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Determination of detonation pressure and velocity for RDX/GAP propellant

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Summary

Detonation velocity and detonation pressure have been determined for the solid propellant D-07, a RDX/GAP propellant produced by Nammo Raufoss. Three firings, two with test item diameter 35.6±1 mm and one with diameter 29.1 mm, have been performed with only moderate variations in the results. For the detonation pressure an average pressure of 231±4 kbar was measured. The highest pressure, 236.4 kbar, was measured for the charge with the highest density.

The measured detonation velocity for two of the test items was 7500 m/s. For the third test item, cast no. 11, with highest density, 1.679 g/cm^3, the overall detonation velocity was measured to 8010 m/s.

Sammendrag

Detonasjonshastighet og detonasjonstrykk har blitt eksperimentelt målt for faststoff krutt D-07. D-07 er et RDX/GAP-krutt produsert av Nammo Raufoss. Tre fyringer er utført, to med testobjekt med diameter 35,6±1 mm og en med diameter 29,1 mm, med kun moderate variasjoner i målte egenskaper. Gjennomsnittlig detonasjonstrykk for de tre fyringene var 231±4 kbar. Høyest detonasjonstrykk, 236,4 kbar, ble målt for testobjektet med høyest tetthet.

For to av testobjektene ble gjennomsnittlig detonasjonshastighet målt til 7500 m/s med kun minimal variasjon i enkeltmålingene. For det tredje testobjektet, støp nr.11, med høyest tetthet, 1,679 g/cm^3, var detonasjonshastigheten noe høyere, 8010 m/s, og med noe variasjon i enkeltmålingene.

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Abbreviations

AOP	Allied Ordnance Publication
BuNENA	Butyl-nitratoethylnitramine
GAP	Glycidyl Azide Polymer, $(C_3H_5N_3O)_n$
HWC	Hexogen/Wax/Graphite (94.5/4.5/1)
LLM	Lightweight Multirole Missile
RDX	Hexogen/1,3,5-trinitro-1,3,5-triazacyclohexane, $C_3H_6N_6O_6$
STANAG	Standardization Agreement

1 Introduction

The Lightweight Multirole Missile (LMM) developed by Thales Land & Air Systems is a precision lightweight weapon for light platforms to counter the modern and emerging threats of land, sea and air targets. The LMM contains a booster motor with the solid propellant D-07, produced by Nammo Raufoss AS. This is a new minimum smoke propellant, a propellant containing RDX as the main component and a binder of GAP/BuNENA. At the moment the propellant is not type qualified but will soon be it.

To obtain type qualification, according to the STANAG 4170 (1) and the accompanying AOP-7 (2), for the solid propellant D-07, a large number of properties have to be characterized. During the development of the composition, most of the required properties were characterized. In reference 3 the majority of mandatory test results were reported. However, critical diameter was not among the tested properties. Critical diameter, a mandatory property to know to obtain type qualification of solid propellants, was therefore measured and reported in (4). In the preparation of the critical diameter testing, in addition to the conical test items some cylindrical charges with different diameters were casted, since we in advance did not know the critical diameter. In (4) we obtained a critical diameter for solid propellant D-7 of 3.6-3.8 mm. Therefore cylindrical charges with diameter from 30 mm to 50 mm were available for additional testing. These charges were applied to determine the detonation pressure and the detonation velocity for the solid propellant D-7 propellant, even though these properties are not mandatory to obtain type qualification.

In this report 3 test items with diameter 30-35 mm have been tested with regard to detonation velocity and detonation pressure. The detonation velocity was measured by use of ionization pins as described in reference 5. Detonation pressure was measured by use of the plate Dent test (6-7).

2 Experimentally

All test items for characterization of the RDX/GAP solid propellant D-07 were casted by Nammo Raufoss. The tested material is all from lot PD-07-005/2016.

2.1 Density of test items

For the three test items applied in the determination of detonation pressure and velocity the dimensions and weights were measured. A summary of these properties in addition to the calculated densities is given in Table 2.1. All charges were X-rayed in the casting moulds, but there was nothing of interest to see on the pictures due to the moulds. Figure 2.1 shows a picture of the three selected test items for the determination of the detonation velocity and the detonation pressure.

Cast No	Weight	Average diameter (mm)	Length (mm)	Volume (cm^3)	Density (g/cm^3)
1	164.76	29.10	151.6	100.826	1.634
11*	489.32	34.82	306	291.386	1.679
12*	456.38	35.05	287	276.916	1.648

**Conical charge*

Table 2.1 Dimensions and densities of test items.

Figure 2.1 The charges to be tested with regard to detonation velocity and pressure.

The longest test item contained cast No 1 in the bottom and cast No 2 in the top. Both these charges were cylindrical charges. Test item No 2 was cast No 11 and test item No 3 was cast No 12. Both had a slightly conical form.

2.2 Detonation velocity

Determination of the detonation velocities were done by applying ionization pins and a method described in ref. (5).

2.2.1 Test item No 1

Test item No 1 was glued together by two charges, cast No 1 and cast No 2, Figure 2.2. The end surface of charge No 1 to be in contact with the Dent plate was modified to be smooth. The test item was fitted with 4 ionization pins, two in cast No 1 and two in cast No 2 as shown in Figure 2.2.

Figure 2.2 To the left the conglutinated test item, to the right the test item with ionization pins and booster added.

2.2.2 Test item No 2

Test item No 2 was cast No 11. The length of the corrected charge was 306 mm, diameter in the bottom 35.64 mm and in the top 34.0 mm. The charge was slightly conical. This charge was instrumented with 5 ionization pins. The distance between the pins was 60 mm. The distance from the bottom to the first pin (No 5) was 40 mm. The distance from the booster to the first pin was 26 mm. Figure 2.3 shows pictures of the test item before and after addition of booster and ionization pins.

