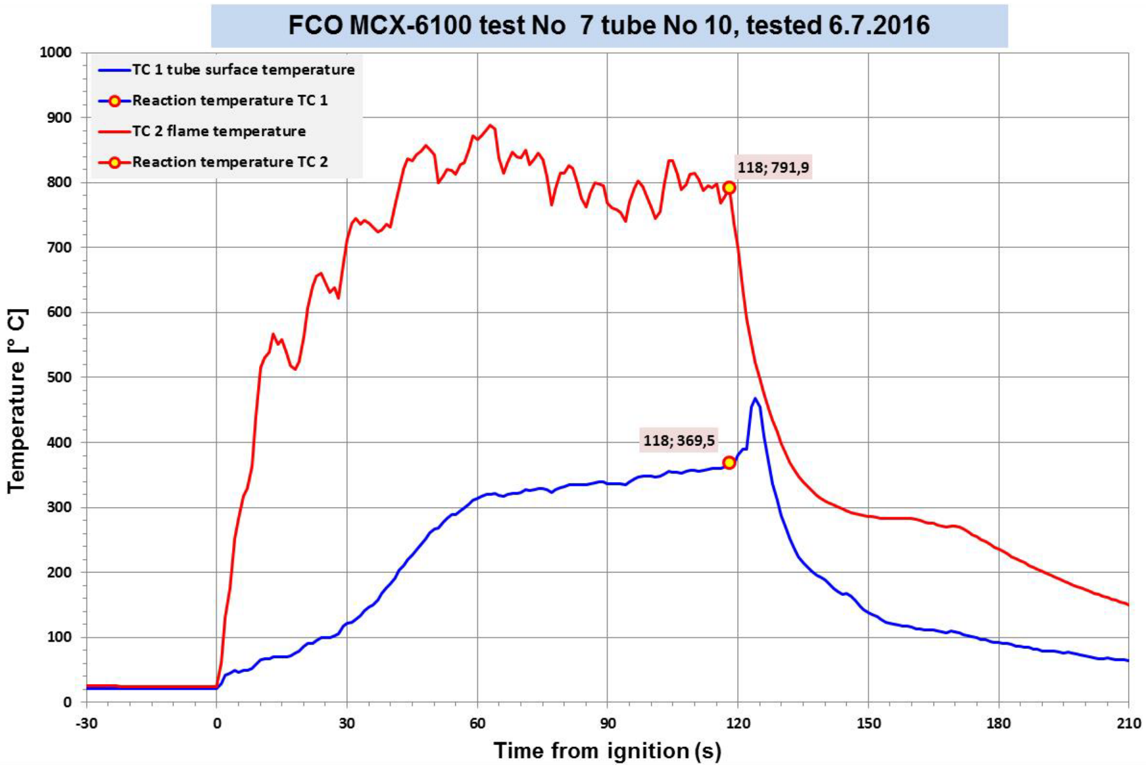


Figure 3.13 Temperatures in the flame and on the tube surface for tube No 10 filled with MCX-6100 CH 6054/15.

The manually measured event time was 1 minute and 58 seconds. Figure 3.14 shows the recovered tube. The weight of the recovered tube was 3690.41 g. The empty tube had a weight of 3687.5 g. The observed difference is due to soot and combustion deposits. No rests of unreacted MCX-6100 filler was observed.

