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Gunnar Ove Nevstad

FFI Forsvarets forskningsinstitutt

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Norwegian Defence Research Establishment (FFI)

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Approved by

Ivar Sollien	Project Manager
Jon Skjervold	Director of Research

English summary

Detonation velocity can be measured by different methods. Earlier two probes of isolated twisted copper wires have been used to measure the time the detonation front uses for a predefined distance. The drawback with this method is that if one of the probes fails registration, no result is obtained. To increase the probability to get a velocity determination, we have investigated the possibility to use a more robust method with probes of ionization pins. In addition, ionization pin probes make it easy to increase the number of measuring points.

The ionization pin probes we have tested have been prepared from a semi-rigid coax cable with an outer conductor of copper. In addition to the probes, a switch box with ten channels and one trigger channel has been built. An oscilloscope has been used to register the arrival time of the detonation front at the different probes. Tests of the method have been performed on a detonating cord and pressed charges of HWC (RDX/Wax/Graphite).

Twelve probes have been tested out. We obtained registration on the oscilloscope for eleven probes at the expected times. The twelve probes were placed in three test items with four probes in each. The experimentally obtained detonation velocities both for the detonating cord and the HWC charges were all as expected. The values were 7291 m/s for the detonating cord, 8387 m/s (ϕ = 18.6 mm) and 8422 m/s (ϕ = 31.8 mm) for the HWC charges.

The time signals we obtain have some oscillations. However, there is no problem to separate the arrival time of the detonation front for each probe, and the start time is unambiguous defined.

Sammendrag

Detonasjonshastighet kan måles med forskjellige metoder. Vi har i lang tid benyttet to sensorer bestående av tvinnede kobbertråder med diameter 0,15 mm med et om lag 0,01 mm tykt lakklag. Med to sonder kan man måle hvor lang tid detonasjonsfronten bruker over en gitt avstand. Svakheten med metoden er at dersom registrering uteblir for en av sondene, gir det ingen hastighet. For å øke sannsynligheten for å oppnå et resultat har vi undersøkt om vi kan benytte sonder av ionisasjonspinner. De er mer robuste målesonder enn tvinnede kobbertråder. Ionisasjonspinner gjør det dessuten mulig å øke antall målepunkter.

Vi har laget ionisasjonspinner fra en semi-rigid koaksialkabel med ytre ledende kappe av kobber. I tillegg har vi konstruert en koplingsboks med ti kanaler og en triggekanal. Tester av utstyret og målemetoden har vi gjennomført på detonerende lunte samt pressede ladninger av HWC (RDX/voks/grafitt) med to ulike diametere.

Testene har vist at av tolv sonder ble det oppnådd registrering på elleve ved forventet tid. Sondene var plassert i tre testlegemer med fire sonder i hver, derfor ble det oppnådd resultat også for testlegemet hvor en registrering uteble. Oppnådde detonasjonshastigheter er alle som forventet: 7291 m/s for detonerende lunte, og 8387 m/s (ϕ= 18.6 mm) og 8422 m/s (ϕ= 31.8 mm) for HWC-legemene.

Ved lang kabel mellom skop og koplingsboks har tidssignalet ringing. Tidsbestemmelsen for hver sonde er imidlertid upåvirket av denne forstyrrelsen. I tillegg er definisjonen av start entydig og krever derfor ingen tolkning.

Contents

Abbreviates

BKWC	Becker-Kistiakowski-Wilson. C,N,O,H,F product library
BKWS	Becker-Kistiakowski-Wilson. Sandia product library
HMX	Octogen/1,3,5,7-tetranitro-1,3,5,7-tetrazacyclooctane
HWC	Hexogen/Wax/Graphite (94.5/4.5/1)
PTFE	Polytetrafluoroethylene
RDX	hexogen/1,3,5-trinitro-1,3,5-trizacyclohexane
TMD	Theoretical Maximum Density
TNT	2,4,6-trinitrotoluene

1 Introduction

For determination of detonation velocity for explosives charges, we have for the last 30 years (1) used probes of isolated twisted copper wire for registration of start and stop time of the detonation front. The wire has a diameter of 0.15 mm and the lacquer a thickness of 0.01 mm. This method is easy to use but has a drawback since we only have two registrations. Loss of registration for one probe gives no detonation velocity result. In addition this method gives only the average detonation velocity. To have the possibility to study the detonation velocity as a function of the distance from the initiation point more probes are required.

To increase the possibility to obtain a result and to obtain more information about the detonation velocity in the longitudinal direction of an explosive charge, we therefore decided to try to use ionization pins for determination of the detonation velocity. Use of ionization pins is more reliable since the pins are soldered to the connection cable. In addition we can have a significantly higher number of registrations. We therefore decided to build a switch box with 10 channels in addition to a trigger channel based on the principles described in reference (2). This makes it possible to increase the number of registrations from 2 to 10.

To test if ionization pins will give the expected results we procured a semi-rigid coax cable to produce ionization pins and built a switch box to get the signal to a digital storage oscilloscope. To test if the method and the equipment did functioned as expected testing were carried out on a detonating cord and pressed test items of HWC (RDX/Wax/Graphite) explosive.

2 Experimental

2.1 Ionization pins and connection cable/contact

The ionization pin probes were made from a semi-rigid coax cable with a Copper outer conductor. The specification of the cable is given in Appendix A. It was procured from the US company Pasternack. From the received 1.5 m long cables pins were cut to a length of 6-7 cm. 1 cm of the outer copper shield was removed before 0.5 cm of the PTFE insolation was removed. The left picture in Figure 2.1 shows some pins after this operation.

An RP-174 coax cable with a length of 4 m was used between the pin and the switch box. This cable was, after removing the insolation, soldered to the ionization pin as shown in Figure 2.1. The length of this cable will be increased to 5-6 m to get the switch box farther away from the detonation.

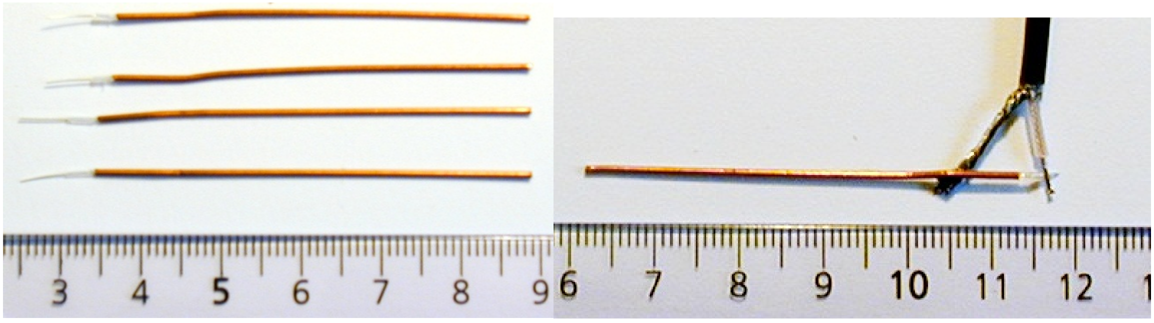

Figure 2.1 Picture of the ionization pins before and after being soldered to the connection cable.

In our test setup we used 4 pins and these were all soldered to a connector with 10 points.

2.2 Pin switch box

A switch box for 10 ionization pin probes and a trigger channel was produced at FFI. 4 1.5 V batteries were used as power supply instead of the electrical net. This makes it possible to perform the testing at locations without access to the net and avoid the use of long power cables.

Figure 2.2 Picture of the switch box developed to transform the signal from the ionization pins to the scope.

Figure 2.3 Picture of the end of the switch box and the power supply unit.

Between the switch box and the scope a coaxial cable RP-58 with a length of 30 m was used.

2.3 Oscilloscope

The scope we used to collect the results was a GW Instek GDS-3354, Digital Storage Oscilloscope, 350 MHz 5 GS/s adjusted to DC. The conditions used for the test firings are given in Table 2.1.

Memory Length	25000	25000	25000
Trigger Level	-2.76V	-2.76V	-2.76V
Source	CH1	CH1	CH1
Probe	1.000E+00	1.000E+00	1.000E+00
Vertical Units	V	V	V
Vertical Scale	2.000E+00	2.000E+00	2.000E+00
Vertical Position	-3.200E-01	-3.200E-01	-3.200E-01
Horizontal Units	S	S	S
Horizontal Scale	2.000E-05	5.000E-06	5.000E-06
Horizontal Position	6.000E-05	1.980E-05	1.980E-05
Horizontal Mode	Main	Main	Main
Sampling Period	1.000E-08	2.000E-09	2.000E-09
Firmware	V1.09	V1.09	V1.09
Time	01.07.2013 11:53:06	01.07.2013 12:06	01.07.2013 12:27
Mode	Detail	Detail	Detail
Waveform Data			

Table 2.1 The conditions used to collect the results for the three test firings.

The obtained results for each firing were stored on a memory pin as a Microsoft Excel Comma Separated Values File. In addition a picture of the scope was taken after each firing. Both the picture and the results presented as an Excel plot are given in the result section.

2.4 Samples preparation

2.4.1 Detonating cord

The detonating cord was cut to the wanted length before it was attached to a wood board. The holes for placing the ionization pin probes were drilled by hand with a 0.95 mm drill, Figure 3.4.

2.4.2 Pressed HWC test items

The pellets of HWC were pressed at room temperature with a press pressure of 10 tons and a dwell time of 60 seconds. Two tools with different diameter were used to press pellets of different diameter. To obtain the required length of the test items, 10 pellets were glued together by use of Aralit with 10 minutes curing time. The holes for the ionization pins were drilled by hand with a 0.95 mm drill after first being marked by use of the positioning board. The depth of the holes was 3 mm.