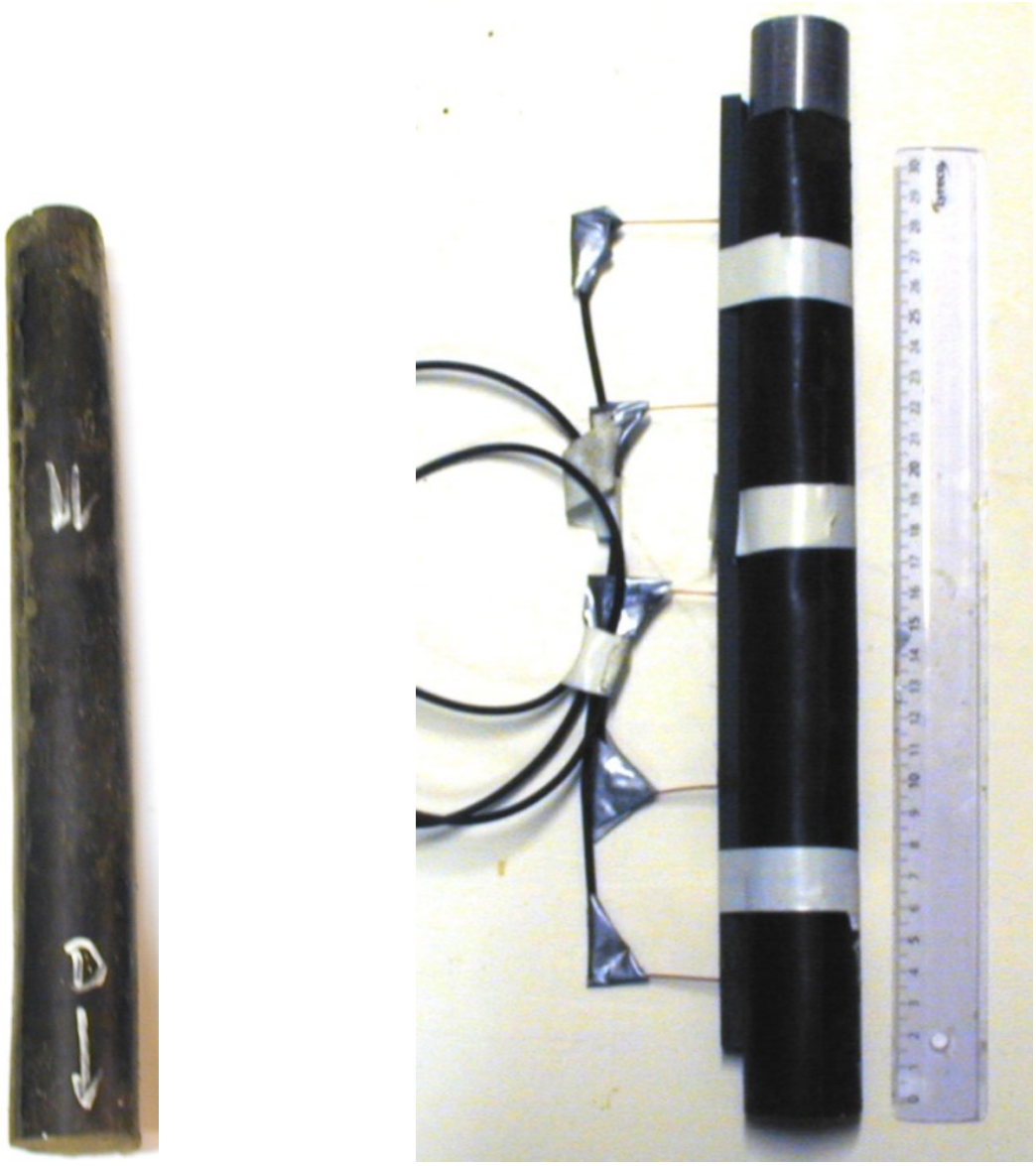

Figure 2.3 Pictures of test item 2 before and after addition of the booster and the ionization pins.

2.2.3 Test item No 3

Test item No 3 was cast No 12. The length of the corrected charge was 287 mm, diameter in the bottom 35.5 mm and in the top 34.6 mm. The charge was slightly conical. This charge was instrumented with 4 ionization pins. The distance between pin No 1 and No 2 was 100 mm, between pin No 2 and pin No 3 50 mm and between pin No 3 and pin No 4 100 mm.. The distance from the bottom to the first pin (No 4) was 17 mm. The distance from the booster to the first pin was 20 mm. Figure 2.3 shows pictures of the test item before and after addition of booster and ionization pins.

Figure 2.4 Pictures of test item 3 before and after addition of the booster and the ionization pins.

2.2.4 Instrumentation

The ionization pins and setup for registration on the scope is described in (5).

The scope we used to collect the results was a GW Instek GDS-3352, Digital Storage Oscilloscope, 350 MHz 5 GS/s adjusted to DC. The other settings/conditions under the test firings are all summarized in Table 2.2.

	Firing No 1	Firing No 2	Firing No 3
Memory Length	25000	25000	25000
Trigger Level	-2.24V	-2.24V	-2.56V
Source	CH1	CH1	CH1
Probe	1.00E+00	1.000E+00	1.000E+00
Vertical Units	V	V	V
Vertical Scale	2.00E+00	2.000E+00	2.000E+00
Vertical Position	3.84E+00	3.840E+00	4.080E+00
Horizontal Units	S	S	S
Horizontal Scale	1.00E-05	1.000E-05	1.000E-05
Horizontal Position	4.01E-05	4.010E-05	3.970E-05
Horizontal Mode	Main	Main	Main
Sampling Period	4.00E-09	4.000E-09	4.000E-09
Firmware	V1.09	V1.09	V1.09
Time	30.01.2017 14:12:42	30.01.2017 14:24	30.01.2017 14:38
Mode	Detail	Detail	Detail
Waveform Data			

Table 2.2 The conditions used to collect the results for the different firings.