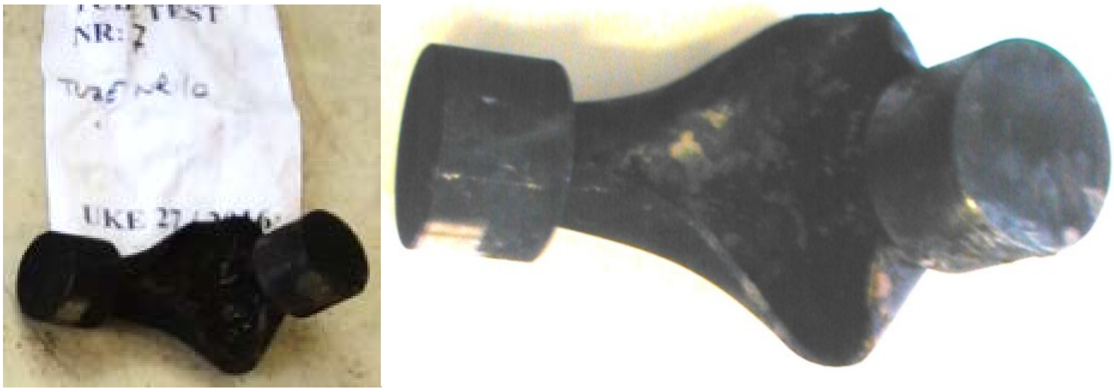


Figure 3.14 Pictures of the recovered tube after testing.

3.8 Summary of the test results

In the test description (12) the guidance below to interpret the results is given.

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 guidance above we obtain the results given in Tables 3.1 and 3.2 for MCX-6100. All tested tubes gave mild reactions. However, for the two tubes that had the lowest temperature influence the time to event is longer than the average time. When the time to event increases the reaction severity also increases. For both tube No 4 and tube No 6 we got more than one fragment and thereby a degree 2 reaction of deflagration. For the 5 remaining tubes we got only a degree 1 burning reaction. The degree 1 reaction occurs typically after approximately 2 minutes or slightly longer time. For the degree 2 reactions the time to reaction were 383 seconds (6+ minutes) for tube No 4 and 197 seconds (3+ minutes) for tube No 6.

Round No	Vehicle 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

****Included unconsumed MCX-6100 filler.***

Table 3.1 Summary of the results for the EMTAP 41 fast heating tube test of MCX-6100.

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				
1	4	060716	1.715	3	3	94	0	2	383	Wind
2	5	060716	1.715	1	1	100	0	1	136	
3	6	060716	1.710	2	2	100	12	2	197	Wind
4	7	060716	1.715	1	1	100	0	1	118	
5	8	060716	1.716	1	1	100	0	1	106	
6	9	060716	1.709	1	1	100	0	1	151	
7	10	060716	1.706	1	1	100	0	1	118	

Table 3.2 Summary of the results for the EMTAP 41 fast heating tube test of MCX-6100.

The responses in the fast heating tube tests are reproducible. The observed differences are due to external variations in the test conditions due to wind influence. All the tube responses are either degree 1 or degree 2. A fast heating or cook-off threat to munitions filled with the MCX-6100 composition will probably result in a mild reaction if the right or an effective mitigation technique is applied.

