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English summary

Five compositions containing five different GA/BAMO binders with HMX as filler have been studied in pressing. From the obtained pressed pellets, test items for determination of detonation velocity and detonation pressure have been glued together to get test items with required length.

The obtained densities for the majority of the pellets were 97% of TMD (Theoretical Maximum Density) or higher, an acceptable density for this material containing granulates with small diameter. The lowest pellet density compared to TMD was obtained for Sats-258/13. This composition contains less binder than the four other compositions. Sats-258/13 has only 3.0 wt% binder and this gives a dryer powder. For this composition the density of the pellets was on average 1.77 g/cm3 or 95.2% TMD. This TMD is approximately 2% lower than for the four other compositions. However, the density of the pellets is not far from the density of the pellets of the other compositions.

For the three final compositions, which all contain 5.3–5.7 wt% binder, we obtained more or less the same pellet density. From the pressing experiments where different press pressures, diameters of tool and amount of powder (height of pellet) had been used, we concluded that Sats-400/13 and Sats-432/13 should be selected for the final fragmentation study.

For all five compositions, detonation velocity and detonation pressure were determined. Except for composition Sats-230/13, three tests were performed for all compositions. For Sats-230/13 only one test was performed. This test showed lower detonation velocity and detonation pressure than the four other compositions. For the remaining four compositions the variation in detonation velocity and detonation pressure between the three parallels and between the different compositions was moderate. Sats-400/13 gave the highest average detonation velocity of 8669+14 m/s and the lowest detonation pressure with 281.5+2.3 kbar. The results with regard to detonation velocity and detonation pressure were for Sats-258/13 8534+16 m/s and 284+14 kbar, for Sats 430/13 8506+6 m/s and 291.1+11.6 kbar, and for Sats-432/13 8583+47 m/s and 284.2+5.5 kbar.

Sammendrag

Fem komposisjoner med fem ulike polymerer, to med GA/BAMO og tre med GA/BAMO/IPDI samt HMX, har vært studert med hensyn på presseegenskaper. Pressede legemer ble limt sammen til testenheter med tilstrekkelig lengde til bestemmelse av detonasjonshastighet og detonasjonstrykk.

Oppnådde tettheter for majoriteten av de pressede legemene var 97 % av TMD eller høyere, en akseptabel tetthet for det benyttede granulatet som var noe tørt og finkornet. Lavest tetthet sammenlignet med TMD ble oppnådd for legemene av Sats-258/13. Denne komposisjonen inneholder mindre bindemiddel enn de fire andre komposisjonene. I Sats-258/13 er det kun tre vektprosent bindemiddel, noe som gir et tørrere pressepulver. Legemene med Sats-258/13 har en tetthet på 1,77 g/cm3 eller 95,2 % TMD. Det er en 2 % lavere TMD enn for de resterende komposisjonene, men tettheten på selve legemene er om lag den samme som for de andre komposisjonene.

For de tre komposisjonene i den avsluttende karakteriseringen, hvor alle hadde et bindemiddelinnhold på 5,3–5,7 vektprosent, oppnådde vi mer eller mindre identisk tetthet. Fra pressestudiene, hvor forskjellige pressetrykk, diameter på presseverktøy samt mengde pulver (høyde på legeme) ble variert, ble det konkludert med at Sats-400/13 samt Sats-432/13 var enklest å presse, og disse ble valgt som fylling i 40 mm granater for fragmenteringsstudier.

For alle de fem komposisjonene er detonasjonshastighet og detonasjonstrykk bestemt. Tre tester ble gjennomført for all komposisjonene med unntak av Sats-230/13, hvor kun én test ble gjennomført. Sats-230/13 ga lavere detonasjonshastighet og detonasjonstrykk enn de fire resterende komposisjonene. For disse var variasjonen i detonasjonshastighet og detonasjonstrykk mellom de tre parallellene og de ulike komposisjonene moderat. Sats-400/13 har høyest gjennomsnittlig detonasjonshastighet på 8669+14 m/s og lavest detonasjonstrykk på 281,5+2,3 kbar. Resultatene med hensyn til detonasjonshastighet og detonasjonstrykk var for Sats-258/13 8534+16 m/s og 284+14 kbar, for Sats-430/13 8506+6 m/s og 291,1+11,6 kbar, og for Sats-432/13 8583+47 m/s og 284,2+5,5 kbar.

Contents

Abbreviations

BAMO	3,3-bis(azidomethyl) oxetane, $C_5H_8N_6O$
GA	Glycidyl azide, $C_3H_5N_3O$
GA/BAMO	Glycidyl azide/3,3-bis(azidomethyl)oxetane Copolymers
GA/BAMO/IPDI	Glycidyl azide/3,3-bis(azidomethyl)oxetane/ Isophorone diisocyanate
GAP	Glycidyl azide polymer, $(C_3H_5N_3O)_n$
HMX	Octogen/1,3,5,7-tetranitro-1,3,5,7-tetrazacyclooctane, $C_4H_8N_8O_8$
HWC	Hexogen/Wax/Graphite (94.5/4.5/1)
IM	Insensitive Munitions
IPDI	Isophorone diisocyanate, $C_{12}H_{18}N_2O_2$
RDX	Hexogen/1,3,5-trinitro-1,3,5-trizacyclohexane, $C_3H_6N_6O_6$
TMD	Theoretical Maximum Density

1 Introduction

In the EDA project No B-0585-GEM2-GC “Formulation and Production of New Energetic Materials” compositions containing GA/BAMO polymers have been studied. Norway’s main activity in the project has been on synthesizing different GA/BAMO polymers suitable for coating nitramines for production of press granules for press filling of munitions units. The compositions we produced have high content of HMX with primary applications as boosters and main filling for shaped charges.

Norway was the only country that used the energetic binder for explosive charges. Italy and Germany used their polymers in propellant formulations (1-4). The required properties for binders for coating crystals to produce granules are different from what is required for a binder to be used in cast-cure compositions. For cast-cure compositions the binder must be a liquid, and also after 80-90 wt. % of filler is added the composition must be castable. The GA/BAMO binder consists of two binders, GAP which is soft (liquid) and BAMO which is a solid when polymerized. The ratio between these two building units determines the properties of the combined polymer. For cast-cure applications 70-75/30-25 ratio between GA/BAMO gives polymers with required viscosity. For coating of crystals to prepare press granules we need rubbery polymers, not liquid. In the synthesis of polymers, polymers with ratio of GA/BAMO up to 25-30/75-70 were produced. These polymers have very high viscosity close two what we see as optimal for our use. However, the solubility of these binders in normal solvents is low. Especial not azidated pre-polymers had low solubility and were difficult to purify when the content of BAMO were more than 60 wt. %. Therefore changing the properties of the polymer had to be done by partly curing. Coupling of polymer chains were performed with curing by IPDI. Not all polymers chains contained hydroxyl end groups and could take part in chain elongation. However, these molecules could function as plasticizer. By performing partly curing we obtained a polymer with the consistence we were looking for.

The coating of HMX was performed in a two phase slurry process with HMX and polymer in two separate phases. Five of the polymers, two with only GA/BAMO and three where IPDI had been added for chain elongation, were used to coat HMX crystals. Obtained granulates were in general small, but applicable for pressing charges for characterization.

In this report we have studied conditions for pressing of pellets. Different tools and press conditions have been applied to obtain optimal pellet density. Obtained pellets have been used to characterize the performance of the compositions by measuring detonation velocity and detonation pressure. The test items used for these determinations were produced by gluing together 15-20 pellets to obtain test items with the required length.

Detonation velocity was measured by use of 4-6 ionization pins (5). Detonation pressure was determined by use of the Plate Dent test (6).

2 Experimentally

2.1 Press powder

All powders used or tested in this report were produced by Chemring Nobel. The binders were produced either by FFI or Chemring Nobel. Press powders made from 5 different binders with different content of HMX were tested. Table 2.1 summarizes the content of tested compositions.

Composition	Binder				HMX
	Components	Content GA/BAMO	Wt. %	Synthesized at	Wt. %
Sats-230/13	GA/BAMO	40/60	5.72	FFI	94.28
Sats-258/13	GA/BAMO/IPDI (I)	40/60	3.0	FFI	97.0
Sats-400/13	GA/BAMO/IPDI (II)	40/60	5.3	FFI	94.7
Sats-430/13	GA/BAMO	30/70	5.7	Chemring	94.3
Sats-432/13	GA/BAMO/IPDI	50/50	5.7	FFI	94.3

Table 2.1 Content of tested compositions containing different energetic binders and HMX.