2.3 Initiation

All firings were performed with a booster of HWC and a detonator No 8. Appendix A gives the certificate of the used HWC explosive. The boosters were pressed in a tool with diameter 31.5 mm with 10 tons pressure and a dwell time of 60 seconds, weight 30 g.

2.4 Plate Dent test

Detonation pressure has been determined by use of the Plate Dent test (6-7). Bolt steel plates of ST-52 quality with diameter 160 mm were used as witness plates. For the two charges with diameter 35-36 mm the bolt had a height of 60 mm, and for firing No 1 50 mm. Figure 2.5 shows how the Dent depth was measured with a micrometer screw, a steel ring and a steel ball.

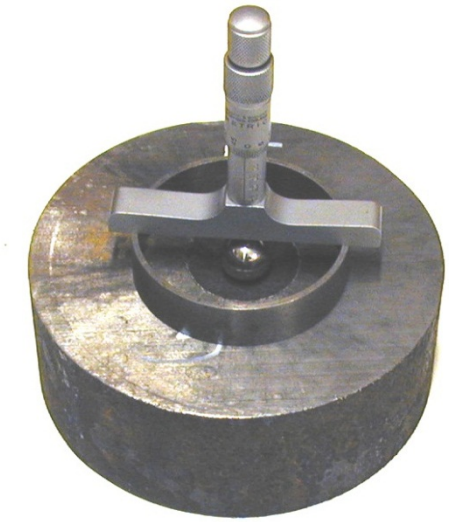

Figure 2.5 Picture of the tool used to measure the Dent depth.

3 Results

3.1 Detonation velocity

3.1.1 Firing No 1

In firing No 1 test item No 1, glued together of cast No 1 in the bottom and cast No 2 in the top, was tested. The test item was fitted with 4 ionization pins, two pins, No 1 and No 2, in cast No 2 and two pins, No 3 and No 4, in cast No 1. The distance between pin No 1 and pin No 2 was 100 mm, between pin No 2 and pin No 3 50 mm and between pin No 3 and pin No 4 100 mm. Figure 3.1 shows pictures of the test item and the test setup.

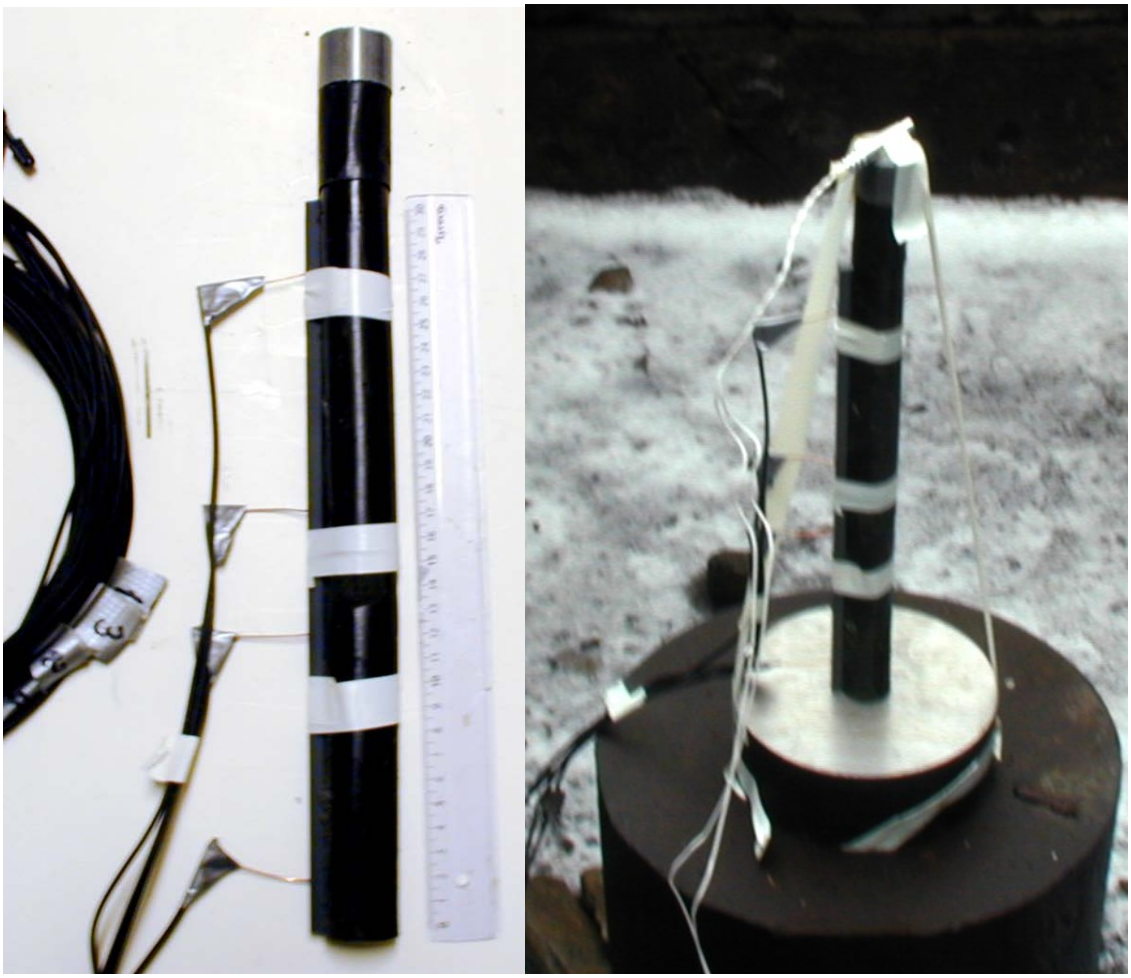

Figure 3.1 The test item and the test setup for firing No 1.

For firing No 1 we obtained registrations on all 4 ionization pins. In Figure 3.2 the arrival times of the detonation front at each ionization pin together with the distances between the pins are given.