Appendix

A Tube drawings

A.1 The body and the end caps

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

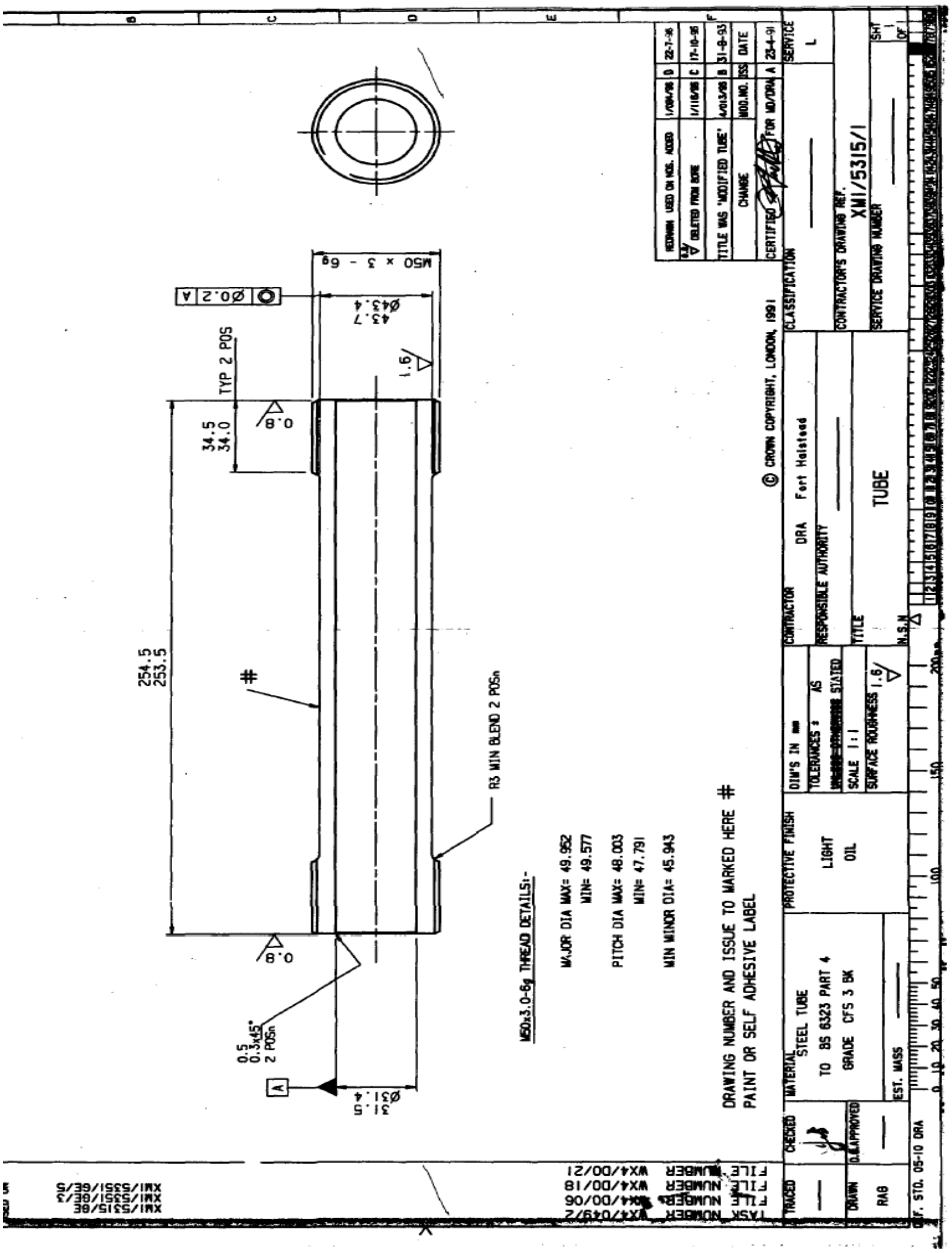


Figure A.1 Drawing of the tube body.