2.2 Pressing of pellets

2.2.1 Initial testing

Two compositions were first studied with regard to pressing properties and performance. For these two compositions, Sats-258/13 and Sats-230/13, pellets were pressed under different conditions. Parameters as press pressure, amount of powder, dwell time and press tool were studied. A new tool with diameter 16.14 mm was produced for the initial press experiments.

2.2.1.1 Sats-258/13

The first composition we tested with regard to pressability was Sats-258/13. A new tool was produced, Figure 2.1. Pressing was performed with a 10 tons press shown in Figure 2.1. The initial pressing was performed with 5 g samples. Applied pressure was 5 tons on the press with a dwell time of 60 seconds. Picture of obtained pellets is shown in Figure 2.2. Table 2.2 gives measured properties with regard to dimensions and calculated density of the obtained pellets. As the results of density measurements show, the reproducibility with regard to density is good. However, the mechanical properties of the pellets were moderate. The surface inside the tool was not as smooth as we expected. This gave some problems when the pellets were pressed out from the bolt. Some pellets had tendency to slice due to no continuous movement during the press out process of the tool bolt. This gave reduced pellet density. Trials with increasing the press pressure gave no significant increase of the pellet density. The same result was obtained by changing the amount of powder. However, polishing the surface inside the bolt with graphite increased the density of the pellets as shown in Table 2.3 and 2.4.

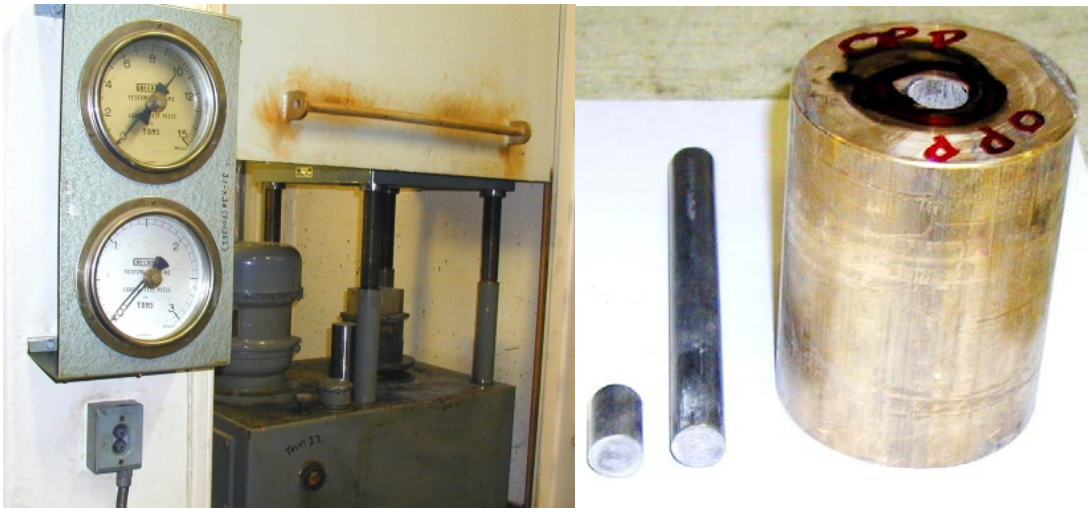
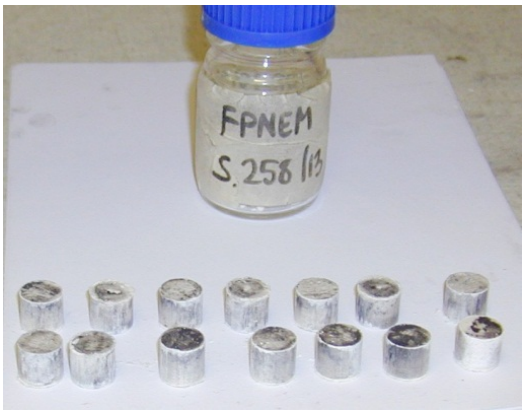


Figure 2.1 Pictures of applied press and tool for initial press study of composition Sats-258/13.



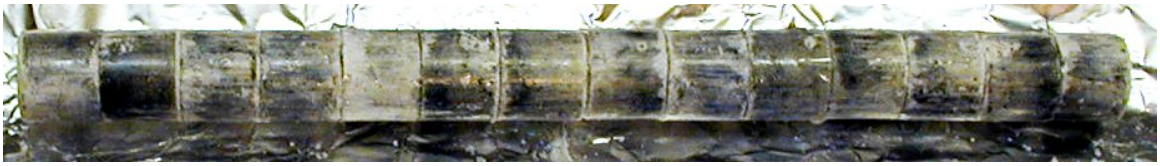


Figure 2.2 The figure shows pictures of the pellets obtained of composition Sats-258/13.

We have not determined the experimental density of the binder, but if we use 1.1 g/cm^3 the pellets in Table 2.2 -2.4 have an average density of 94.28%, 95.24% and 95.14% of TMD. These numbers could have been higher, but is acceptable. The low binder content of 3 wt. % may be the main explanation for the relative moderate obtained density for pellets of this composition.

Pellet No	Weight (g)	Height (mm)	Diameter (mm)	Volume (mm^3)	Density (g/cm^3)
1	5.0972	14.36	16.14	2938.0	1.735
2	4.9524	13.92	16.13	2844.4	1.741
3	4.9095	13.74	16.13	2807.7	1.749
4	4.9905	13.97	16.13	2854.7	1.748
5	4.8241	13.52	16.13	2762.7	1.746
6	4.9090	13.65	16.13	2789.3	1.760
7	5.4366	15.23	16.13	3112.1	1.747
8	4.9611	13.78	16.13	2815.8	1.762
9	5.1801	14.44	16.12	2947.0	1.758
10	5.1664	14.42	16.14	2950.3	1.751
11	4.9741	13.84	16.13	2828.1	1.759
12	5.0355	13.99	16.13	2858.8	1.761
13	4.9582	13.82	16.13	2824.0	1.756
14	4.8993	13.54	16.14	2770.2	1.769
	Average density				**1.753±0.009**

Table 2.2 Properties of pressed pellets containing Sats-258/13 pressed with 5 tons pressure and a dwell time of 60 seconds, initial pressing.

Pellet No	Weight (g)	Height (mm)	Diameter (mm)	Volume (mm^3)	Density (g/cm^3)
1	5.4123	15.04	16.11	3065.69	1.765
2	5.4465	15.08	16.11	3073.85	1.772
3	5.5370	15.26	16.11	3110.54	1.780
4	5.6385	15.60	16.12	3183.79	1.771
5	5.3796	14.90	16.13	3044.70	1.767
6	5.2781	14.58	16.12	2975.62	1.774
7	5.4531	15.05	16.10	3063.93	1.780
8	5.3858	14.88	16.13	3040.62	1.771
9	5.4980	15.23	16.13	3112.14	1.767
10	5.3156	14.75	16.13	3014.05	1.764
11	5.4953	15.15	16.13	3095.79	1.775
12	5.4975	15.25	16.12	3112.36	1.766
13	5.4536	15.10	16.11	3077.92	1.772
14	5.3701	14.85	16.12	3030.72	1.772
15	5.3226	14.71	16.11	2998.43	1.775
16	5.5291	15.32	16.14	3134.41	1.764
17	5.4208	15.00	16.13	3065.14	1.769
	Average density				**1.771±0.005**

Table 2.3 Properties of pressed pellets containing Sats-258/13 pressed with 5 tons pressure and a dwell time of 60 seconds, 5 g pellets.

Pellet No	Weight (g)	Height (mm)	Diameter (mm)	Volume (mm^3)	Density (g/cm^3)
1	5.0695	14.04	16.14	2872.53	1.765
2	5.0676	14.04	16.13	2868.97	1.766
3	5.1158	14.15	16.13	2891.45	1.769
4	5.0302	13.92	16.10	2833.88	1.775
5	5.0351	13.94	16.13	2848.53	1.768
6	5.1138	14.10	16.13	2881.23	1.775
7	5.0400	13.92	16.13	2844.45	1.772
8	5.0266	13.94	16.13	2848.53	1.765
9	5.0656	14.06	16.13	2873.05	1.763
10	5.0521	13.98	16.13	2856.71	1.769
11	5.1343	14.19	16.13	2899.62	1.771
12	5.0062	13.87	16.11	2827.21	1.771
13	5.0378	13.93	16.12	2842.96	1.772
14	5.1511	14.26	16.13	2913.92	1.768
15	5.1349	14.21	16.13	2903.71	1.768
16	5.0864	14.06	16.12	2869.49	1.773
17	5.0929	14.10	16.13	2881.23	1.768
18	5.0646	14.03	16.12	2863.37	1.769
19	5.0796	14.02	16.13	2864.88	1.773
	Average density				**1.769±0.003**

Table 2.4 Properties of pressed pellets containing Sats-258/13 pressed with 5 tons pressure and a dwell time of 60 seconds, 5.4 g pellets.