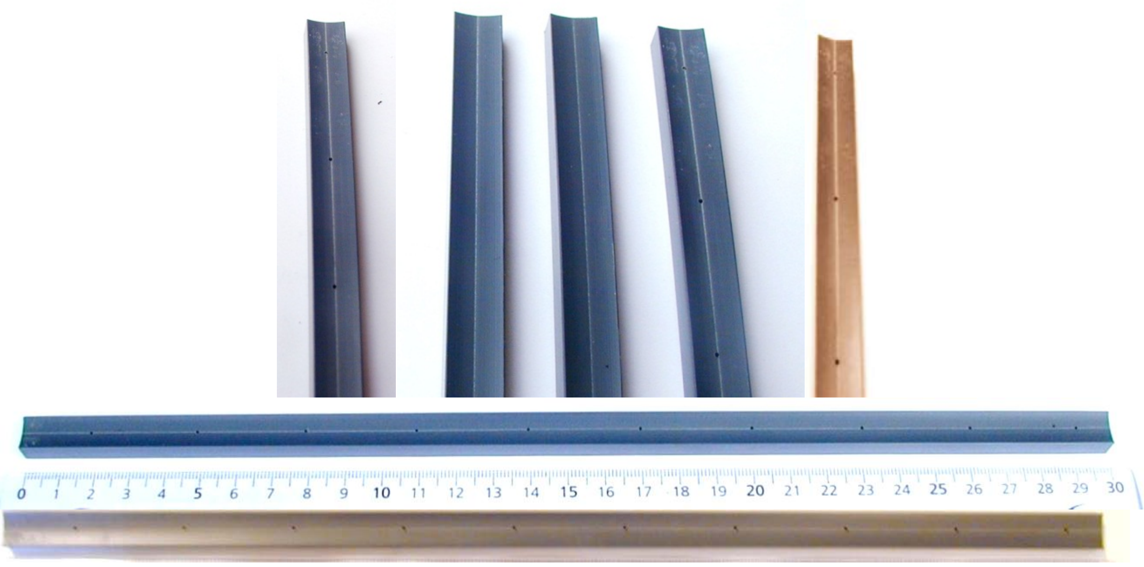

Figure 2.4   Pictures of the board used to hold the probes in correct position.

2.5 Detonation Pressure

The detonation pressure has been determined by use of the Plate Dent test (1, 3). We use steel bolts of ST-52 quality with diameter 160 mm as witness plates. For the charge with diameter 18.6 mm the bolt had a height of 50 mm while for the ϕ = 30 mm charge it had a height of 75 mm.

2.6 Cheetah calculations

All theoretical calculations have been performed with Cheetah 2.0 (4).

3 Results

3.1 Cheetah calculations

Cheetah 2.0 (4) was used to calculate the thermochemical properties for HWC. The used content for the explosive is the real content given in Appendix C: 94.7 wt. % RDX with 6.1wt. % HMX/ 4.4 wt. % wax/0.9 wt. % graphite. Table 3.1 summarizes the obtained theoretical properties obtained by use of the BKWS and the BKWC product libraries. In addition to at the TMD (Theoretical Maximum Density) calculations have been performed for the two densities obtained for the tested pressed pellets. Appendix D gives the summary print outs from Cheetah.

Property	BKWS Product Database			BKWC Product Database		
% of TMD	100	98.34	97.52	100	98.34	97.52
Density (g/cc)	1.7135	1.685	1.671	1.7135	1.685	1.671
The C-J condition:						
Pressure (GPa)	**29.44**	**28.34**	**27.81**	**28.54**	**27.39**	**26.84**
Volume (cc/g)	0.446	0.453	0.446	0.440	0.448	0.451
Density (g/cc)	2.242	2.209	2.193	2.272	2.234	2.216
Energy (kJ/cc explosive)	3.47	3.36	3.31	3.51	3.47	3.30
Temperature (K)	3876	3893	3901	3962	3974	3979
Shock velocity (m/s)	**8537**	**8420**	**8363**	**8233**	**8132**	**8082**
Particle velocity (m/s)	2013	1997	1990	2023	1999	1988
Speed of sound (m/s)	6525	6423	6373	6210	6132	6094
Gamma	3.242	3.216	3.203	3.069	3.067	3.066
Freezing occurred at T = 1800 K and relative V =	1.625	1.640	1.647	1.652	1.664	1.670
Mechanical energy of detonation (kJ/cc)	-9.728	-9.520	-9.418	-9.432	-9.222	-9.119
Thermal energy of detonation (kJ/cc)	-0.000	-0.000	-0.000	-0.000	-0.000	0.000
Total energy of detonation (kJ/cc)	-9.728	-9.520	-9.418	-9.432	-9.222	-9.119

Table 3.1 Cheetah calculations for the composition HWC 08/02 used in test items.

3.2 Pressing of test items

The explosive composition used for testing HWC with content given in Annex C was delivered by Chemring Nobel. Cylindrical charges with diameter of 18.6 mm and 31.8 mm were pressed with a pressure of 10 tons and dwell time of 60 seconds. The measured properties for the 18.6 mm pellets are given in Table 3.2.

Pellet No	Weight (g)	Height (mm)	Diameter (mm)	Volume (mm^3)	Density (g/cm^3)
1	14.1103	31.18	18.60	8472.12	1.665
2	14.1140	30.74	18.60	8352.56	1.690
3	14.0901	31.01	18.59	8416.87	1.674
4	14.1488	31.00	18.57	8396.06	1.685
5	14.1185	30.90	18.58	8377.99	1.685
6	14.0778	30.90	18.58	8377.99	1.680
7	14.1400	30.83	18.58	8359.01	1.692
8	14.0600	30.80	18.57	8341.89	1.685
9	14.1105	30.85	18.58	8364.43	1.687
10	14.1702	30.86	18.57	8358.14	1.695
11	14.2013	30.86	18.59	8376.15	1.695
12	14.0737	30.80	18.58	8350.88	1.685
13	14.0038	30.70	18.58	8323.76	1.682
14	19.9341	43.26	18.60	11754.45	1.696
15	14.0305	30.85	18.58	8364.43	1.677
	Average density (g/cm^3)				**1.685$\pm$0.008**

Table 3.2 Table shows properties for pressed pellets (diameter = 18.6 mm) to be used for testing of detonation pressure and velocity.

From the results in Table 3.2 we see that the obtained average density 1.685 g/cm^3 is not far from the TMD of 1.7135 g/cm^3, (98.34 % of TMD).

In addition to pellets with diameter 18.6 mm pellets with diameter 31.8 mm were pressed under the same conditions. The obtained properties of these pellets are summarized in Table 3.3. Obtained density for these pellets, 1.671 g/cm^3 or 97.52 % of TMD, is slightly lower than for the pellets with diameter18.6 mm.

Pellet No	Weight (g)	Height (mm)	Diameter (mm)	Volume (mm^3)	Density (g/cm^3)
1	39.5882	30.01	31.83	23879.72	1.658
2	40.0584	30.12	31.82	23952.19	1.672
3	39.8660	30.05	31.81	23881.51	1.669
4	39.9474	30.04	31.82	23888.57	1.672
5	40.0205	30.13	31.81	23945.08	1.671
6	40.0293	30.12	31.82	23952.19	1.671
7	39.9549	30.03	31.80	23850.61	1.675
8	40.0110	30.11	31.81	23929.19	1.672
9	39.9211	30.07	31.81	23897.40	1.671
10	39.9509	30.05	31.82	23896.52	1.672
11	35.1101	26.35	31.82	20954.19	1.676
12	39.9587	30.10	31.81	23921.24	1.670
13	39.9561	30.04	31.81	23873.56	1.674
	Average density				**1.671+0.004**

Table 3.3 Table shows properties for pressed pellets (diameter = 31.8 mm) to be used for testing of detonation pressure and velocity.

3.3 Ionization pins

For all three measurements of detonation velocity in this report we used four ionization pins. This number was selected to demonstrate that the system functions as expected. In the study of new compositions we will however, from time to time use a larger number of pins.

For the testing of the pressed charges these pins were mounted on a board as shown in Figure 3.1.

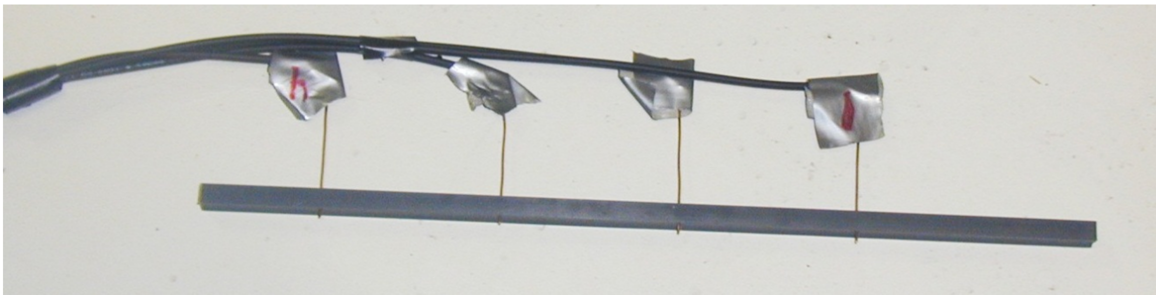

Figure 3.1 The figure shows a picture of a board with 4 ionization pin probes.

30 cm long boards have been produced with 10 holes in fixed positions, starting at 20 mm from the top and ending 10 mm from the bottom. Knowing the distance between the probes is critical for the accuracy of the detonation velocity measurement. The holes in the board were therefore

drilled in a lathe to obtain the same distance between the probes. The surface towards the charge was curved with a diameter of 30 mm to better fit to the charge.

Figure 3.2 shows the probes used to measure the detonation velocity for the detonating cord.