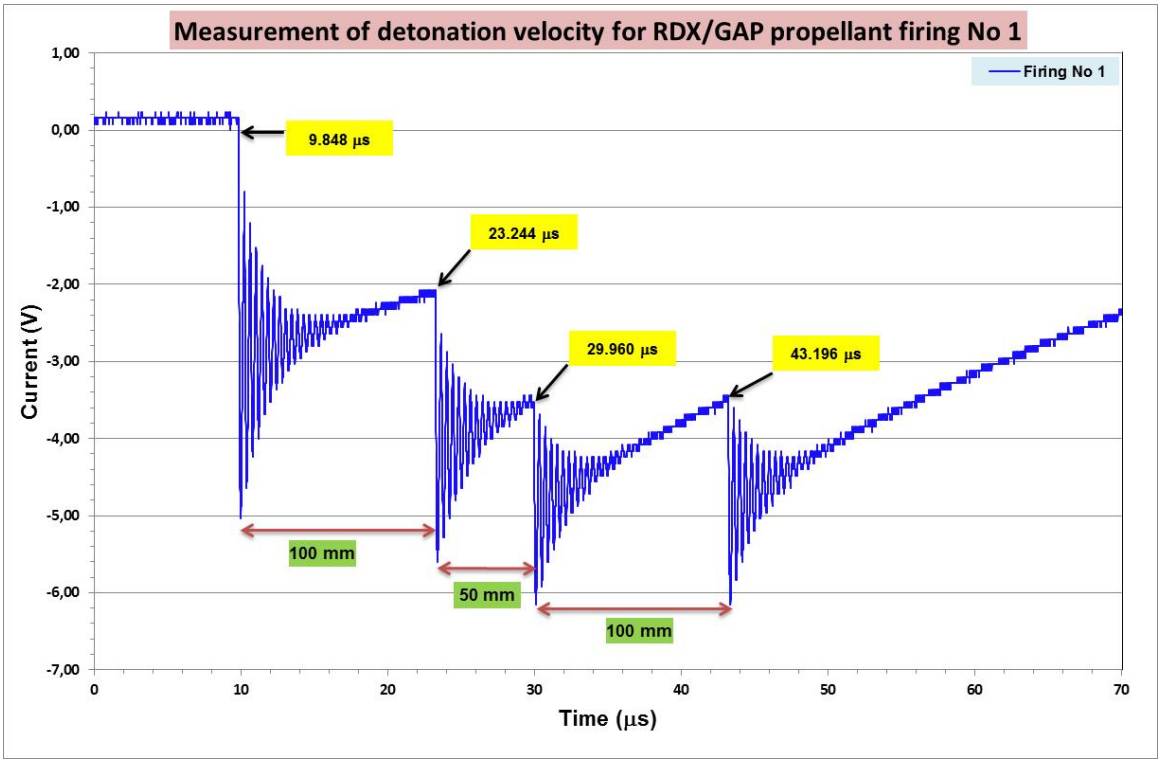

Figure 3.2 The arrival times of the detonation front for all ionization pins in addition to the distances between the pins.

Table 3.1 shows the measured detonation velocities. For cast No 2, 7465 m/s and for cast No 1, 7555 m/s. The detonation velocity from the bottom of cast No 2 to the top of cast No 1 is 7445 m/s. Overall (pin No 1 to pin No 4) the detonation velocity is 7497 m/s.

Pin No	Arrival time (µs)	Time between Pin No X and Pin X-1 (µs)	Distance from Pin X to Pin X-1 (mm)	Detonation Velocity (m/s)
	Firing No 1 containing RDX/GAP propellant D-07			
1	9.848			
2	23.244	13.396	100	7465
3	29.960	6.716	50	7445
4	43.196	13.236	100	7555
1-4		33.348	250	**7497**

Table 3.1 Detonation velocities for firing No 1.

3.1.2 Firing No 2

In firing No 2 the test item was cast No 11. The test item was fitted with 5 ionization pins. The distance between each pin was 60 mm. Figure 3.3 shows pictures of the test item and the test setup.

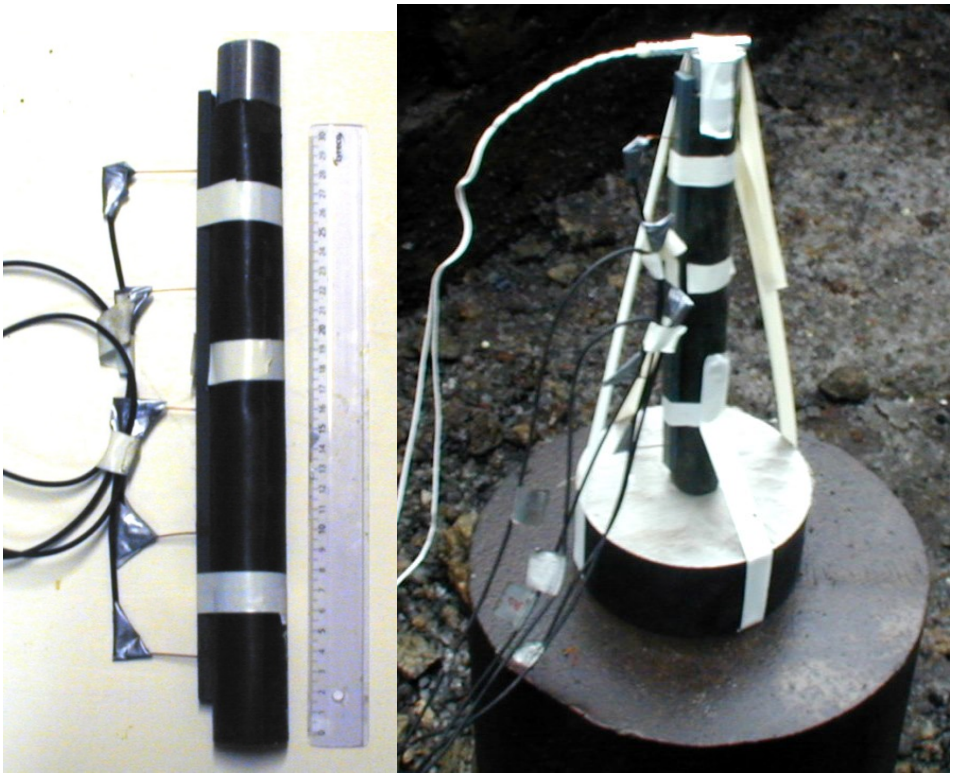

Figure 3.3 The test item and the test setup for firing No 2.