2.2.1.2 Sats–230/13

The second composition we tested was Sats-230/13. This composition contained 5.72 wt. % GA/BAMO (40/60) polymer and 94.28 wt. % HMX. The pellets were pressed with a pressure of 5 tons and a dwell time of 60 seconds. Most pellets contained 5 g powder, but two with 6 g were also pressed. The later ones had slightly higher density than the first ones. Figure 2.3 shows a picture of the pressed pellets and Table 2.5 gives all dimensions and the calculated density of each pellet. The density of the pellets are relatively homogenous and of the same magnitude as for Sats-258/13. However, since the amount of binder is nearly doubled, the TMD for Sats-230/13 is lower than for Sats-258/13, and the average density of the pellets is 97.36 % of TMD. This is significantly higher than for Sats-258/13.

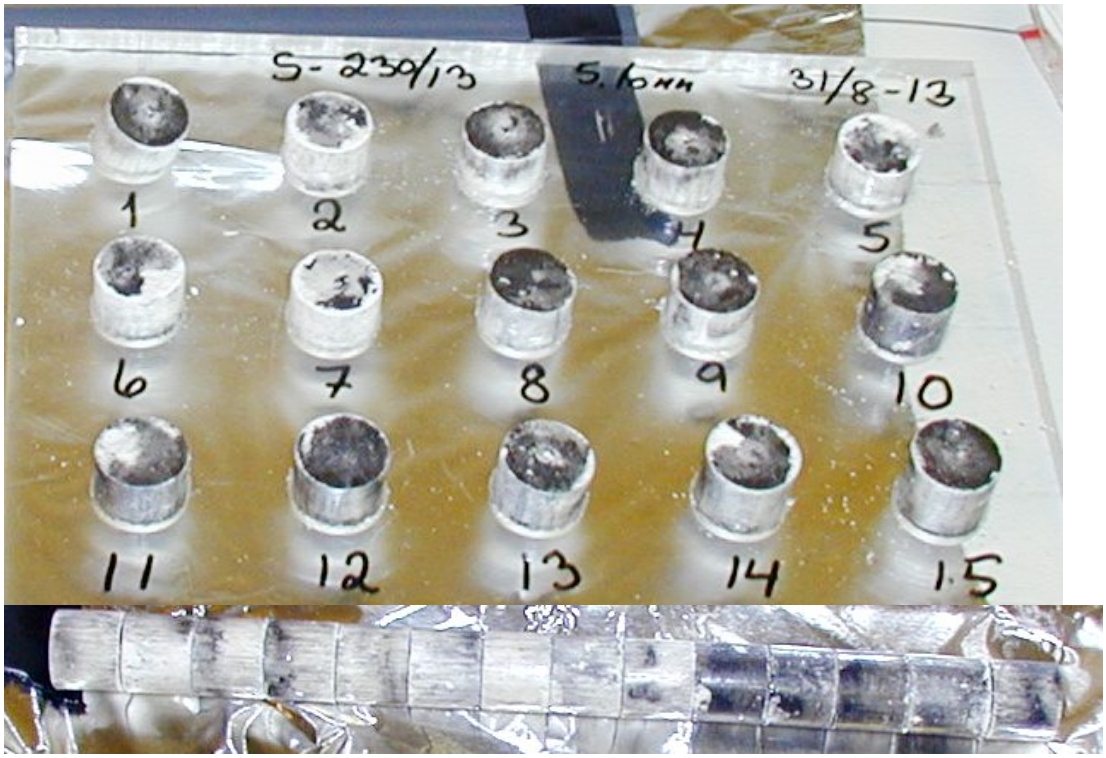


Figure 2.3 Pellets of Sats-230/13 pressed for testing of detonation velocity and pressure.

Pellet No	Weight (g)	Height (mm)	Diameter (mm)	Volume (mm^3)	Density (g/cm^3)
1	5.0412	13.99	16.02	2819.89	1.788
2	5.1202	14.25	16.02	2872.30	1.783
3	5.1694	14.40	16.00	2895.29	1.785
4	5.0801	14.15	16.00	2845.03	1.786
5	5.1595	14.30	16.00	2875.19	1.794
6	5.1387	14.27	16.11	2908.74	1.767
7	4.9844	13.90	16.07	2819.27	1.768
8	5.1001	14.20	16.13	2901.66	1.758
9	5.1886	14.44	16.10	2939.74	1.765
10	5.3367	14.86	16.11	3029.00	1.762
11	4.8317	13.35	16.11	2721.21	1.776
12	5.2517	14.55	16.11	2965.81	1.771
13	5.0359	14.05	16.09	2856.79	1.763
14	6.0909	17.00	16.03	3430.88	1.775
15	6.0434	16.75	16.00	3367.79	1.794
	Average density				**1.776±0.012**

Table 2.5 Properties of pressed pellets containing Sats-230/13 pressed with 5 tons pressure and a dwell time of 60 seconds.

2.2.2 Final testing

Before the filling of two 40 mm shells for the fragmentation study, a press study of three compositions was carried out. The two compositions with the best pressing properties were selected to be filled into the 40 mm shells. The contents of the three compositions are given in Table 2.1.

2.2.3 Sats-400/13

Sats-400/13 containing 5.3 wt. % 40/60 GA/BAMO (2) + IPDI and 94.7 wt. % HMX was pressed under different conditions. Properties of pellets pressed with press pressures 5 and 6 tons and a dwell time of 60 seconds, on 2/9-13 and 7/1-14, are given in Table 2.6. The three average densities of the pellets in Table 2.6 correspond to 97.40, 97.08 and 97.57 % of TMD. Pellets 1-6 were pressed with

No	Weight (g)	Height (mm)	Diameter (mm)	Volume (mm^3)	Density (g/cm^3)
1	5.9247	16.30	16.16	3343.18	1.772
2	5.7364	15.78	16.16	3236.53	1.772
3	5.7387	15.76	16.15	3228.43	1.778
4	5.5878	15.34	16.15	3142.39	1.778
5	5.6888	15.60	16.16	3199.61	1.778
6	5.6917	15.63	16.15	3201.80	1.778
7	5.44	14.82	16.15	3035.87	1.792
8	5.04	13.79	16.15	2824.87	1.784
9	5.18	14.14	16.17	2903.75	1.784
10	5.24	14.30	16.17	2936.61	1.784
11	5.26	14.34	16.17	2944.82	1.786
12	5.10	13.93	16.17	2860.63	1.783
13	5.19	14.15	16.17	2905.80	1.786
14	5.22	14.26	16.17	2928.39	1.783
15	5.43	14.81	16.17	3041.34	1.785
16	5.32	14.53	16.16	2980.15	1.785
17	5.19	14.17	16.17	2909.91	1.784
18	5.28	14.43	16.17	2963.30	1.782
19	5.41	14.77	16.17	3033.13	1.784
	Average density all 1-6 7-19				**1.782±0.005 1.776±0.003 1.785±0.003**

Table 2.6 Properties of pellets containing Sats-400/13 composition pressed with 5 and 6 tons pressure.

5 tons press pressure. Pellets 7-19 were pressed with 6 tons press pressure. Increasing the press pressure gave for this composition a slightly better density in the 16.17 mm tool. Properties of pellets with a diameter of 18.66 mm pressed with a press pressure of 6 tons and a dwell time of 60 seconds on 10/11-13 and 8/1-14 are given in Table 2.7. Figure 2.4 shows the charges produced for testing of detonation velocity and pressure. The average density of the pellets in Table 2.7 corresponds to 97.19 % of TMD. This density is slightly lower than for the pellets with diameter 16.17 mm. However, the difference is within the standard deviation.