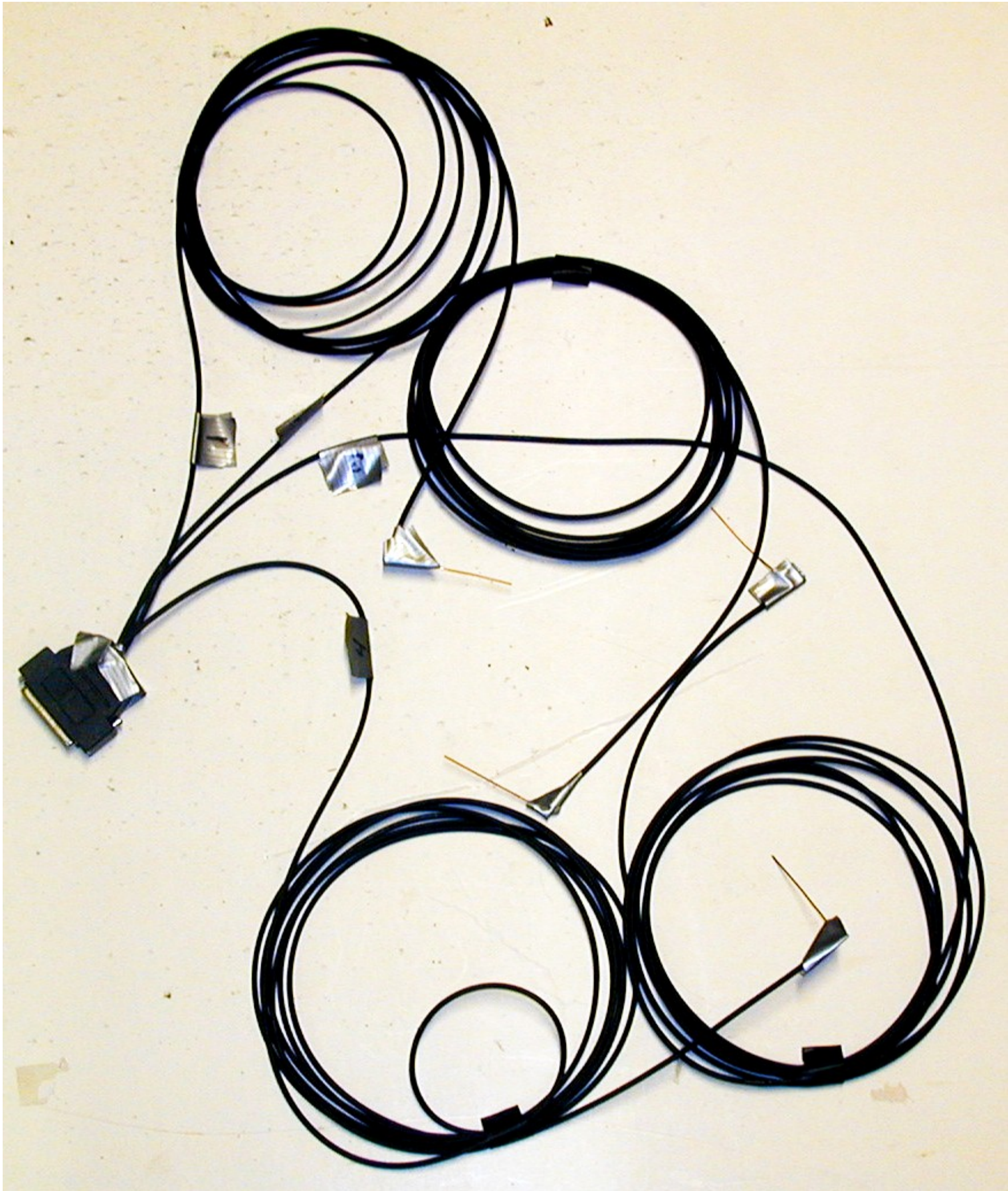

Figure 3.2 The picture of the pins with the cables for connection to the pin switch box.

3.4 Detonation velocity

3.4.1 Detonating Cord

We normally use a detonating cord to check that the measuring equipment operates as expected, because much less preparation work is required compared to pressing or casting of charges. In addition it gives the possibility to have a significantly longer measuring distance and thereby better accuracy. For the test of the new ionization pin probes a cord of 1 m length with 4 pins placed as shown in Figure 3.3 was used. The test item was placed on the ground before firing. Initiation was carried out by the use of a detonator No 8 as shown in Figure 3.4.

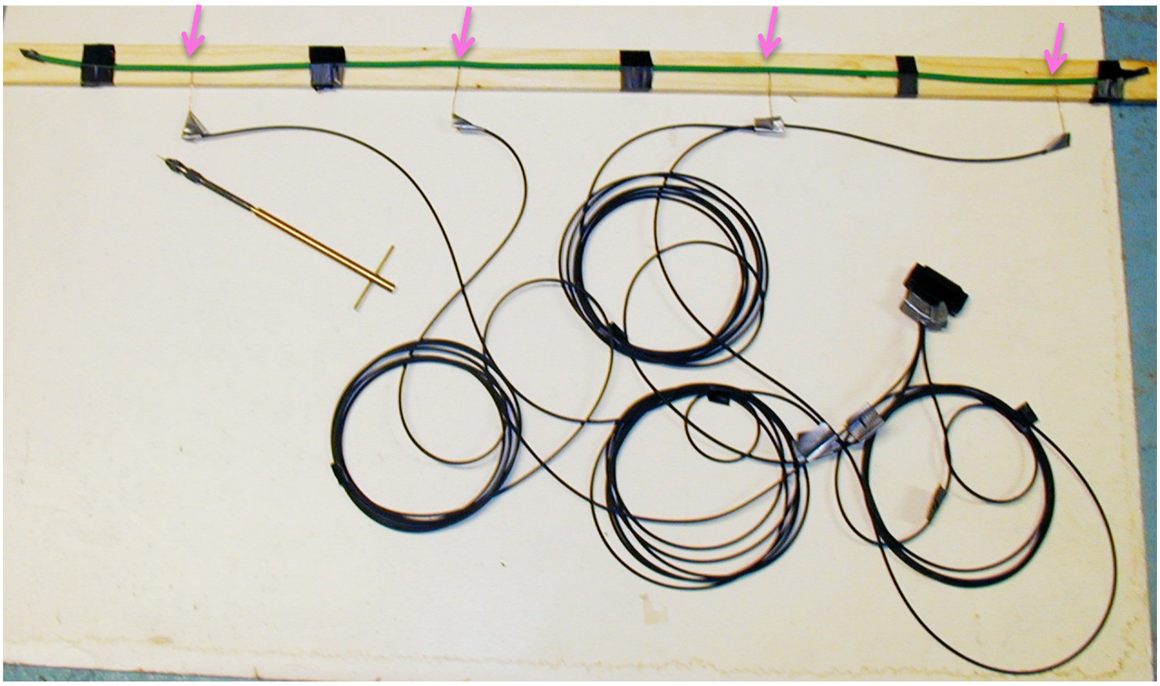

Figure 3.3 Picture of the test item after the pins had been assembled into the detonation cord.

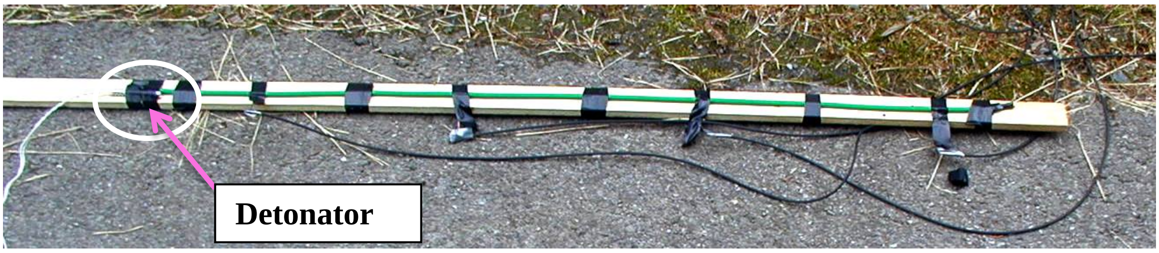

Figure 3.4 Picture of the test item just before firing.

Figure 3.5 shows a picture of the oscilloscope with the obtained registration after the firing was performed. The data obtained was stored on the oscilloscope in addition to a memory stick as an asc-file for later analysis on a PC. The asc-file was transferred to EXCEL and a plot of the data performed. Figure 3.6 shows the obtained plot with the arrival time at each probe. In addition Figure 3.6 shows the distance between each probe.

The distances between the probes were measured before firing and are summarized in Table 3.4 together with the arrival times of the detonation front. Since we know both the distance between each probes and the time the detonation front used between them, the detonation velocity can be calculated and is given in the last column of Table 3.4. The obtained average velocity between pin No 1 and pin No 4 is 7291 m/s.

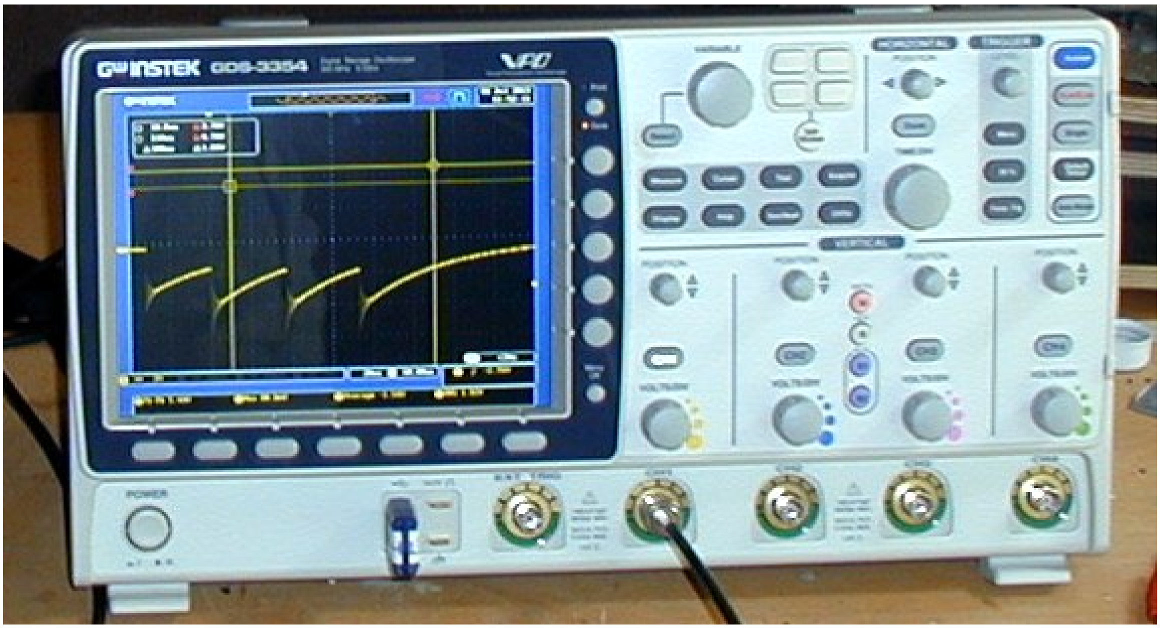

Figure 3.5 Picture of the scope with registration after firing of the detonation cord.