For firing No 2 we obtained registrations on only 4 of the 5 ionization pins. In Figure 3.4 the arrival times on each ionization pin together with the distances between the pins are given. The pin without registration is either No 1 or No 5.

For this firing the obtained detonation velocities do vary for all measurements. There is one explanation for this observation, that pin No 3 has been bended during assembling of the test item since the velocity reduction between pin No 2 and pin No 3 is equal to the increased velocity between pin No 3 and pin No 4. The length of the pin going into the charge was 3-4 mm. However the overall detonation velocity between pin No 1 and No 4 of 8010 m/s is approximately 500 m/s higher than for firing No 1.

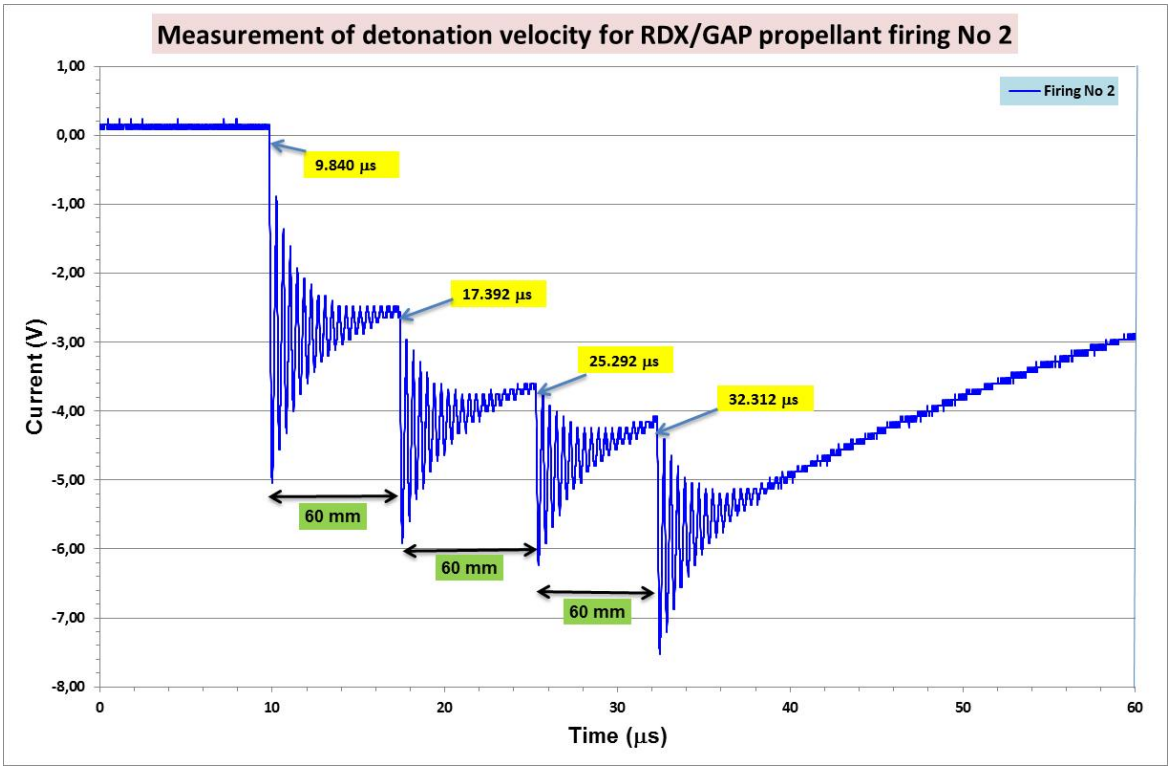

Figure 3.4 The arrival times of the detonation front for all ionization pins in addition to the distances between the pins.

Pin No	Arrival time (µs)	Time between Pin No X and Pin X-1 (µs)	Distance from Pin X to Pin X-1 (mm)	Detonation Velocity (m/s)
	Firing No 2 containing RDX/GAP propellant D-07			
1	9.840			
2	17.392	7.552	60	7945
3	25.292	7.900	60	7595
4	32.312	7.020	60	8547
5*	No registration			
1-4		22.472	180	**8010**

**It may be pin No 1 or No 5.*

Table 3.2 Detonation velocities for firing No 2 with cast No 11.

3.1.3 Firing No 3

In firing No 3 the test item was cast No 12. The test item was fitted with 4 ionization pins. The distance between pin No 1 and No 2 and between pin No 3 and No 4 was 100 mm. The distance between pin No 2 and pin No 3 was 50 mm. Figure 3.5 shows pictures of the test item and the test setup.