No	Weight (g)	Height (mm)	Diameter (mm)	Volume (mm^3)	Density (g/cm^3)
1	7.77	15.92	18.67	4358.34	1.783
2	7.61	15.60	18.67	4270.74	1.782
3	7.76	15.92	18.67	4358.34	1.780
4	7.53	15.43	18.67	4224.20	1.783
5	7.58	15.60	18.67	4270.74	1.775
6	7.66	15.72	18.67	4303.59	1.780
7	7.63	15.72	18.67	4303.59	1.773
8	7.66	15.72	18.67	4303.59	1.780
9	7.70	15.78	18.67	4320.02	1.782
10	7.73	15.84	18.67	4336.44	1.783
11	7.53	15.43	18.67	4224.20	1.783
12	7.66	15.68	18.67	4292.64	1.784
13	7.66	15.70	18.67	4298.12	1.782
14	7.61	15.64	18.67	4281.69	1.777
15	7.75	15.88	18.67	4347.39	1.783
16	7.67	15.73	18.67	4306.33	1.781
17	7.64	15.75	18.67	4311.80	1.772
18	7.86	16.13	18.67	4415.84	1.780
19	7.59	15.50	18.67	4243.36	1.789
20	7.72	15.82	18.67	4330.97	1.783
21	7.62	15.57	18.67	4262.53	1.788
22	7.52	15.44	18.67	4226.94	1.779
23	7.74	15.89	18.67	4350.13	1.779
24	7.73	15.92	18.67	4358.34	1.774
25	7.54	15.49	18.67	4240.63	1.778
26	7.58	15.57	18.67	4262.53	1.778
27	7.49	15.45	18.67	4229.68	1.771
28	7.62	15.75	18.67	4311.80	1.767
29	7.61	15.68	18.67	4292.64	1.773
30	7.72	15.86	18.67	4341.92	1.778
31	7.58	15.65	18.67	4284.43	1.769
32	7.68	15.86	18.67	4341.92	1.769
33	7.75	15.94	18.67	4363.82	1.776
34	7.44	15.34	18.67	4199.56	1.772
	Average density				**1.778±0.001**

Table 2.7 The table shows the properties of 7.6 g pellets containing Sats-400/13 composition.

Figure 2.4 Picture of Sats-400/13 pellets after they were glued together to three test items for determination of detonation velocity and pressure.

2.2.4 Sats-430/13

Sats-430/13 contains 5.7 wt. % 30/70 GA/BAMO and 94.3 wt. % HMX. Pellets with diameter 16.1 mm were pressed with press pressures 5 and 6 tons and a dwell time of 60 seconds on 2/9-13 and 7/1-14. Table 2.8 shows obtained properties and Figure 2.5 shows a picture of the pellets after they were glued together to a test item. The three average densities of the pellets in Table 2.8 correspond to 97.68, 97.35 and 97.79 % of TMD. Pellets 1-5 were pressed with 5 tons press pressure. Pellets 6-22 were pressed with 6 tons press pressure. Increasing the press pressure gave slightly higher pellet density in the 16.14 mm tool.

No	Weight (g)	Height (mm)	Diameter (mm)	Volume (mm^3)	Density (g/cm^3)
1	5.9070	16.22	16.16	3326.78	1.776
2	5.6441	15.49	16.16	3177.05	1.777
3	5.6497	15.46	16.14	3163.05	1.786
4	5.4993	15.10	16.14	3089.40	1.780
5	5.9680	16.33	16.14	3341.05	1.786
6	5.16	14.10	16.14	2884.80	1.789
7	5.07	13.86	16.14	2835.70	1.788
8	5.18	14.21	16.14	2907.31	1.782
9	5.18	14.13	16.14	2890.94	1.792
10	5.09	13.87	16.14	2837.75	1.794
11	5.21	14.21	16.14	2907.31	1.792
12	5.19	14.21	16.14	2907.31	1.785
13	5.12	13.95	16.14	2854.11	1.794
14	5.17	14.11	16.14	2886.85	1.791
15	5.12	14.01	16.14	2866.39	1.786
16	5.23	14.18	16.14	2901.17	1.803
17	5.22	14.26	16.14	2917.54	1.789
18	5.29	14.46	16.14	2958.46	1.788
19	5.09	13.93	16.14	2850.02	1.786
20	5.14	14.12	16.14	2888.89	1.779
21	5.24	14.32	16.14	2929.81	1.789
22	5.03	13.70	16.14	2802.96	1.795
	Average density		**All**		**1.787±0.006**
			1 - 5 5 tons press pressure		**1.781±0.005**
			6-22 6 tons press pressure		**1.789±0.005**

Table 2.8 The table gives properties of pellets containing Sats-430/13 composition.

Properties of pellets of Sats-430/13 with diameter 18.66 mm pressed on 10/11-13 and 8/1-14 with a press pressure of 6 tons and a dwell time of 60 seconds are given in Table 2.9. Figure 2.5 shows the two test items produced from these pellets to determinate detonation velocity and pressure. The three average densities of the pellets in Table 2.9 correspond to 97.51, 97.46 and 97.51 % of TMD. The amount of powder in pellets 1-16 was 7.65±0.14 g and for pellets 17-35 5.19±0.11 g. This variation in amount of powder (pellet height) did not change the pellet density.

No	Weight (g)	Height (mm)	Diameter (mm)	Volume (mm^3)	Density (g/cm^3)
1	7.80	16.10	18.66	4402.90	1.772
2	7.81	16.02	18.66	4381.02	1.783
3	7.79	15.98	18.66	4370.09	1.783
4	7.64	15.69	18.66	4290.78	1.781
5	7.58	15.50	18.66	4238.82	1.788
6	7.74	15.92	18.66	4353.68	1.778
7	7.47	15.45	18.66	4225.15	1.768
8	7.72	15.88	18.66	4342.74	1.778
9	7.43	15.31	18.66	4186.86	1.775
10	7.45	15.35	18.66	4197.80	1.775
11	7.48	15.41	18.66	4214.21	1.775
12	7.49	15.34	18.66	4195.06	1.785
13	7.69	15.83	18.66	4329.06	1.776
14	7.74	15.92	18.66	4353.68	1.778
15	7.68	15.81	18.66	4323.60	1.776
16	7.83	16.06	18.66	4391.96	1.783
17	5.29	10.79	18.66	2950.76	1.798
18	5.26	10.73	18.66	2934.36	1.793
19	5.17	10.52	18.66	2876.93	1.797
20	5.03	10.29	18.66	2814.03	1.787
21	5.09	10.32	18.66	2822.23	1.804
22	5.24	10.76	18.66	2942.56	1.781
23	5.30	10.88	18.66	2975.38	1.781
24	5.32	10.89	18.66	2978.11	1.786
25	5.49	11.28	18.66	3084.77	1.780
26	5.15	10.67	18.66	2917.95	1.765
27	5.20	10.78	18.66	2948.03	1.764
28	5.12	10.59	18.66	2896.07	1.768
29	5.13	10.62	18.66	2904.27	1.766
30	5.15	10.66	18.66	2915.21	1.767
31	5.08	10.49	18.66	2868.72	1.771
32	5.09	10.48	18.66	2865.99	1.776
33	5.06	10.46	18.66	2860.52	1.769
34	5.27	10.86	18.66	2969.91	1.774
35	5.26	10.81	18.66	2956.23	1.779
	Average density		**All**		**1.779±0.010**
			1-16		**1.778±0.005**
			17-35		**1.779±0.012**

Table 2.9 Properties of pellets containing Sats-430/13 composition with different weight.

Figure 2.5 Picture of Sats-430/13 pellets after being glued together to three test items for determination of detonation velocity and detonation pressure.

2.2.5 Sats-432/13

Sats-432/13 contains 5.7 wt. % 50/50 GA/BAMO/IPDI and 94.3 wt. % HMX. 16.14 mm pellets were pressed on 2/9-13 and 8/1-14 with press pressures 5 and 6 tons and a dwell time of 60 seconds. Table 2.10 shows obtained properties, and Figure 2.6 shows a picture of the pellets after they were glued together to a test item. Pellets No 1 to No 14 was pressed with a press pressure of 5 tons.

Figure 2.6 Picture of Sats-432/13 pellets after they have been glued together to three test items for determination of detonation velocity and pressure.

Pellet No 15 to No 20 was pressed with a press pressure of 6 tons. Increasing the press pressure for this composition gave a slightly higher pellet density. The three average densities of the pellets in Table 2.10 correspond to 97.40, 97.35 and 97.82 % of TMD.