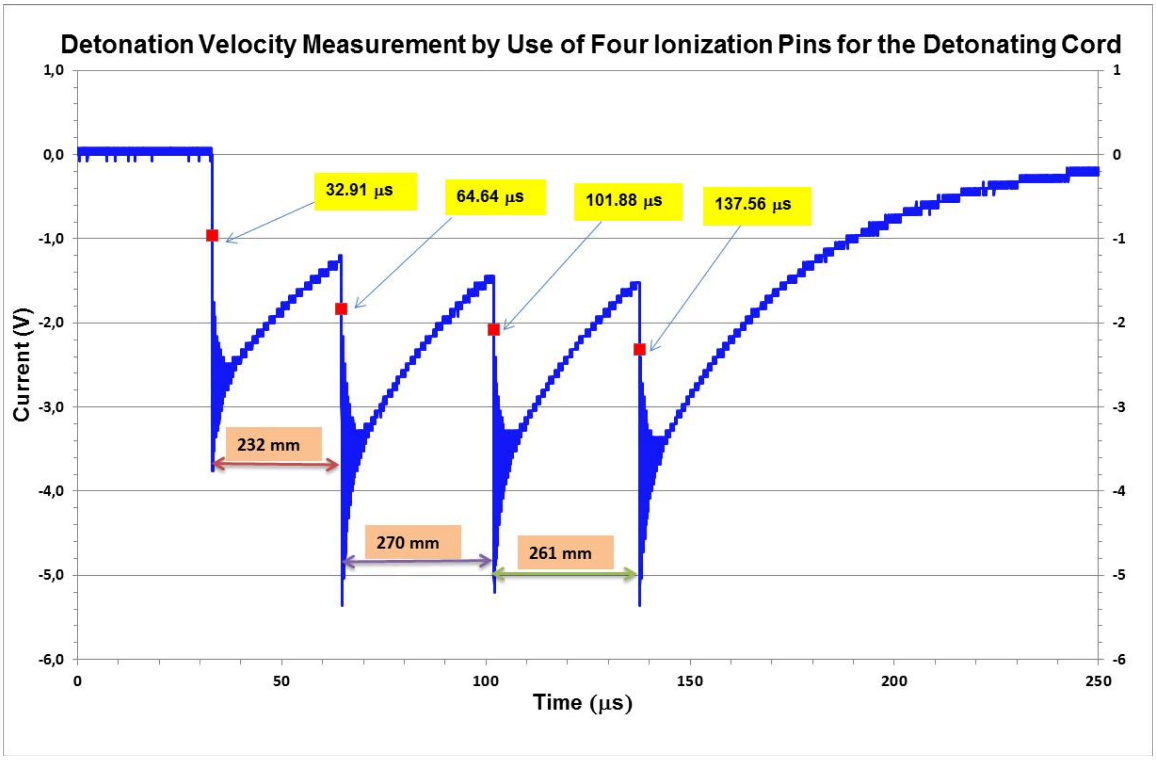

Figure 3.6 The EXCEL plot of the obtained results for the detonation cord.

In earlier determinations of the detonation velocity for the same detonating cord performed with only two probes of twisted copper wires the following detonation velocities have been measured: 7282 m/s (5), 7299 m/s (6) and 7296 m/s (7) for single measurements. By comparing these detonation velocities with the results obtained by use of ionization pins there is no difference. The measuring accuracy of the distance between two probes is determining the accuracy of the detonation velocity. ±1 mm over the total length of 763 mm corresponds to ±10 m/s in the detonation velocity. ± 1 mm between two probes separated by 250 mm corresponds to ± 30 m/s in the detonation velocity.

Pin No	Arrival time (µs)	Time between pin No X + 1 (µs)	Distance from for pin No X-1 (mm)	Detonation Velocity (m/s)
1	32.91			
2	64.64	31.73	232	7312
3	101.88	37.24	270	7250
4	137.56	32.68	261	7315
1-4		104.65	763	7291

Table 3.4 The table shows a summary of the parameters for determination of the detonation velocity for the green detonation cord.

3.4.2 HWC pellets with diameter 18.6 mm

The second firing was with a test item of HWC pellets with diameter 18.61 mm. The test item was made up of 10 pellets, No 1-9 + 14 in Table 3.2. These were glued together with Aralite rapid as shown in Figure 3.7. The positions for placing the probes were marked by placing the board in right the position and by using a 0.8 mm diameter drill through the hole in the board (Figure 3.7). After marking the positions for the probes, holes were drilled by hand with a 0.9 mm diameter drill to a depth of 5 mm.

Figure 3.7 The conglutinated test item from 18.6 mm diameter pellets of HWC.

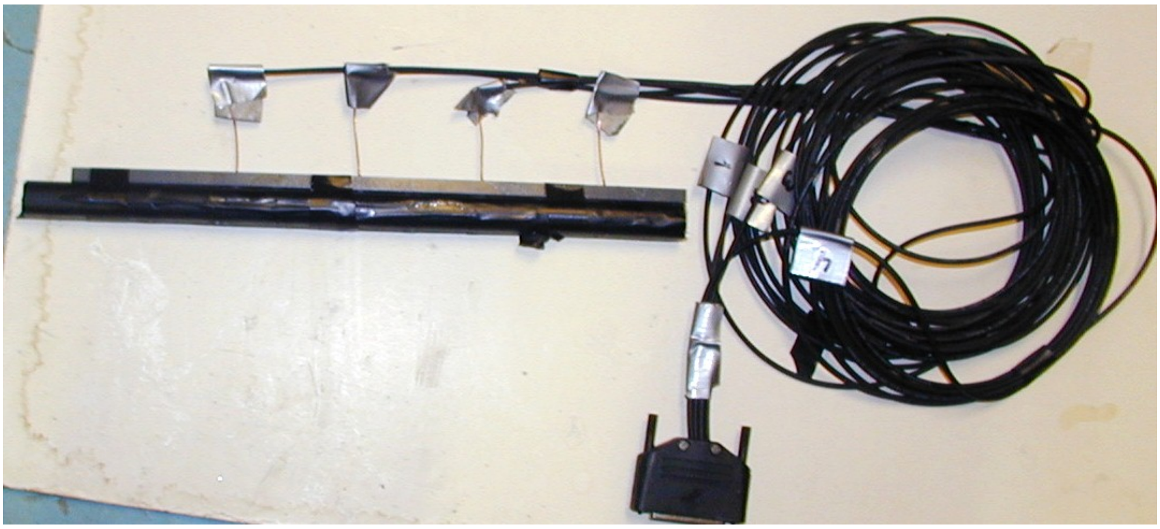

Figure 3.8 Picture of the test item after the ionization pins were put into the charge.

The ionization pins were glued to the board with the pin tip 3-4 mm outside the board. The board was than attached to the charge by tape. In this test we used 60 mm between the probes. The first probe was positioned approximately 100 mm from the initiation end of the charge, Figure 3.8.

Figure 3.9 shows the obtained registration on the scope after firing. Figure 3.10 shows a plot of the asc-file as an EXCEL-figure. For this firing we did get registration on all 4 probes but for probe No 2 the registration occurred strongly delayed. The distance between the probes was 60 mm as shown in Figure 3.8. Figure 3.10 shows the arrival time of the detonation front for those probes with expected registration in addition to the distance between these probes.

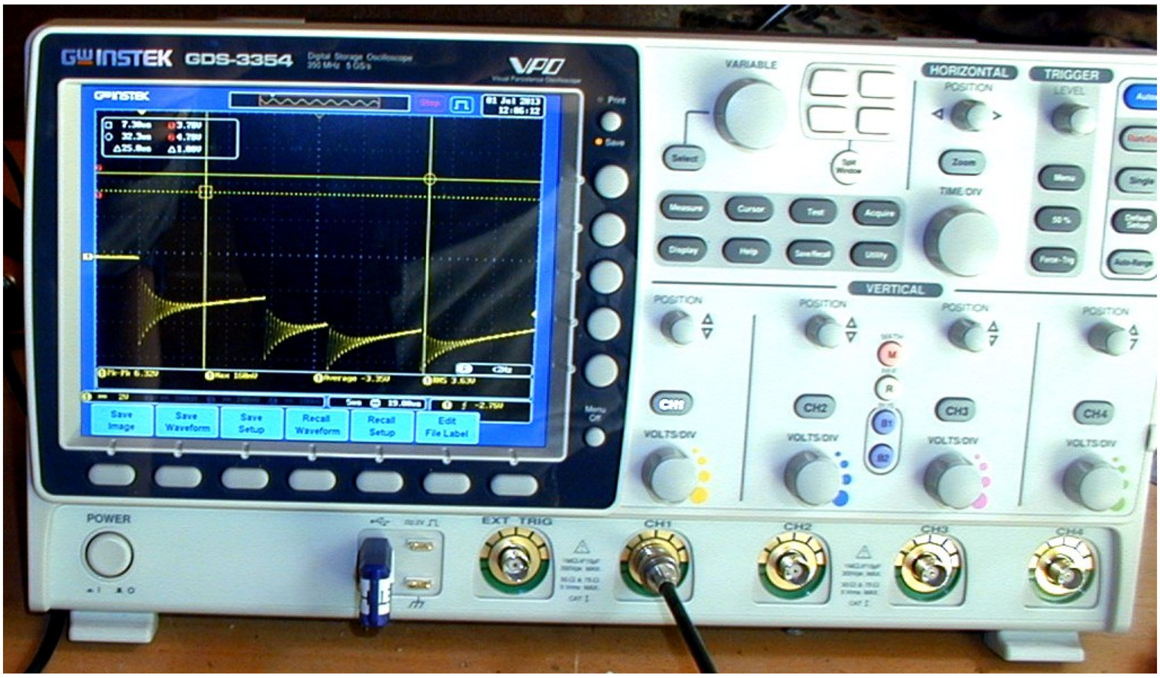

Figure 3.9 Picture of the scope after firing was performed.