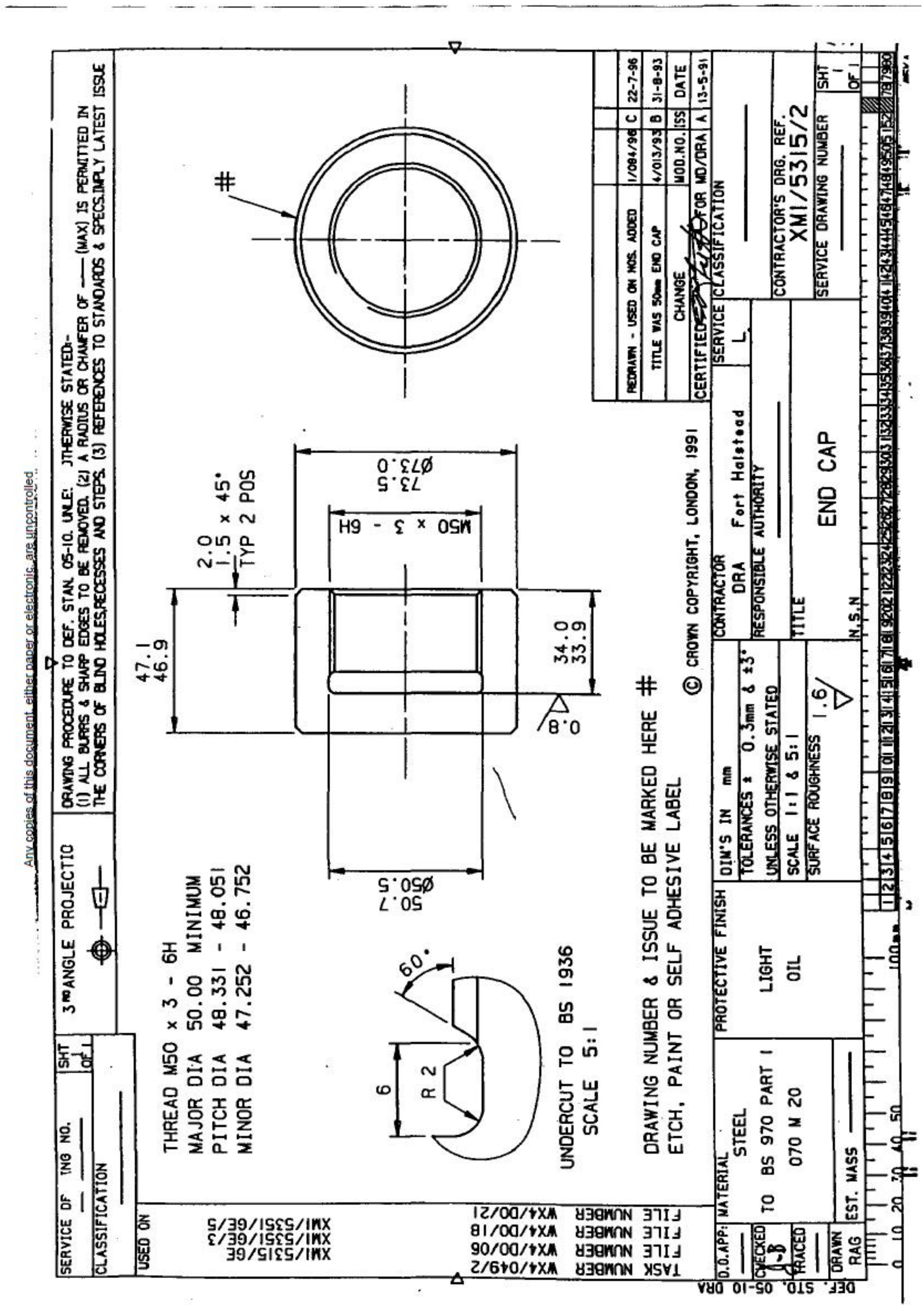


Figure A.2 Drawing of the end cap and thread dimension.