No	Weight (g)	Height (mm)	Diameter (mm)	Volume (mm^3)	Density (g/cm^3)
1	5.3029	14.53	16.14	2972.78	1.784
2	5.4024	14.92	16.14	3052.57	1.770
3	5.0334	13.86	16.14	2835.70	1.775
4	5.3309	14.68	16.14	3003.47	1.775
5	5.1923	14.26	16.14	2917.54	1.780
6	5.2685	14.51	16.14	2968.69	1.775
7	5.2172	14.32	16.14	2929.81	1.781
8	5.4672	15.04	16.14	3077.12	1.777
9	5.6619	15.58	16.14	3187.60	1.776
10	5.2678	14.52	16.14	2970.73	1.773
11	5.2580	14.47	16.14	2960.50	1.776
12	5.1548	14.26	16.14	2917.54	1.767
13	5.2557	14.45	16.14	2956.41	1.778
14	5.2175	14.37	16.14	2940.04	1.775
15	5.04	13.86	16.14	2835.70	1.777
16	5.46	15.00	16.14	3068.94	1.779
17	5.29	14.53	16.14	2972.78	1.779
18	5.07	13.90	16.14	2843.88	1.783
19	5.01	13.73	16.14	2809.10	1.783
20	5.49	15.02	16.14	3073.03	1.787
	Average density	**All**			**1.777±0.005**
		1-14			**1.776±0.004**
		15-20			**1.781±0.003**

Table 2.10 Properties of pellets containing different weight of Sats-432/13 composition pressed with different press pressure.

Properties of pellets of Sats-432/13 with diameter 18.64 mm pressed on 10/11-13 and 8/1-14 with a press pressure of 6 tons and a dwell time of 60 seconds are given in Table 2.11. Figure 2.6 shows the two test items produced from these pellets to determine detonation velocity and detonation pressure. The obtained average density of 1.782 g/cm^3 corresponds to 97.68 % of TMD with a density of the binder of 1.1 g/cm^3. The density of the pellets with diameter 18.66 mm (1.782+0.011 g/cm^3) is the same as for the pellets with diameter 16.14 mm (1.781+0.003 g/cm^3) pressed under the same conditions. There is no density effect of the difference in tool diameter.

No	Weight (g)	Height (mm)	Diameter (mm)	Volume (mm^3)	Density (g/cm^3)
1	7.54	15.51	18.65	4237.01	1.780
2	7.68	15.87	18.64	4330.71	1.773
3	7.49	15.44	18.64	4213.36	1.778
4	7.55	15.51	18.64	4232.47	1.784
5	7.43	15.39	18.64	4199.72	1.769
6	7.39	15.37	18.64	4194.26	1.762
7	7.81	16.08	18.64	4388.01	1.780
8	7.68	15.83	18.64	4319.79	1.778
9	7.62	15.68	18.64	4278.86	1.781
10	7.59	15.69	18.64	4281.59	1.773
11	7.56	15.52	18.64	4235.20	1.785
12	7.80	16.18	18.64	4415.30	1.767
13	7.72	15.47	18.64	4221.55	1.829
14	7.70	15.87	18.64	4330.71	1.778
15	7.59	15.67	18.64	4276.13	1.775
16	7.64	15.72	18.64	4289.77	1.781
17	7.50	15.52	18.64	4235.20	1.771
18	7.53	15.45	18.64	4216.09	1.786
19	7.65	15.67	18.64	4276.13	1.789
20	7.74	15.92	18.64	4344.35	1.782
21	7.79	15.95	18.64	4352.54	1.790
22	7.86	16.13	18.64	4401.66	1.786
23	7.68	15.71	18.64	4287.04	1.791
24	7.62	15.61	18.64	4259.75	1.789
25	7.71	15.77	18.64	4303.42	1.792
26	7.77	15.92	18.64	4344.35	1.789
27	7.63	15.63	18.64	4265.21	1.789
28	7.88	16.16	18.64	4409.84	1.787
29	7.56	15.57	18.64	4248.84	1.779
30	7.86	16.12	18.64	4398.93	1.787
31	7.86	16.15	18.64	4407.11	1.783
32	7.65	15.73	18.64	4292.50	1.782
33	7.67	15.78	18.64	4306.15	1.781
34	7.75	15.97	18.64	4357.99	1.778
	Average density				**1.782±0.011**

Table 2.11 Properties of pellets containing Sats-432/13 composition.

2.3 Firing conditions – detonation velocity determination

2.3.1 Initial testing

The detonation velocity was measured according to the test procedure described in (5). To collect the registrations from the ionization pins for these initial tests we used a storage scope GDS-3354 from Gwinstek. Figure 2.7 shows the scope after a firing. Table 2.12 summarizes the scope setting used to collect the results. All firings were stored on a memory-pin and transferred to a PC for calculations of detonation velocity by use of EXCEL.

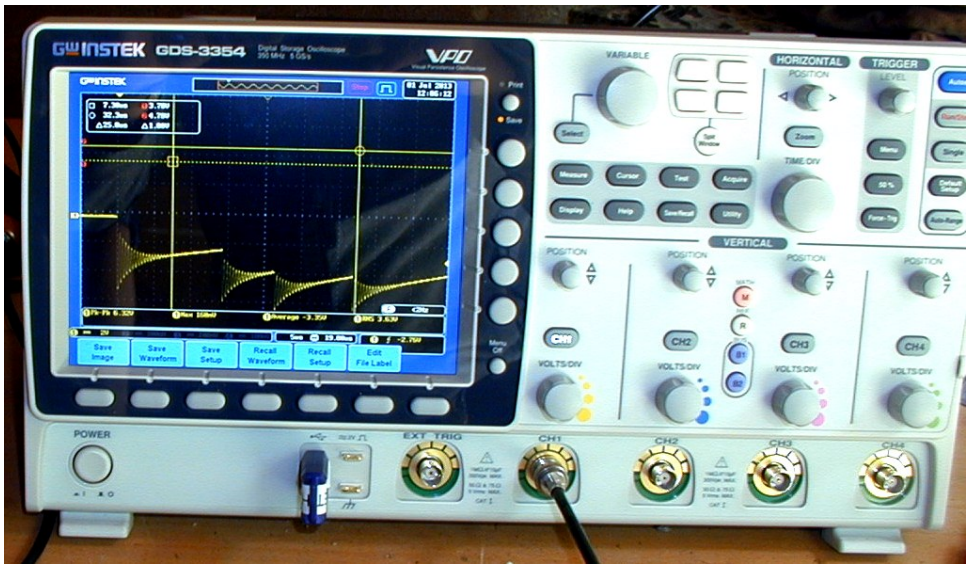


Figure 2.7 Picture of the storage scope used for collecting the information from the firings to determine the detonation velocity.

	Firing No 1	Firing No 2	Firing No 3	Firing No 4
Memory Length	2500	25000	25000	25000
Trigger Level	-3.60V	-2.56V	-2.56V	-2.56V
Source	CH1	CH1	CH1	CH1
Probe	5.00E+00	1.00E+00	1.00E+00	1.000E+00
Vertical Units	V	V	V	V
Vertical Scale	5.00E+00	2.00E+00	2.00E+00	2.000E+00
Vertical Position	-2.00E-01	-8.00E-02	-8.00E-02	-8.000E-02
Horizontal Units	S	S	S	S
Horizontal Scale	1.975E-05	1.00E-05	1.00E-05	1.000E-05
Horizontal Position	6.70E-06	6.70E-06	0.00E+00	0.000E+00
Horizontal Mode	Main	Main	Main	Main
Sampling Period	2.00E-09	4.00E-09	4.00E-09	4.000E-09
Firmware	V1.09	V1.09	V1.09	V1.09
Time	26.08.2013 12:05:50	11.09.2013 08:08:42	11.09.2013 08:17:29	11.09.2013 08:29:52
Mode	Detail	Detail	Detail	Detail

Table 2.12 The conditions used for collecting the results for detonation velocity firings.

2.3.2 Final testing

For the final firings we used a GDS-3352 scope instead of GDS-3354 scope. Table 2.13 and 2.14 shows scope settings for collecting the registrations from the detonations.