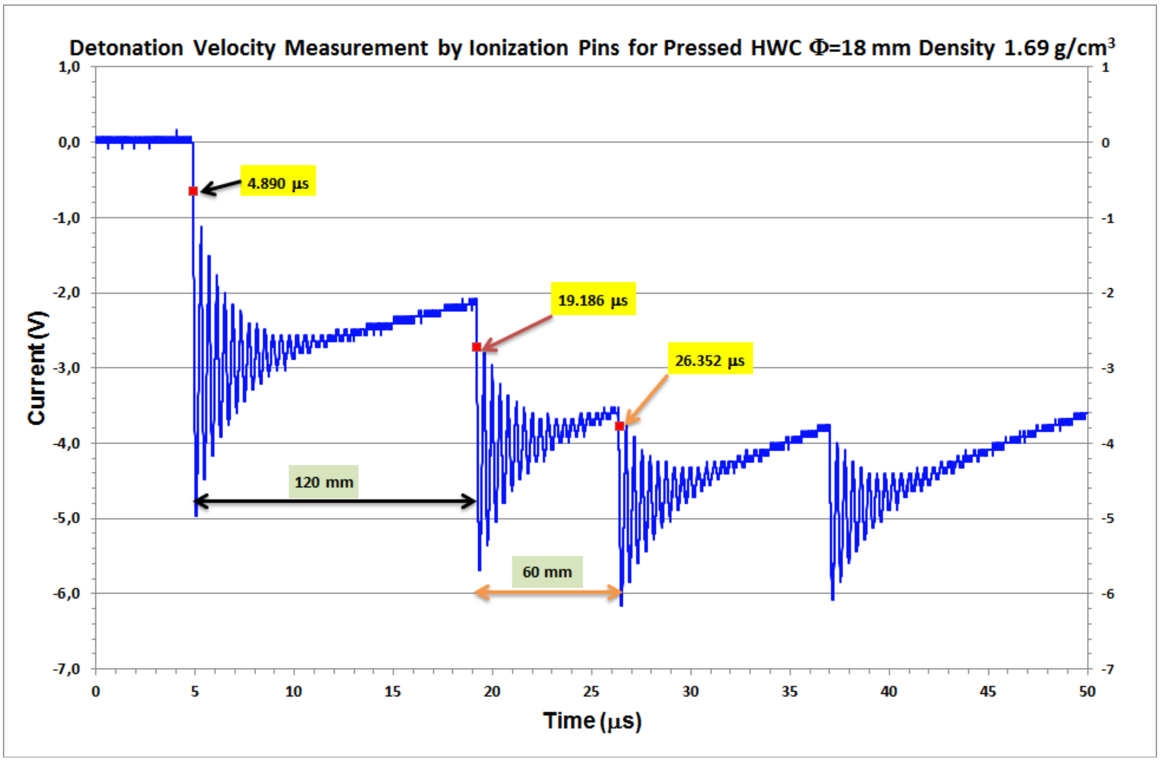

Figure 3.10 The scope data plotted in EXCEL showing the arrival time for the detonation front and distance between the ionization pins.

Table 3.5 gives the obtained average detonation velocity of 8387 m/s between probe No 1 and probe No 4. The difference in detonation velocity for the two measurements between probe No 1 and probe No 3 with 8394 m/s and between probe No 3 and No 4 with 8373 m/s is very small.

Pin No	Arrival time (µs)	Time between pin No X + 1 (µs)	Distance from for pin No X-1 (mm)	Detonation Velocity (m/s)
1	4.89			
2	(37)			
3	19.186	14.296	120	8394
4	26.352	7.166	60	8373
1-4		21.462	180	**8387**

Table 3.5 The table summarize the properties for the 18.6 mm test item with HWC in detonation velocity determination.

3.4.3 HWC pellets with diameter 32 mm

The third firing was performed with a test item of HWC pellets with diameter 31.81 mm. The test item was made up of 10 pellets, No 1 -10 in Table 3.3. The pellets were glued together with Aralite rapid as shown in Figure 3.11. The positions for the pins were marked by placing the board in right position and by using a 0.8 mm diameter drill through the hole in the board (Figure 3.11). After marking the positions for the probes, holes were drilled by hand with a drill with diameter of 0.9 mm to a depth of 5 mm. The positions of the probes are shown in Figure 3.11.

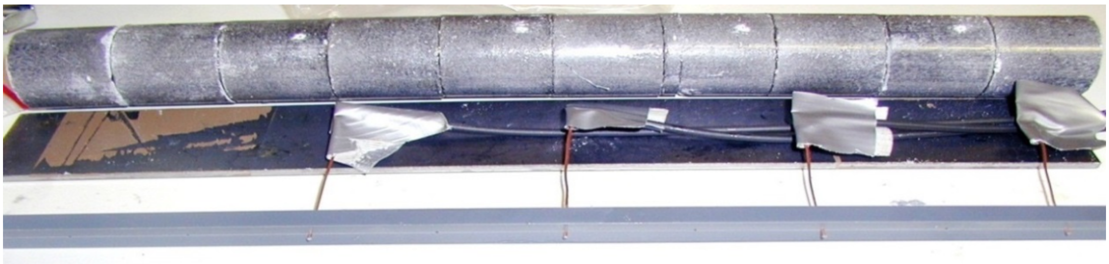

Figure 3.11 Picture of the conglutinated test item of HWC pellets with diameter 31.8 mm showing the position of the ionization pins.

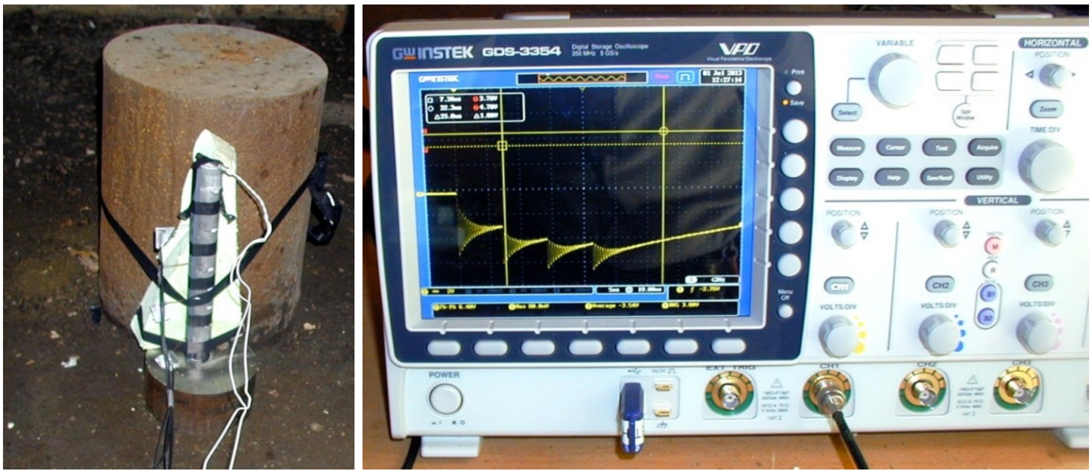

Figure 3.12 Left picture shows the test item just before firing; right picture the obtained registration on the scope after firing.

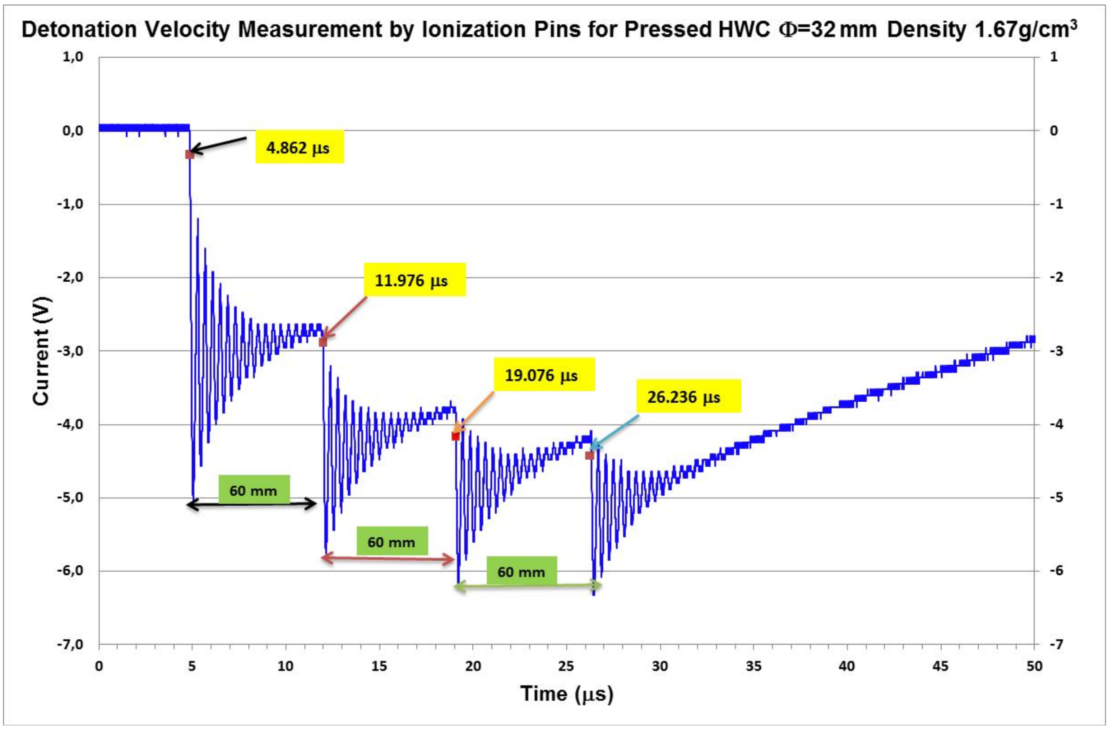

Figure 3.13 The scope data plotted in EXCEL showing arrival times for the detonation front and distances between the ionization pins.