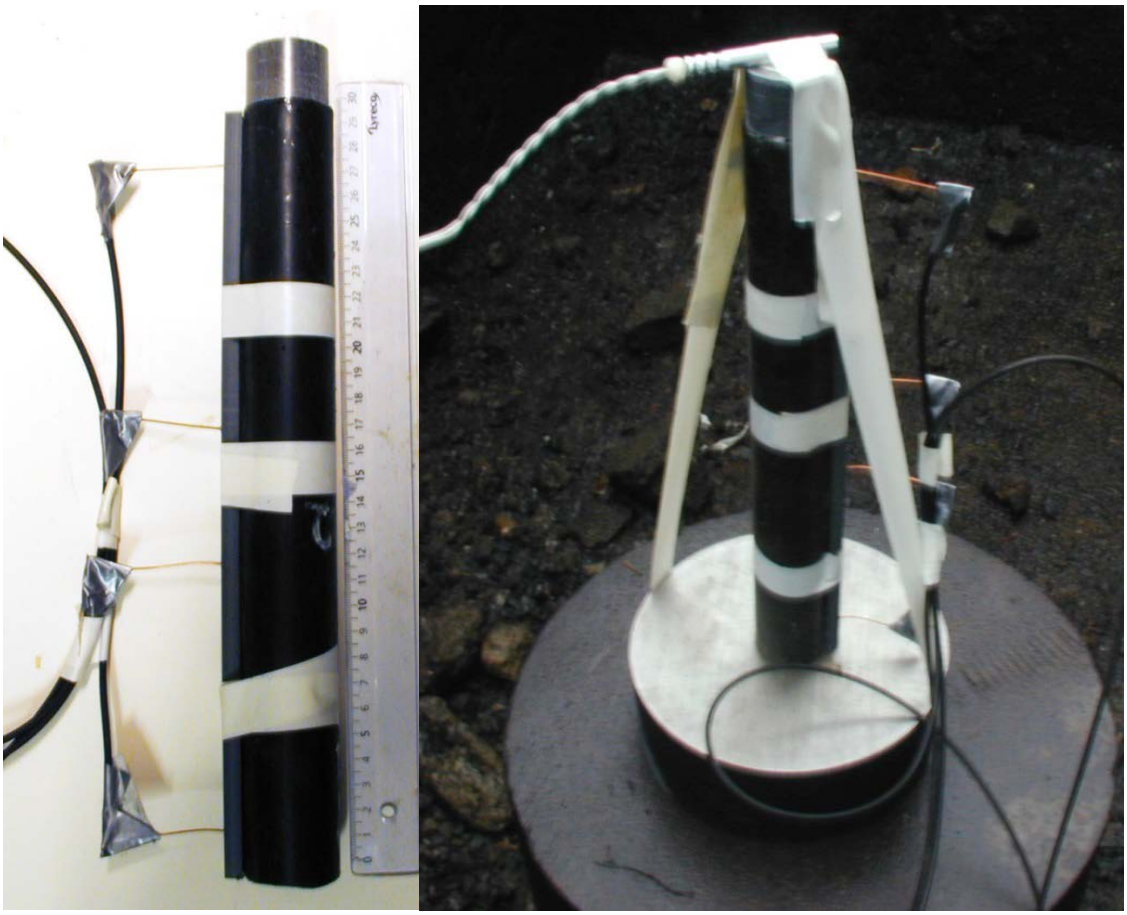

Figure 3.5 The test item and the test setup for firing No 3 with cast No 12.

For firing No 3 we obtained registrations on 3 of the 4 ionization pins. In Figure 3.6 the arrival times on each ionization pin together with the distances between the pins are given. For pin No 2 we had no registration.

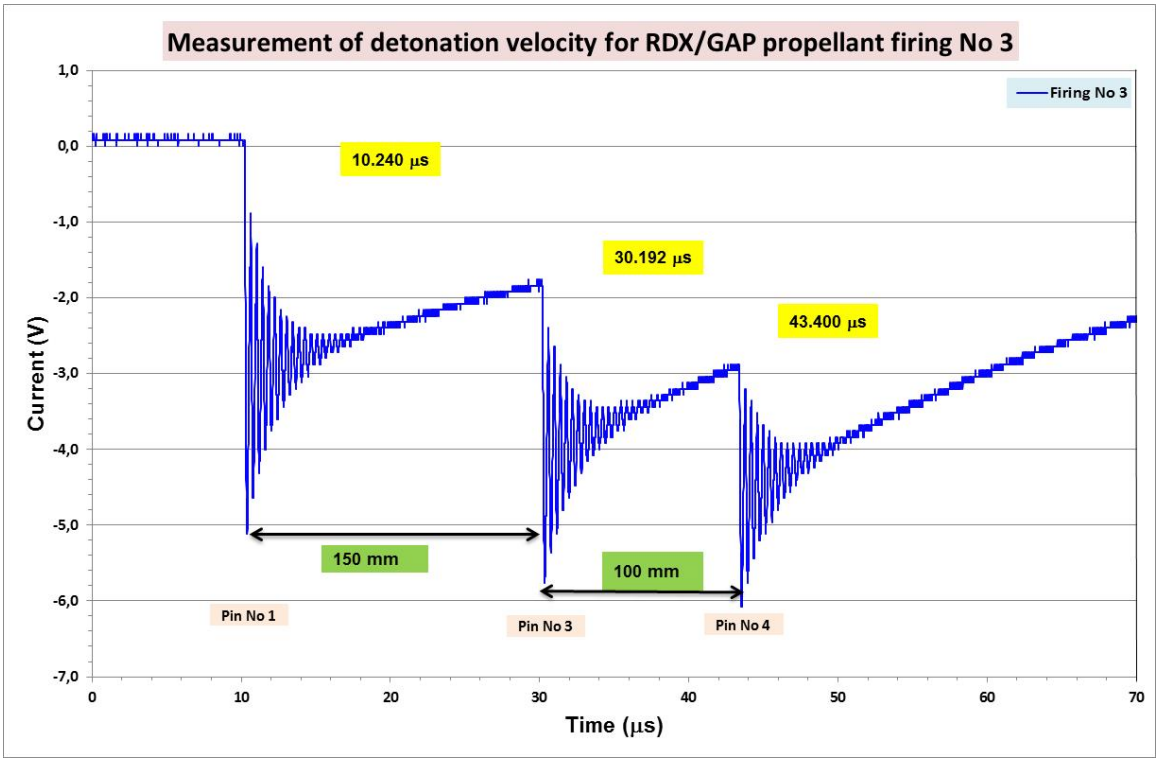

Figure 3.6 The arrival times of the detonation front for all ionization pins in addition to the distances between the pins.