	Firing No 1	Firing No 2	Firing No 3	Firing No 4	Firing No 5
Memory Length	25000	25000	25000	25000	25000
Trigger Level	-2.64V	-2.64V	-2.64V	-2.64V	-2.64V
Source	CH1	CH1	CH1	CH1	CH1
Probe	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00
Vertical Units	V	V	V	V	V
Vertical Scale	2.000E+00	2.000E+00	2.000E+00	2.000E+00	2.000E+00
Vertical Position	6.480E+00	6.480E+00	6.480E+00	6.480E+00	6.480E+00
Horizontal Units	S	S	S	S	S
Horizontal Scale	1.000E-05	1.000E-05	1.000E-05	1.000E-05	1.000E-05
Horizontal Position	3.980E-05	3.980E-05	3.980E-05	3.980E-05	3.980E-05
Horizontal Mode	Main	Main	Main	Main	Main
Sampling Period	4.000E-09	4.000E-09	4.000E-09	4.000E-09	4.000E-09
Firmware	V1.09	V1.09	V1.09	V1.09	V1.09
Time	20.01.2014 14:16	20.01.2014 14:39	20.01.2014 15:03	22.01.2014 10:05	22.01.2014 10:38
Mode	Detail	Detail	Detail	Detail	Detail

Table 2.13 The scope settings used for collecting the results for detonation velocity firings.

	Firing No 6	Firing No 7	Firing No 8	Firing No 9
Memory Length	25000	25000	25000	25000
Trigger Level	-2.64V	-2.64V	-2.64V	-2.64V
Source	CH1	CH1	CH1	CH1
Probe	1.000E+00	1.000E+00	1.000E+00	1.000E+00
Vertical Units	V	V	V	V
Vertical Scale	2.000E+00	2.000E+00	2.000E+00	2.000E+00
Vertical Position	6.480E+00	6.480E+00	6.480E+00	6.480E+00
Horizontal Units	S	S	S	S
Horizontal Scale	1.000E-05	1.000E-05	1.000E-05	1.000E-05
Horizontal Position	3.980E-05	3.980E-05	3.980E-05	3.980E-05
Horizontal Mode	Main	Main	Main	Main
Sampling Period	4.000E-09	4.000E-09	4.000E-09	4.000E-09
Firmware	V1.09	V1.09	V1.09	V1.09
Time	22.01.2014 10:54	22.01.2014 11:16	22.01.2014 11:37	22.01.2014 11:57
Mode	Detail	Detail	Detail	Detail
Waveform Data				

Table 2.14 The scope settings used for collecting the results for detonation velocity firings.

2.4 Detonation pressure

Detonation pressure has been determined by use of the Plate Dent test (6). As witness plates we used steel bolts of ST-52 quality with diameter 160 mm. Appendix A gives the certificate of the used steel. The bolts had different heights, either 40 or 50 mm, depending on the diameter of the test item. Figure 2.8 shows how the Dent depth was measured with a micrometer screw, a steel ring and a steel ball.

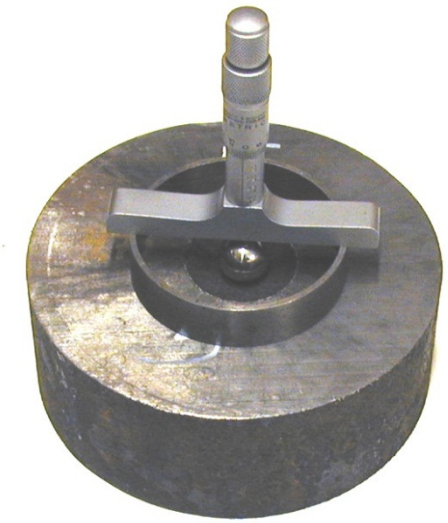


Figure 2.8 Picture of the tool used to measure the Dent depth.

2.5 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 with the same tools as the pellets in 2.1 and 2.2 with diameters 16.14 and 18.66 mm. Applied pressure on the press was 7 tons with a dwell time of 60 seconds. The weight of the booster pellets were 15±1 g.

3 Results

3.1 Press results

The initial pressing showed that the finishing of the surface of the 16.14 mm tool could have been better. For some pellets a continuous movement were not obtained when the pellets were pressed out of the tool. This gave rise to pellets which could or had a tendency to separate into slices. To get rid of or reduce this effect the surface inside the tool was polished with graphite. After this operation we obtained better quality of the pellets as long as the tool had a clean surface and the amount of powder was not to large. The polishing operation had to be repeated after a certain number of pellets had been pressed.

Lowest pellet density compared to TMD was obtained for Sats-258/13. This composition contains less binder than the 4 other compositions. Sats-258/13 has only 3.0 wt. % binder and this gives a dryer powder. For this composition the density of the pellets was on average 1.77 g/cm^3 or 95.2 % TMD. This is approximately a 2% lower TMD than for the 4 remaining compositions even though the density of the pellets is not far from the density of the pellets from the other compositions.

For the three final compositions, which all contain 5.3-5.7 wt. % binder, we obtained more or less the same pellet density. Applying 6 tons press pressure gives slightly higher density than with 5 tons press pressure. Comparing the density of pellets produced in the 16.14 mm tool with the density of pellets produced in the 18.66 mm tool also shows very small differences. For two of the compositions Sats-400/13 and Sats-430/13 the pellets produced with the tool having diameter 16.14 mm gave a slightly higher density. For Sats-432/13 the density of the pellets with both tools are identical.

For Sats-430/13 we, in the 18.66 mm tool, pressed pellets with 5.19±0.11 g mass and with 7.65±0.14 g mass. The change in density of the pellets due to different mass was minimal. However, the compactness of the 5.2 g pellets was slightly better. The reduction in mass was done due to poor mechanical compactness when we used 7.65 g powder.

From the pressing experiments where different press pressures, diameters of tools and amount of powder (height of pellet) had been used, we concluded that composition Sats-430/13 would not be a candidate for filling into 40 mm shells. Sats-400/13 and Sats-432/13 were both easier to press and had better compactness and was therefore selected for the final fragmentation study.

3.2 Detonation velocity initial testing

Most pellets pressed in the initial press study were glued together to test items with required length for determination of detonation velocity and detonation pressure. For Sats-230/13 the pellets were used to produce one test item. For Sats-258/13 the pellets were distributed on 3 test items. The detonation velocity was determined by use of ionization pins (5), while the detonation pressure was determined by use of the Plate Dent test (6).

3.2.1 Sats-230/13

Sats-230/13 contains 5.72 wt. % 40/60 GA/BAMO and 94.28 wt. % HMX as filler. Pellets were pressed with 5 tons pressure and a dwell time of 60 seconds. 14 pellets were glued together to a test charge as shown in Figure 3.1 before it was fitted with 4 ionization pins as shown in Figure 3.2.

Figure 3.1 The figure shows the test charge after being glued together.

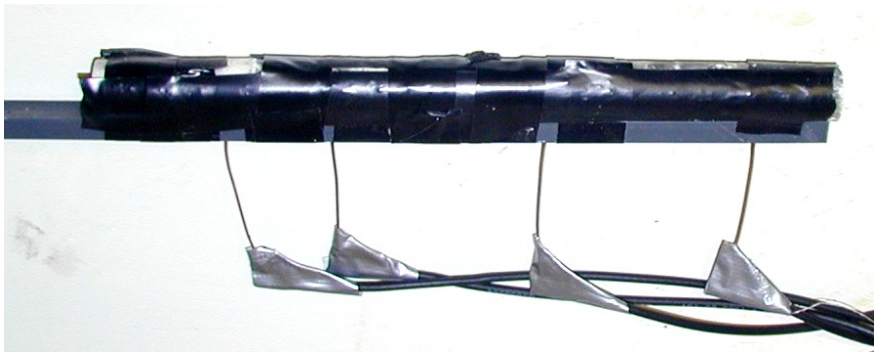


Figure 3.2 The figure shows the assembled test item with the ionization pins in test positions.

The distance between pin No 1 and pin No 2 was 30 mm, while it was 60 mm between pin No 2 and pin No 3 and between pin No 3 and pin No 4. Figure 3.3 shows the test setup.

From Figure 3.4 it can be seen that all ionization pins gave registrations. The obtained overall detonation velocity of 8482 m/s is slightly lower than for Sats-258/13 for which we obtained 40 and 63 m/s higher detonation velocities.