Figure 3.12 shows the test setup in addition to the registration obtained after firing on the oscilloscope. All probes gave registration at expected time. Table 3.6 summarizes the arrival times and the distances between the probes. The average detonation velocity of 8422 m/s between probe No 1 and probe No 4 is slightly higher than 8387 m/s obtained for the test item with a diameter of 18.6 mm. Since the test item with diameter 31.8 mm has lower density than the test item with diameter 18.6 mm one would expect that the detonation velocity was slightly lower. However the difference in charge diameter can also influence on the detonation velocity. Normally a larger charge diameter will give a higher detonation velocity.

Pin No	Arrival time (µs)	Time between pin No X + 1 (µs)	Distance from for pin No X-1 (mm)	Detonation Velocity (m/s)
1	4.862			
2	11.976	7.114	60	8434
3	19.076	7.100	60	8451
4	26.236	7.160	60	8380
1-4		21.374	180	**8422±37**

Table 3.6 The table summarize the properties for the 31.8 mm test item with HWC in detonation velocity determination.

3.5 Plate Dent

By use of the equation (I) given in (1) the detonation pressure can be calculated from the measured Dent depth. The charges used to obtain the calibration equation had diameter 30 mm. To obtain the detonation pressures given in Table 3.7 the pressures have been corrected by the diameter of tested charges.

$$P_J = 48.0 \cdot C \quad (I)$$

P_J : Detonation pressure (kbar)
C : Dent depth (mm)
48.0: Angel coefficient (kbar/mm)

Figure 3.14 Pictures of the Dent Plates after the two firings with HWC.

	Diameter (mm)	Density (g/cm^3)	Dent (mm)	Pressure (kbar)
Shot No 2	18.6	1.685	3.6	**278**
Shot No 3	31.8	1.671	5.9	**267**

Table 3.7 Results for the two Dent Plate determinations of detonation pressure for HWC.

Both measured detonation pressures are as expected. The fact that the test item with18.6 mm diameter pellets obtains slightly higher detonation pressure than the test item assembled of pellets with diameter 31.8 mm is as expected due to the difference in density.

3.6 Comparison of theoretical and experimental results

Table 3.1 gives the theoretical detonation velocities for both densities of HWC tested experimentally. By use of the BKWS product library Cheetah gives for a density of 1.685 g/cm^3 a velocity of 8420 m/s and 8363 m/s for density 1.671 g/cm^3. The experimental velocities we obtained were 8387 m/s and 8422 m/s for these densities. The BKWC product library gives for equivalent charges 8142 m/s and 8082 m/s. From these results the BKWS product library gives a much better fit for the HWC-composition.

Table 3.1 also gives the detonation pressure for tested densities of HWC. For the BKWS product library for a density of 1.685 g/cm^3 Cheetah gives a pressure of 283 kbars and for a density of 1.671 g/cm^3 278 kbars. The experimental detonation pressures we obtained were respectively 278 kbars and 267 kbars for these densities. The BKWC product library gives for equivalent charges a detonation pressure of respectively 274 kbars and 268 kbars. From these results the BKWC product library gives a slightly better fit for the tested HWC-composition.

Litterature

(1) Eriksen Svein, Skarbøvik Knut, Larsen Øivind, Hagen Norman (1984): Bestemmelse av detonasjonsparametre, FFI/NOTAT-84/4041, Unclassified.

(2) Harry E. Cleaver: Pin Switch Instrument for microsecond Velocity Measurement. NSWC MP 88-172, 8 September 1988.

(3) Gibbs&Popolato (1980): LASL Explosive Property Data, Los Alamos Data Center for Dynamic Material Properties.

(4) Laurence E. Fried, W. Michael Howard, P. Clark Souers (1998): Cheetah 2.0 User's Manual, UCRL-MA-117541 Rev. 5; Energetic Materials Center Lawrence Livermore National Laboratory, 20 August.

(5) Nevstad Gunnar Ove (2006): Determination of Detonation Velocity and Plate Dent Properties for DPX-6, FFI/RAPPORT-2006/03060, Unclassified.

(6) Nevstad Gunnar Ove (2008): Determination of Detonation Velocity and Plate Dent Properties of DPX-5, FFI/RAPPORT-2008/01155, Unclassified

(7) Nevstad Gunnar Ove (2009): Determination of Detonation Velocity and Plate Dent Properties of DPX-9 and DPX-10. FFI/RAPPORT-2009/01112, Unclassified.

(8) Nevstad Gunnar Ove (2008): Determination of Detonation Velocity and Plate Dent Properties of PBXW-11 with 30 wt. % Aluminum, FFI/RAPPORT-2008/000334, Unclassified.

Appendix A Ionization Pins

Specification of the coaxial cable used to produce the ionization pin probes for measuring the detonation velocity is given in Figure A.1 – A.4.

PASTERNACK®
www.pasternack.com

034 Semi-rigid Coax Cable with Copper Outer Conductor

TECHNICAL DATA SHEET **PE-034SR**

034 Semi-rigid Coax Cable with Copper Outer Conductor

Configuration

Inner Conductor Material and Plating	Copper Clad Steel, Silver
Dielectric Type	PTFE
Shield Materials	Copper
Jacket Material and Color	Tan

Electrical Specifications

Impedance, Ohms	50
Maximum Operating Frequency, GHz	40
Maximum Operating Voltage, Volts	2,000

Electrical Specifications by Frequency

Frequency 1	
Frequency, MHz	1000
Attenuation, dB/100ft [dB/100m]	60 [196.85]
Power Handling, Watts	10
Frequency 2	
Frequency, GHz	10
Attenuation, dB/100ft [dB/100m]	190 [623.36]
Power Handling, Watts	3.1
Frequency 3	
Frequency, GHz	20
Attenuation, dB/100ft [dB/100m]	280 [918.64]
Power Handling, Watts	2

Mechanical Specifications

Temperature	
Operating Range, deg C	-55 to +100
Inner Conductor	
Number of Strands	1
Material	Copper Clad Steel
Plating	Silver
Diameter, in [mm]	0.008 [0.2]
Dielectric:	
Type	PTFE
Diameter, in [mm]	0.026 [0.66]

Click the following link (or enter part number in "SEARCH" on website) to obtain additional part information including price, inventory and certifications: 034 Semi-rigid Coax Cable with Copper Outer Conductor PE-034SR

The information contained in this document is accurate to the best of our knowledge and representative of the part described herein. It may be necessary to make modifications to the part and/or the documentation of the part, in order to implement improvements. Pasternack reserves the right to make such changes as required. Unless otherwise stated, all specifications are nominal.

Pasternack Enterprises, Inc. • P.O. Box 16759, Irvine, CA 92623
Phone: (866) 727-8376 or (949) 261-1920 • **Fax:** (949) 261-7451
Sales@Pasternack.com • Techsupport@Pasternack.com

ISO 9001 : 2008 Registered

© 2013 Pasternack Enterprises All Rights Reserved PE-034SR REV 1

Figure A.1 Page No 1 in the product sheet for the coaxial cable used to produce the ionization pins.

PASTERNACK
www.pasternack.com

034 Semi-rigid Coax Cable with Copper Outer Conductor

TECHNICAL DATA SHEET **PE-034SR**

Shield:	
Number of	1
Material 1	Copper
Diameter, in [mm]	0.034 [0.86]
Jacket:	
Color	Tan
One Time Minimum Bend Radius, in [mm]	0.5 [12.7]
Weight, lbs/ft [Kg/m]	0.002 [0]

Compliance Certifications (visit www.Pasternack.com for current document)

RoHS Compliant	Yes

Plotted and Other Data

Notes:	Values at 25 °C, sea level

034 Semi-rigid Coax Cable with Copper Outer Conductor from Pasternack Enterprises has same day shipment for domestic and International orders. Our RF, microwave and fiber optic products maintain a 99% availability and are part of the broadest selection in the industry.

Click the following link (or enter part number in "SEARCH" on website) to obtain additional part information including price, inventory and certifications: 034 Semi-rigid Coax Cable with Copper Outer Conductor PE-034SR

URL: http://www.pasternack.com/semirigid-0.034-50-ohm-coax-cable-copper-pe-034sr-p.aspx

The information contained in this document is accurate to the best of our knowledge and representative of the part described herein. It may be necessary to make modifications to the part and/or the documentation of the part, in order to implement improvements. Pasternack reserves the right to make such changes as required. Unless otherwise stated, all specifications are nominal.

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 PE-034SR REV 2

Figure A.2 Page No 2 in the product sheet for the coaxial cable used to produce the ionization pins.