For the results shown in Table 3.3 the variation in detonation velocities is small. Both single velocity measurements and the overall detonation velocity between the end pins (No 1 and No 4) show values close to the values obtained in firing No 1. The differences are within the accuracy of the method.

Pin No	Arrival time (µs)	Time between Pin No X and X-1 (µs)	Distance from Pin X to Pin X-1 (mm)	Detonation Velocity (m/s)
	Firing No 3 containing RDX/GAP propellant D-07			
1	10.240			
2	No registration		100	
3	30.192	19.952	50	7518
4	43.400	13.208	100	7571
1-4		33.16	250	**7539**

Table 3.3 Detonation velocities for firing No 3 cast No 12.

3.1.4 Summary detonation velocity

Table 3.4 summarizes all measured detonation velocities. For Firing No 1 and No 3 we obtain the same detonation velocity, 7500 m/s. For firing No 2 with the test item with the highest density, the overall detonation velocity is 8010 m/s.

Firing No	Cast No	Charge diameter (mm)	Charge density (g/cm^3)	Between pin No	Measuring distance (mm)	Detonation velocity (m/s)
1	1 and 2	29.1	1.634	1-2	100	7465
				2-3	50	7445
				3-4	100	7555
				1-4	250	**7497**
2	11	34.0 Top 35.64 Bottom	1.679	1-2	60	7945
				2-3	60	7595
				3-4	60	8547
				1-4	180	**8010**
3	12	34.6 Top 35.5 Bottom	1.648	1-2	100	
				1-3	150	7518
				3-4	50	7571
				1-4	250	**7539**

Table 3.4 Measured detonation velocities for tested charges.

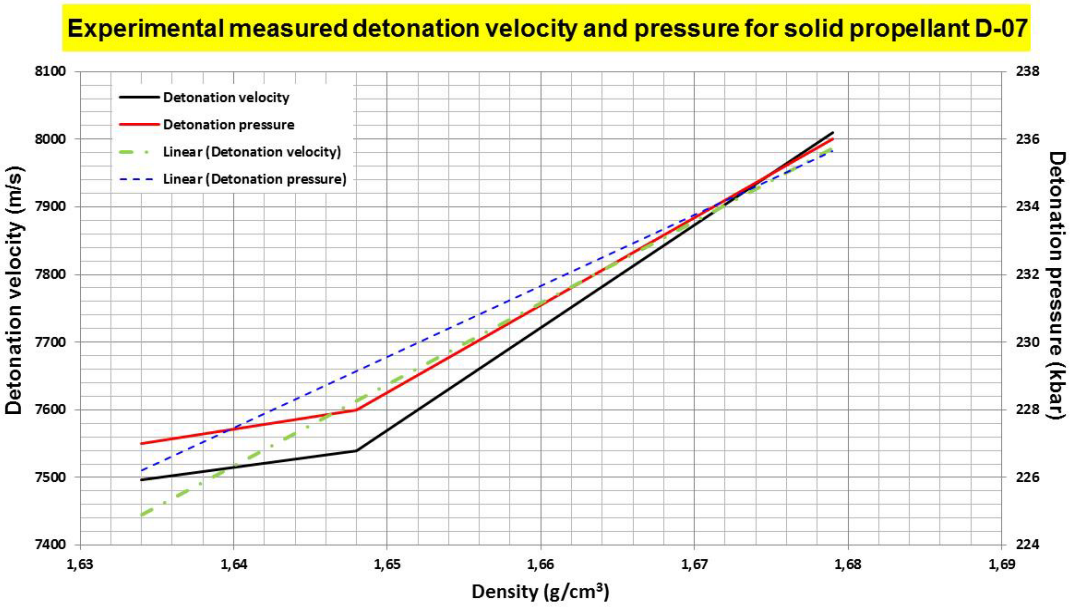

Figure 3.7 Plots of measured detonation velocities and pressures for the solid propellant D-07.

3.2 Detonation pressure

The detonation pressures were measured for the three test items used for detonation velocity determination by use of the Plate Dent test. The Dent plates were cylindrical with diameter 160 mm.

3.2.1 Firing No 1

For this firing the Dent plate was cylindrical with diameter 160 mm and thickness of 50 mm of ST-52 quality. Figure 3.8 shows pictures of the Dent plate after firing and the test setup before firing. For firing No 1 we obtained a Dent depth of 4.59 mm equal to a pressure of 227.1 kbar.