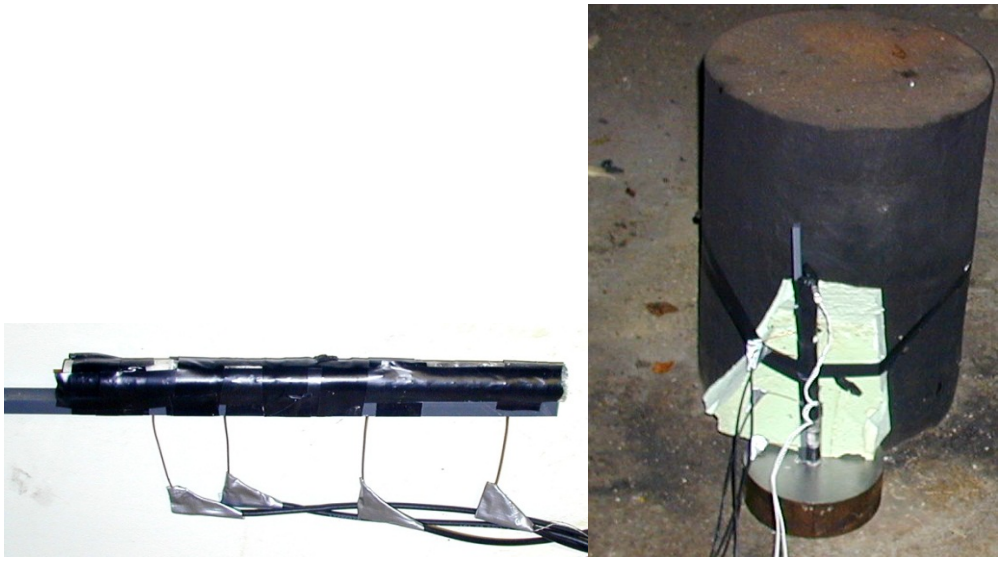


Figure 3.3 The figure shows the test setup for firing No 4 with a test item containing Sats-230/13 pressed pellets.

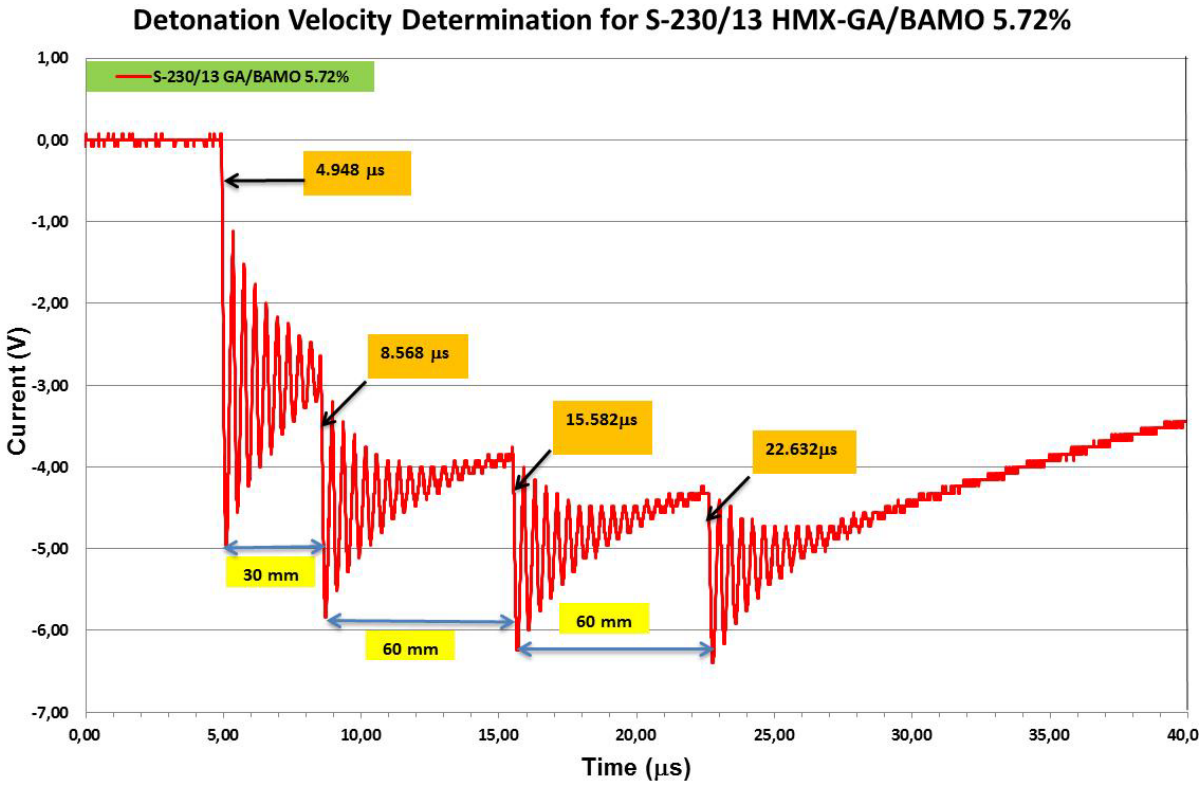


Figure 3.4 Arrival times and distances for each ionization pin for the firing with Sats-230/13.

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 4 containing Sats-230/13			
1	4.948			
2	8.568	3.620	30	8287
3	15.582	7.014	60	8554
4	22.632	7.050	60	8511
1-4		17.684	150	**8482**

Table 3.1 The table shows arrival times of the detonation front and distances between ionization pins in addition to calculated detonation velocities for firing No 4 with Sats-230/13.

3.2.1.1 Sats-258/13

3.2.1.2 Firing No 1

Sats-258/13 contains HMX and 3 wt. % 60/40 GA/BAMO + IPDI (I) binder. For the first charge a picture of the test item containing 14 pellets glued together of single pellets is shown in Figure 3.5. The test item was equipped with 5 ionization pins as shown in Figure 3.6.

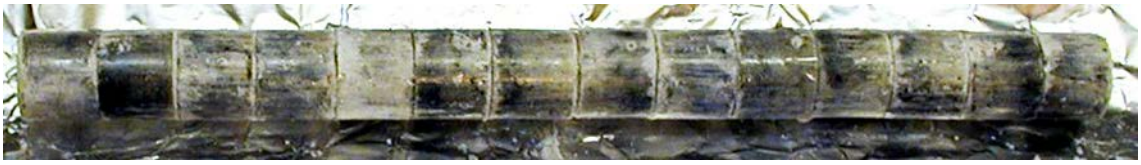


Figure 3.5 The pellets of Sats-258/13 after been glued together to a test item.

Figure 3.6 Test setup for firing No 1 with Sats-258/13.

To simultaneously measure the detonation pressure the test item was placed on a Dent plate, Figure 3.6. The registration from the ionization pins failed. However, the pressure was recorded from the Dent witness plate shown in Figure 3.39.

3.2.1.3 Firing No 2

The second firing of composition Sats-258/13 was performed with a test item glued together of 19 pellets. Figure 3.7 shows the test item after four ionization pins were added. The distances between the ionization pins were 60 mm. Figure 3.7 shows the test setup. For this firing we obtained registrations for three of the four ionization pins as shown in Figure 3.8.

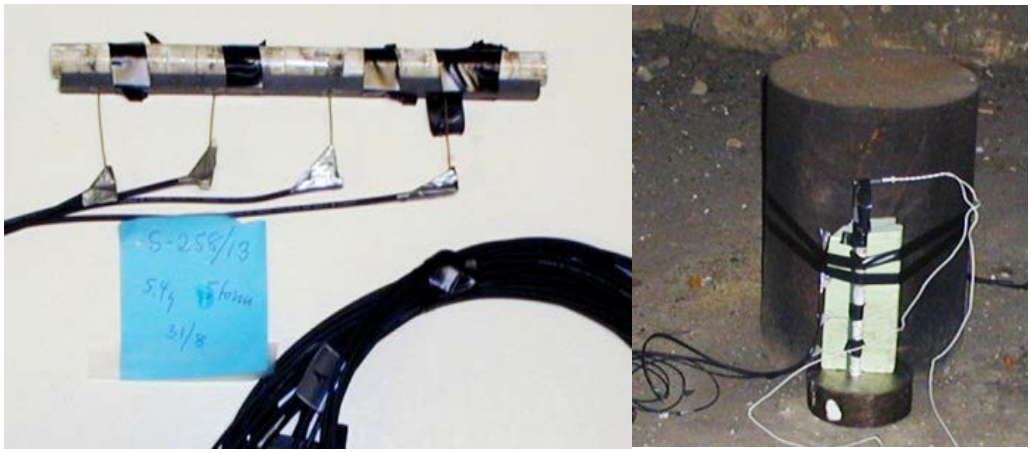


Figure 3.7 Pictures of the test item after the ionization pins were added, to the left, and test setup for firing No 2 with Sats-258/13 to the right.