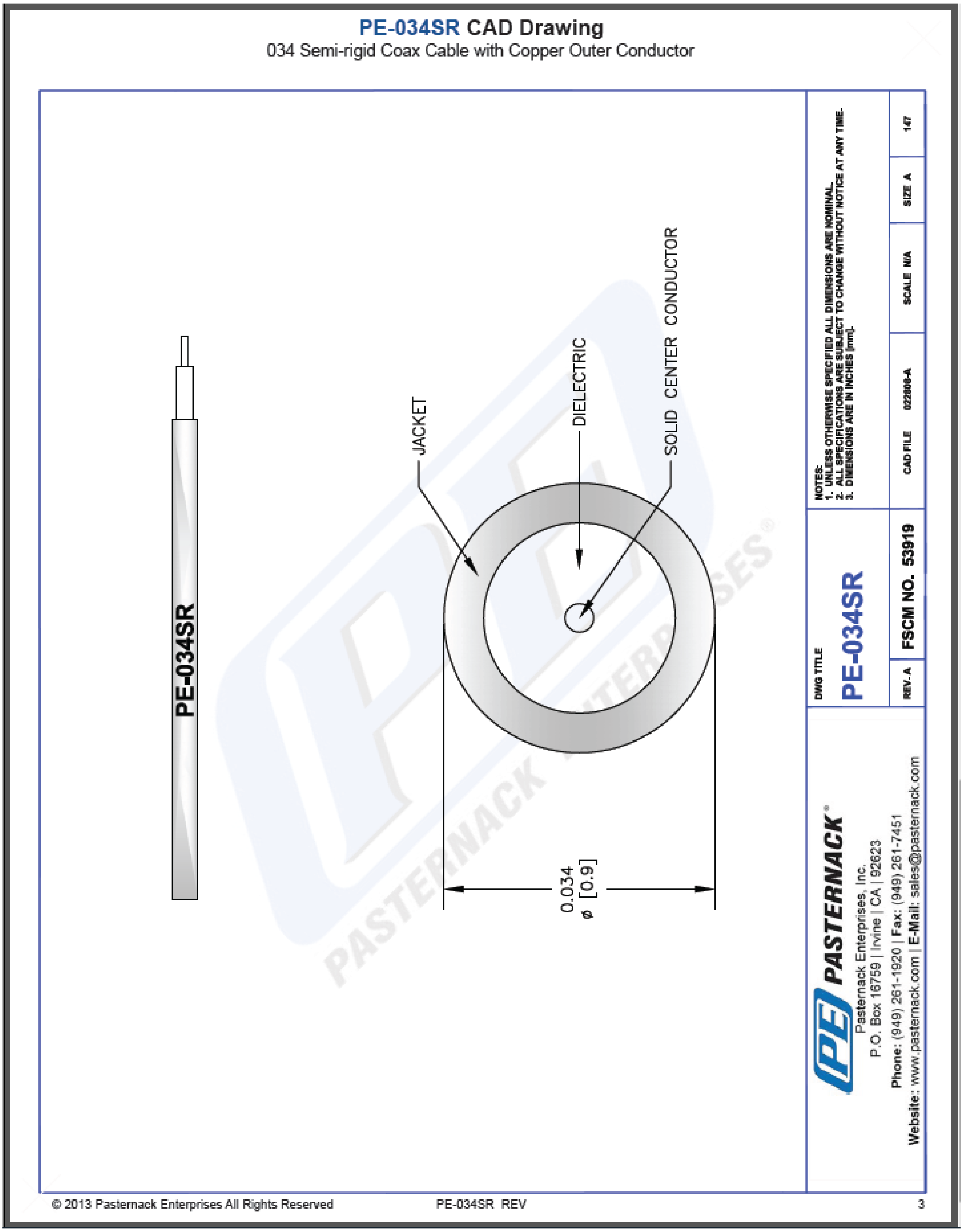
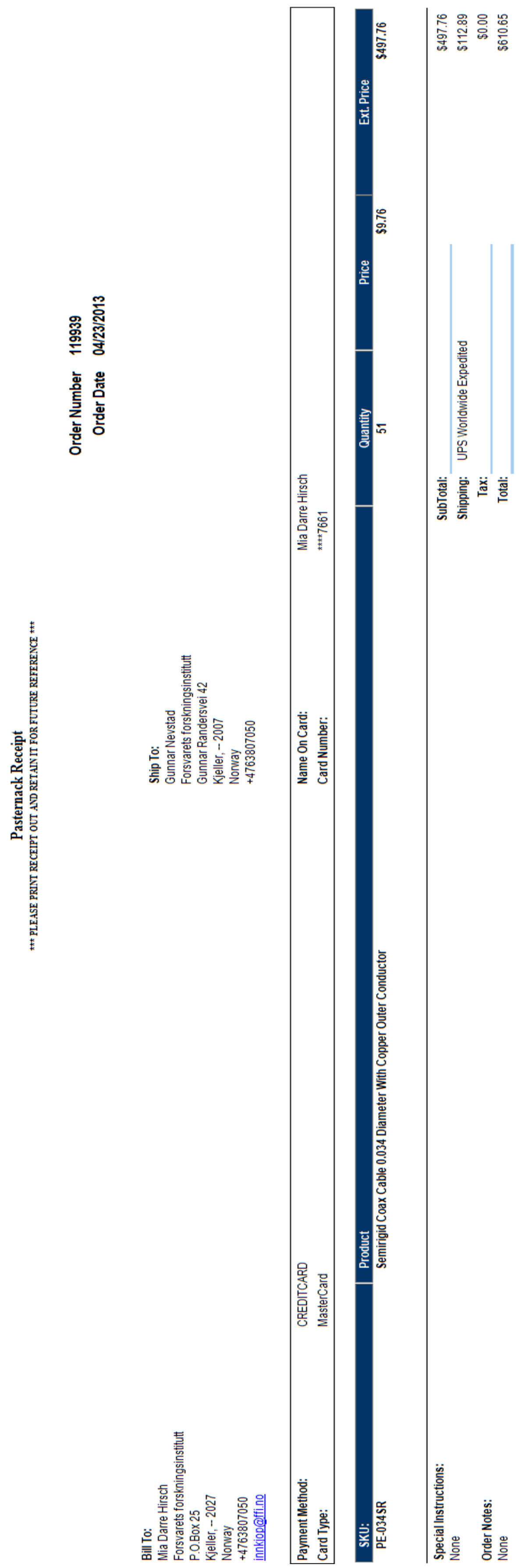


Figure A.3 Page No 3 in the product sheet for the coaxial cable used to produce the ionization pins.



Pasternack Receipt

*** PLEASE PRINT RECEIPT OUT AND RETAIN IT FOR FUTURE REFERENCE ***

Order Number 119939
Order Date 04/23/2013

Bill To:
Mia Darre Hirsch
Forsvarets forskningsinstitutt
P.O.Box 25
Kjeller, -- 2027
Norway
+4763807050
innkjop@ffi.no

Ship To:
Gunnar Nevstad
Forsvarets forskningsinstitutt
Gunnar Randersvei 42
Kjeller, -- 2007
Norway
+4763807050

Payment Method:	CREDITCARD	**Name On Card:**	Mia Darre Hirsch
Card Type:	MasterCard	**Card Number:**	****7661

SKU:	Product	Quantity	Price	Ext. Price
PE-034SR	Semirigid Coax Cable 0.034 Diameter With Copper Outer Conductor	51	$9.76	$497.76

Special Instructions:
None

Order Notes:
None

SubTotal:		$497.76
Shipping:	UPS Worldwide Expedited	$112.89
Tax:		$0.00
Total:		$610.65

Figure A.4 Picture of the order of the ionization pin material.

Appendix B Connection cable

The below Figure gives the type and cost of the coaxial cable used between the switch box and the ionization pins.

A Datwyler Company

ELFA DISTRELEC

Ordrebekreftelse

1 (1)

Fakturaadresse
FFI Forsvarets Forskningsinstitutt
Postboks 25
2027 KJELLER

Godsadresse
Forsvarets Forskningsinstitutt
Gunnar Randers vei 42
2007 KJELLER

Ordrenummer	74219248
Ordredato	2013.05.13
Kundenummer	1150975
Customer Name	ffi innkjøp
Din referanse	120131389

Vilkår

Betalingsvilkår	30 dgr netto		Valuta	NOK
Leveringsvilkår	Normal to door	Fraktfritt	Antall posisjoner	1

Pos	Beskrivelse	Artikkelnr / Antall	Pris per stykk	Discount %	Pris
1	Koaxialkabel 50Ohm 1 core	55-909-14 500 M	8,00	10%	**3 600,00**
	Produsentens art.nr RG-174				
	Beregnet sendt fra vårt lager	2013.05.13			
	Oppfyller RoHS-direktivet				

Pristype	Kurs	Enhet	Per	Basis	Verdi
Rabatter ELFA	- 10,00	%		4 000,00	- 400,00
Sum EKS. MVA					3 600,00
MVA	25,00	%		3 600,00	900,00

15:57:03 2013.05.13 CHBM

Totalsum	**4 500,00**

Elfa Distrelec AS, Postboks 414, 1411 Kolbotn
Telefon: 23 12 49 00 - Telefaks: 23 12 49 20 - E-post: norge@elfa.se
Org.nr. 958 975 260

Figure B.1 Picture of the order for the Coaxial cable between the ionization pins and the switch box.

Appendix C HWC control report

The explosive used for testing of the equipment was produced by Chemring Nobel. Below figure shows the control report or analysis certificate of the explosive.

DYNO
High Energy Materials

KONTROLLRAPPORT B
etter EN 10204 - 3.1 B

Kjøper/Mottaker Forsvarets Forskningsinstitutt Avd. for våpen og matriell Postboks 25, 2007 Kjeller	Bestillingsnummer V/ Gunnar Nevstad Bestillingsdato 19.08.05	Rapportnummer 372 Kontrolldato 24.08.05
Produsent Dyno Nobel ASA N-3476 Sætre NORWAY	Produksjonsdato 04-05.04	Offentlig oppdragsnummer
Lot nummer	Mengde 20 kg	
Sprengstofftype **RDX/VOKS/GRAFITT, 94,5/4,5/1**	Leveringsbetingelser/Teknisk underlag	

Analyseresultater for loten

	Sammensetning			HMX i RDX	Surhet	Fuktighet og flyktige bestanddeler
	RDX	Voks	Grafitt			
KRAV	94,5 ± 0,5 %	4,5 ± 0,5 %	1.0 ± 0,2 %	4 -15 %	≤ 0,02 %	≤ 0,1%
RESULTAT 08/02	94,7	4,4	0,9	6,1	0,00	0,01

	Uløste partikler på USSS No. 60	Vacuum stabilitet	Volumvekt	Kornfordeling %, USSS No.		
				> 12	> 18	< 100
KRAV	Ingen	≤ 1,2 ml/g	0,86 - 0,93g/ml	0	≤ 2	≤ 1
RESULTAT 08/02	ingen	0,05	0,88	0	0	0,8

Kvalitetssjef

DYNO
High Energy Materials
Manager QA

Figure C.1 Control report for the HWC explosive batch tested.