B Nammo tube design

B.1 Material applied

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

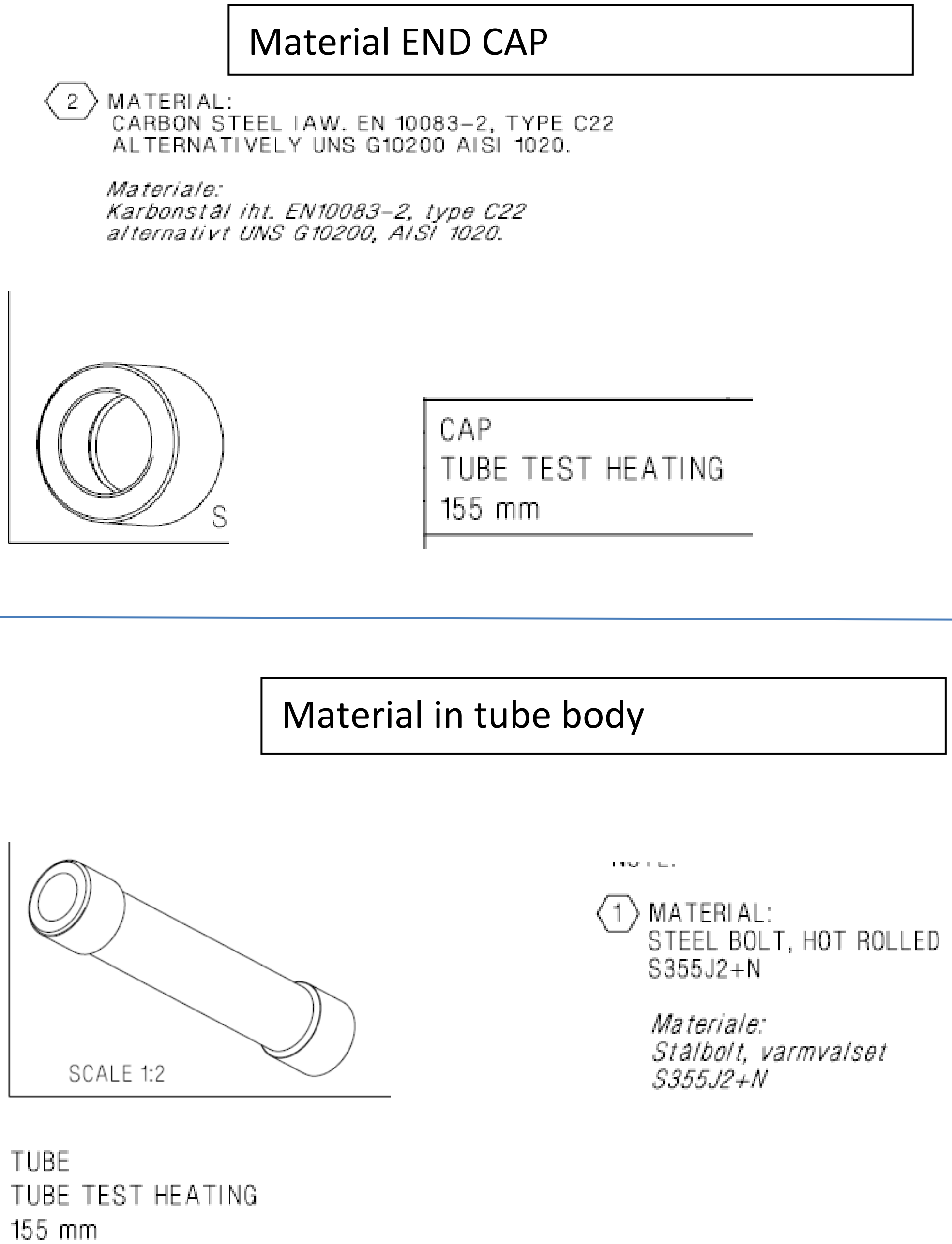
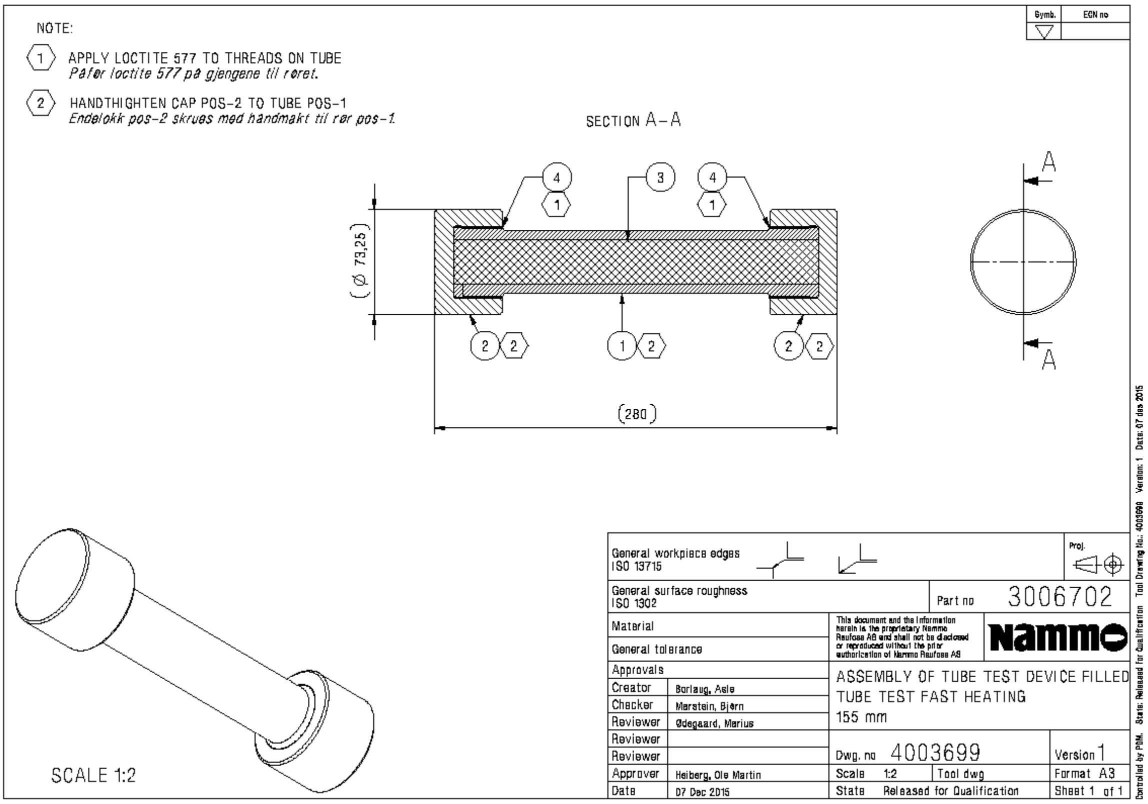