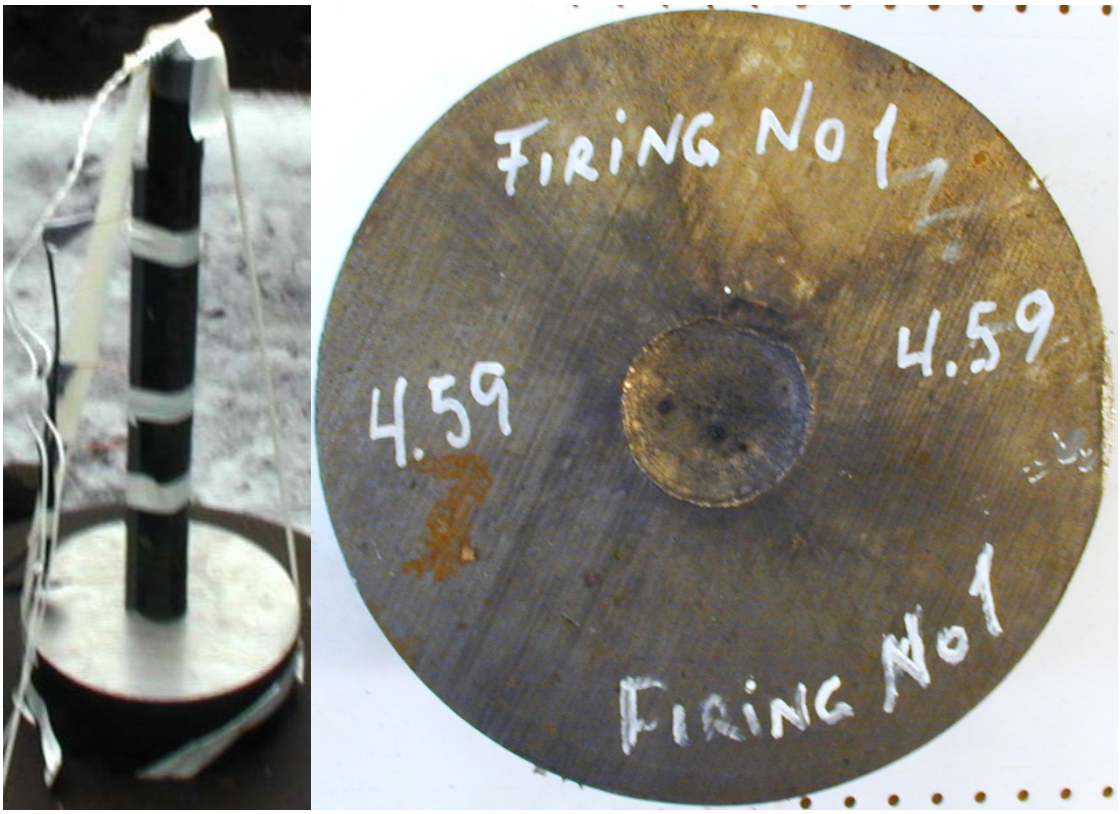

Figure 3.8 Test setup and the Dent plate for firing No 1 with cast No 1 (2).

3.2.2 Firing No 2

For firing No 2 the applied Dent plate was cylindrical with diameter 160 mm and thickness of 60 mm. In Figure 3.9 pictures of the Dent plates after firing in addition to the end of the test item is given. For firing No 2 we obtained a Dent depth of 5.85 mm equal to a pressure of 236.4 kbar.

Figure 3.9 Dent plate for firing No 2 with cast No 11.

3.2.3 Firing No 3

For firing No 3 the applied Dent plate was cylindrical with diameter 160 mm and thickness of 60 mm. Figure 3.10 shows pictures of the Dent plate after firing and the test setup before firing. For firing No 3 we obtained a Dent depth of 5.63 mm equal to a pressure of 228.4 kbar.

Figure 3.10 Test setup and Dent plate for firing No 3 with cast No 12.

3.2.4 Summary of pressure measurements

Table 3.5 summarizes the detonation pressure measurements for the RDX/GAP propellant. The average detonation pressure is 231±4 kbar. The highest pressure is, as expected, measured for the test item with the highest density. In Figure 3.7 a plot of the measured detonation pressures as function of the density of the test items is given.

Firing No	Charge Diameter * (mm)	Charge density (g/cm^3)	Dent (mm)	Detonation Pressure (kbar)
1	29.10	1.634	4.59	227.1
2	35.64	1.679	5.85	236.4
3	35.50	1.648	5.63	228.4
Average				**231±4**

**For the end of the charges placed on the Dent plate.*

Table 3.5 Detonation pressures for the tested charges.

4 Conclusion

Detonation velocity and detonation pressure have been determined for the solid propellant D-07, an RDX/GAP propellant produced by Nammo Raufoss. Three firings have been performed with only moderate variations in the results. For the detonation pressures we obtained an average pressure of 231±4 kbar. The highest detonation pressure, 236.4 kbar, was obtained for the charge cast No 11, with highest density.

Measured detonation velocities for two of the test items were 7500 m/s. For the third test item, cast No 11, with highest density, 1.679 g/cm^3, we obtained an overall detonation velocity of 8010 m/s.

Appendix

A Control report HWC

The control report for the HWC composition used to press boosters for initiation of the different test items is given in Figure A.1. The applied HWC was manufactured by Chemring Nobel.

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

Kvalitetssjef

Chemring Nobel AS
High Energy Materials
Manager QA

Figure A.1 Control report for the HWC composition used in applied boosters.

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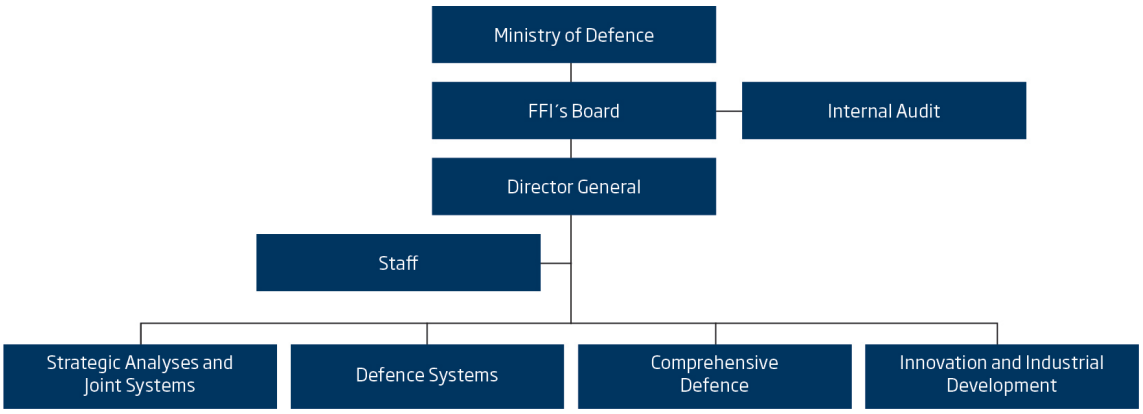
FFIs VERDIER

Skapende, drivende, vidsynt og ansvarlig.

FFI's organisation



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