Appendix D Cheetah calculations

D.1 BKWS product library

Product library title: bkws library
Reactant library title: # Version 2.0 by P. Clark Souers

The composition:

Name	% wt.	% mol	% vol	Heat of formation (cal/mol)	Mol. wt.	TMD (g/cc)	
rdx	88.92	78.18	84.36	16496	222.13	1.81	c3h6n6o6
paraffin	4.40	3.38	9.70	-128107	254.48	0.78	c18h38
graphite	0.90	14.63	0.73	0	12.01	2.10	c1
hmx	5.78	3.81	5.20	17866	296.17	1.91	c4h8n8o8

Product library title: bkws library

<u>Density = 1.7135 g/cc</u> Mixture TMD = 1.7135 g/cc % TMD = 100.0000

The C-J condition:
The pressure = 29.44 GPa
The volume = 0.446 cc/g
The density = 2.242 g/cc
The energy = 3.47 kJ/cc explosive
The temperature = 3876 K
The shock velocity = 8.537 mm/us
The particle velocity = 2.013 mm/us
The speed of sound = 6.525 mm/us
Gamma = 3.242

Cylinder runs: % of standards

V/V0 (rel.)	Energy (kJ/cc)	TATB 1.83g/cc	PETN 1.76g/cc	HMX 1.89g/cc	CL-20 2.04g/cc	TRITON 1.70g/cc
1.00	-1.11					
2.20	-6.21	128	98	83	69	142
4.10	-7.49	129	97	85	71	136
6.50	-8.01	129	97	85	72	131
10.00	-8.36	128	96	85	73	127
20.00	-8.77	128	96	86	74	122
40.00	-9.06	127	95	86	75	117
80.00	-9.29	126	95	87	75	113
160.00	-9.48					

Freezing occurred at T = 2145.0 K and relative V = 1.625
The mechanical energy of detonation = -9.728 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -9.728 kJ/cc

JWL Fit results:
E0 = -10.042 kJ/cc
A = 1014.37 GPa, B = 10.86 GPa , C = 1.62 GPa
R[1] = 4.93, R[2] = 1.11, omega = 0.39
RMS fitting error = 0.99 %

<u>Density = 1.6850 g/cc</u> Mixture TMD = 1.7135 g/cc % TMD = 98.3389

The C-J condition:
The pressure = 28.34 GPa
The volume = 0.453 cc/g
The density = 2.209 g/cc

The energy = 3.36 kJ/cc explosive
The temperature = 3893 K
The shock velocity = 8.420 mm/us
The particle velocity = 1.997 mm/us
The speed of sound = 6.423 mm/us
Gamma = 3.216

Cylinder runs: % of standards

V/V0 (rel.)	Energy (kJ/cc)	TATB 1.83g/cc	PETN 1.76g/cc	HMX 1.89g/cc	CL-20 2.04g/cc	TRITON 1.70g/cc
1.00	-1.07					
2.20	-6.04	124	95	81	67	138
4.10	-7.29	126	94	82	69	132
6.50	-7.81	125	94	83	70	128
10.00	-8.16	125	94	83	71	124
20.00	-8.56	125	93	84	72	119
40.00	-8.86	124	93	85	73	115
80.00	-9.09	123	93	85	74	110
160.00	-9.27					

Freezing occurred at T = 2145.0 K and relative V = 1.640
The mechanical energy of detonation = -9.520 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -9.520 kJ/cc

JWL Fit results:
E0 = -9.832 kJ/cc
A = 955.08 GPa, B = 10.54 GPa , C = 1.61 GPa
R[1] = 4.92, R[2] = 1.11, omega = 0.39
RMS fitting error = 0.98 %

Density = 1.6710 g/cc Mixture TMD = 1.7135 g/cc % TMD = 97.5219

The C-J condition:
The pressure = 27.81 GPa
The volume = 0.456 cc/g
The density = 2.193 g/cc
The energy = 3.31 kJ/cc explosive
The temperature = 3901 K
The shock velocity = 8.363 mm/us
The particle velocity = 1.990 mm/us
The speed of sound = 6.373 mm/us
Gamma = 3.203

Cylinder runs: % of standards

V/V0 (rel.)	Energy (kJ/cc)	TATB 1.83g/cc	PETN 1.76g/cc	HMX 1.89g/cc	CL-20 2.04g/cc	TRITON 1.70g/cc
1.00	-1.06					
2.20	-5.95	123	94	80	66	136
4.10	-7.20	124	93	81	68	130
6.50	-7.71	124	93	82	69	126
10.00	-8.06	124	93	82	70	123
20.00	-8.46	123	92	83	71	118
40.00	-8.76	122	92	84	72	113
80.00	-8.99	122	92	84	73	109
160.00	-9.17					

Freezing occurred at T = 2145.0 K and relative V = 1.647
The mechanical energy of detonation = -9.418 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -9.418 kJ/cc

```
JWL Fit results:
E0   =       -9.729 kJ/cc
A    =       927.45 GPa, B    =     10.39 GPa , C     =      1.60 GPa
R[1] =         4.92,     R[2] =      1.11,      omega =      0.39
RMS fitting error =   0.97 %
```

D.2 BKWC product library

```
Product library title: bkwc
Reactant library title: # Version 2.0 by P. Clark Souers

The composition:
Name      % wt.   % mol  % vol    Heat of     Mol.   TMD
                                 formation    wt.    (g/cc)
                                 (cal/mol)
rdx        88.92  78.18  84.36    16496   222.13     1.81 c3h6n6o6
paraffin    4.40   3.38   9.70  -128107   254.48     0.78 c18h38
graphite    0.90  14.63   0.73        0    12.01     2.10 c1
hmx         5.78   3.81   5.20    17866   296.17     1.91 c4h8n8o8
```

Density = 1.7135 g/cc

```
Mixture TMD =  1.7135 g/cc   % TMD = 100.0000

The C-J condition:
The pressure          =          28.54 GPa
The volume            =          0.440 cc/g
The density           =          2.272 g/cc
The energy            =           3.51 kJ/cc explosive
The temperature       =           3962 K
The shock velocity    =          8.233 mm/us
The particle velocity =          2.023 mm/us
The speed of sound    =          6.210 mm/us
Gamma                 =          3.069

Cylinder runs:             % of standards
  V/V0     Energy    TATB     PETN      HMX    CL-20   TRITON
 (rel.)   (kJ/cc)  1.83g/cc 1.76g/cc 1.89g/cc 2.04g/cc 1.70g/cc
   1.00    -1.06
   2.20    -5.87     121       92       79       65      135
   4.10    -7.11     122       92       80       67      129
   6.50    -7.64     123       92       81       69      125
  10.00    -7.99     123       92       82       70      122
  20.00    -8.41     122       92       83       71      117
  40.00    -8.73     122       92       83       72      113
  80.00    -8.97     122       92       84       73      109
 160.00    -9.16

Freezing occurred at T =     2145.0 K and relative V =   1.652
The mechanical energy of detonation =     -9.432 kJ/cc
The thermal energy of detonation    =     -0.000 kJ/cc
The total energy of detonation      =     -9.432 kJ/cc

JWL Fit results:
E0   =       -9.774 kJ/cc
A    =       813.06 GPa, B    =       9.53 GPa , C    =        1.64 GPa
R[1] =         4.75,     R[2] =       1.10,      omega =        0.38
RMS fitting error =   0.74 %
```

Density = 1.6850 g/cc

```
Mixture TMD =  1.7135 g/cc   % TMD = 98.3389

The C-J condition:
```

The pressure = 27.39 GPa
The volume = 0.448 cc/g
The density = 2.234 g/cc
The energy = 3.37 kJ/cc explosive
The temperature = 3974 K
The shock velocity = 8.132 mm/us
The particle velocity = 1.999 mm/us
The speed of sound = 6.132 mm/us
Gamma = 3.067

Cylinder runs: % of standards

V/V0 (rel.)	Energy (kJ/cc)	TATB 1.83g/cc	PETN 1.76g/cc	HMX 1.89g/cc	CL-20 2.04g/cc	TRITON 1.70g/cc
1.00	-1.03					
2.20	-5.70	118	90	76	63	131
4.10	-6.93	119	90	78	66	125
6.50	-7.45	120	90	79	67	122
10.00	-7.80	120	90	80	68	119
20.00	-8.21	120	90	81	69	115
40.00	-8.52	119	90	81	70	110
80.00	-8.76	119	90	82	71	106
160.00	-8.95					

Freezing occurred at T = 2145.0 K and relative V = 1.664
The mechanical energy of detonation = -9.222 kJ/cc
The thermal energy of detonation = -0.000 kJ/cc
The total energy of detonation = -9.222 kJ/cc

JWL Fit results:
E0 = -9.561 kJ/cc
A = 782.18 GPa, B = 9.27 GPa , C = 1.63 GPa
R[1] = 4.76, R[2] = 1.10, omega = 0.38
RMS fitting error = 0.75 %

Density = 1.6710 g/cc Mixture TMD = 1.7135 g/cc % TMD = 97.5219

The C-J condition:
The pressure = 26.84 GPa
The volume = 0.451 cc/g
The density = 2.216 g/cc
The energy = 3.30 kJ/cc explosive
The temperature = 3979 K
The shock velocity = 8.082 mm/us
The particle velocity = 1.988 mm/us
The speed of sound = 6.094 mm/us
Gamma = 3.066

Cylinder runs: % of standards

V/V0 (rel.)	Energy (kJ/cc)	TATB 1.83g/cc	PETN 1.76g/cc	HMX 1.89g/cc	CL-20 2.04g/cc	TRITON 1.70g/cc
1.00	-1.01					
2.20	-5.62	116	89	75	62	129
4.10	-6.84	118	89	77	65	124
6.50	-7.35	118	89	78	66	120
10.00	-7.70	118	89	79	67	117
20.00	-8.12	118	89	80	68	113
40.00	-8.43	118	89	80	69	109
80.00	-8.66	118	89	81	70	105
160.00	-8.85					

Freezing occurred at T = 2145.0 K and relative V = 1.670

```
The mechanical energy of detonation =     -9.119 kJ/cc
The thermal energy of detonation    =     -0.000 kJ/cc
The total energy of detonation      =     -9.119 kJ/cc

JWL Fit results:
E0   =        -9.533 kJ/cc
A    =        770.87 GPa, B    =     9.22 GPa , C     =    1.44 GPa
R[1] =          4.77,     R[2] =     1.06,      omega =    0.35
RMS fitting error =   0.96 %
```