Figure B.1 Information about selected materials used in production of tube body and end cap.



PARTSLIST REPORT

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			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 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	Present:	Ole Martin Heiberg
	Test Manager.		Marius Ødegård

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

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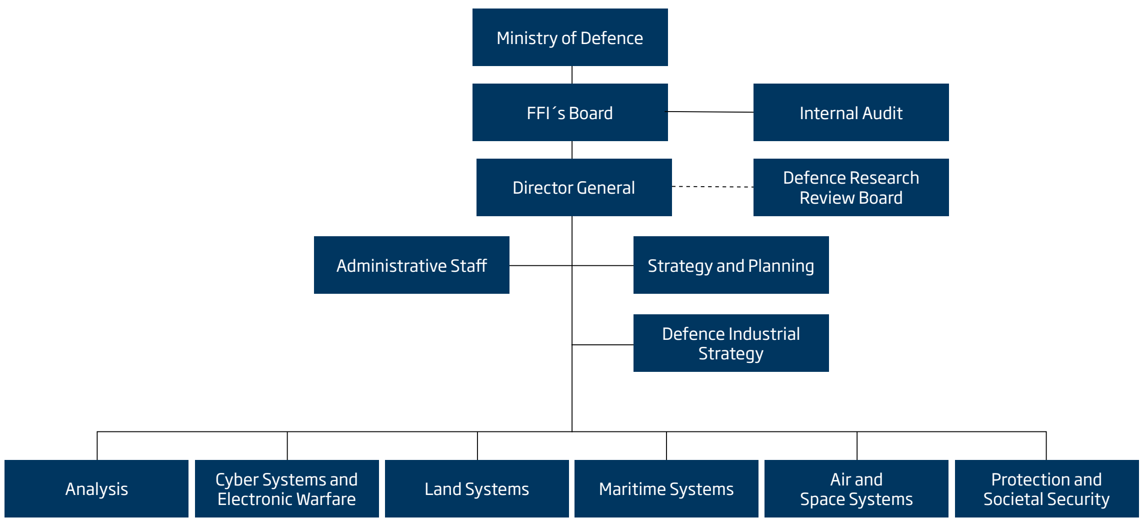

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