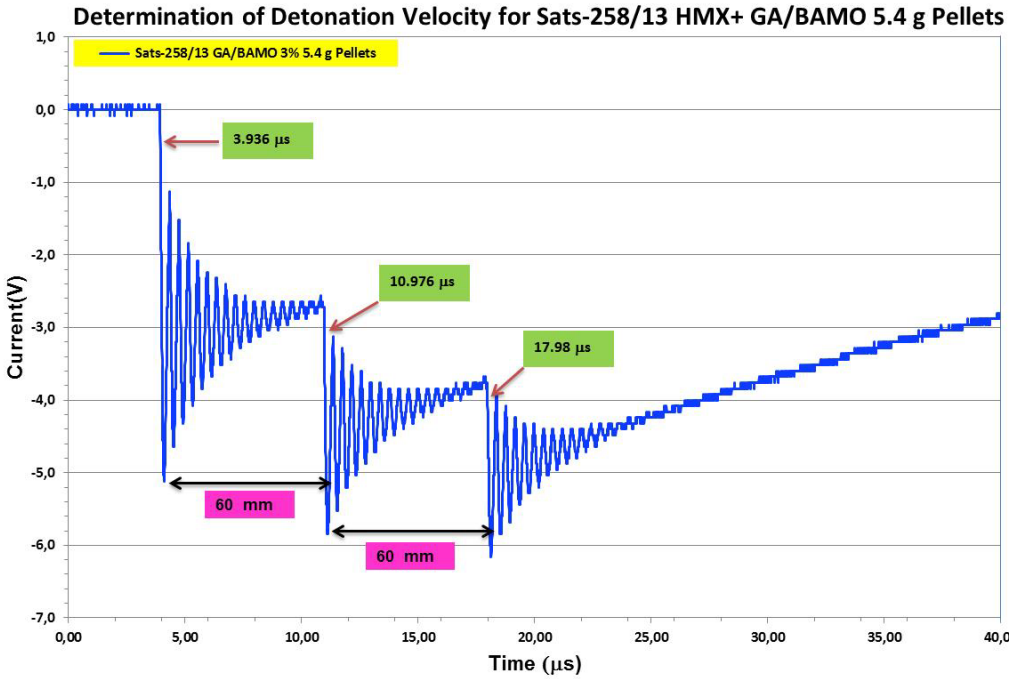


Figure 3.8 The figure shows arrival times of the detonation front and distances between each ionization pin.

Table 3.2 summarizes the obtained results giving an average detonation velocity of 8545 m/s. The difference between the two measurements is very small and indicates that the density of the charge is homogeneous.

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 2 containing Sats-258/13			
1	3.936			
2	10.976	7.040	60	8523
3	17.980	7.004	60	8567
4	No registration			
1-3		14.044	120	**8545**

Table 3.2 Arrival times and positions of the ionization pins with determined detonation velocity for firing No 2 with Sats-258/13 composition.

3.2.1.4 Firing No 3

The last firing for Sats-258/13 containing HMX and 3 wt. % 60/40 GA/BAMO +IPDI (I) binder, was firing No 3. The test item contained 17 pellets glued together to the test charge shown in Figure 3.9.

Figure 3.9 Pellets of Sats-258/13 after being glued together to be test item No 3.

Figure 3.10 shows the test item after four ionization pins had been added with a distance of 61.5 mm between pin No 1 and pin No 2, 59.5 mm between pin No 2 and pin No 3 and finally 60 mm between pin No 3 and pin No 4. This figure also shows test setup for the firing with the Dent witness plate for pressure determination.

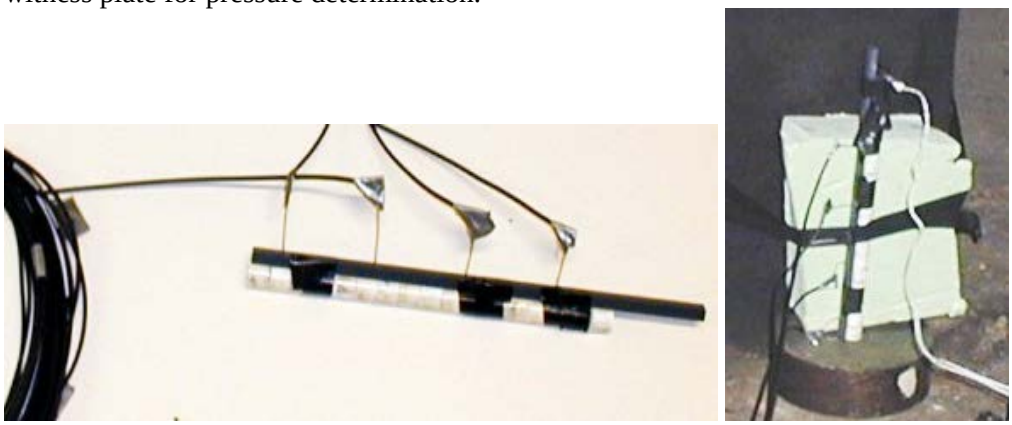


Figure 3.10 The figure shows pictures at left of the test item No 3 for Sats-258/13 with 4 ionization pins and the setup for firing at the right.

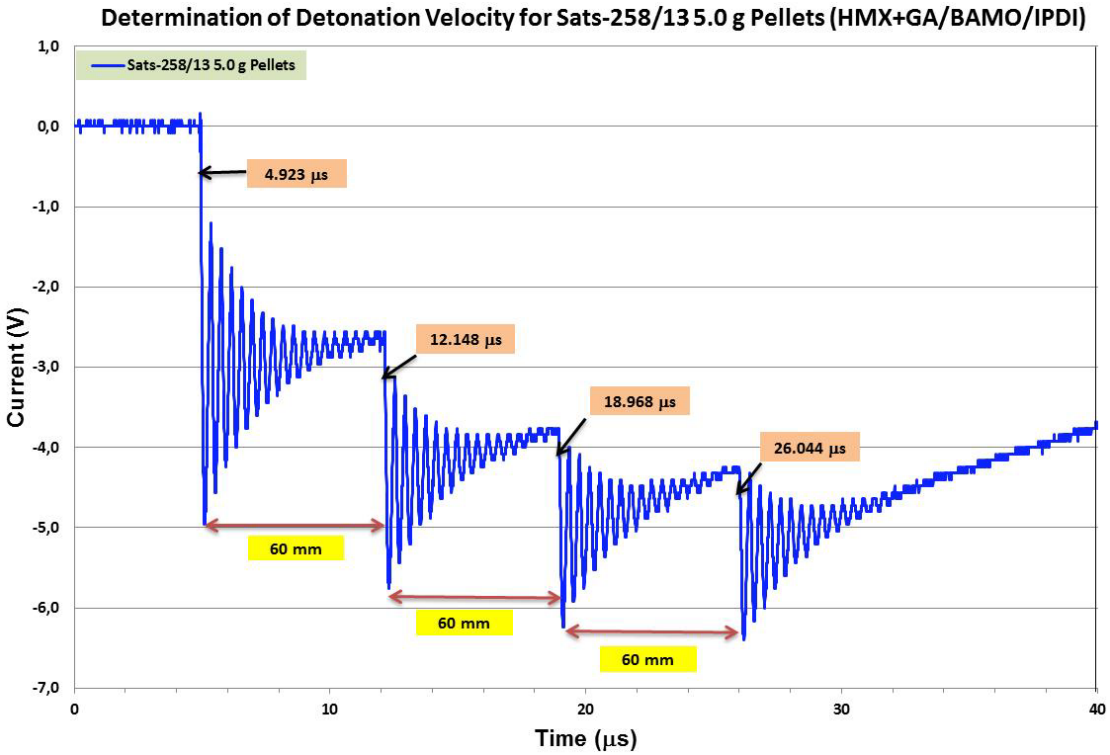


Figure 3.11 Detonation front arrival times and distances between ionization pins for firing No 3 with Sats-258/13.

Figure 3.11 shows the registrations obtained on the scope. All four ionization pins gave registrations. The velocity could then be calculated for three intervals as shown in Table 3.3. The obtained average velocity of 8522 m/s is equal to the velocity for firing No 2 with 8545 m/s.

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 Sats-258/13			
1	4.923			
2	12.148	7.225	61.5	8512
3	18.968	6.820	58.5	8578
4	26.044	7.076	60	8479
1-4		21.121	180	**8522**

Table 3.3 The Table gives arrival times, distances between pins and determined detonation velocities for firing No 3 with Sats-258/13.

3.2.2 Summary detonation velocity initial testing

Table 3.4 summarizes the obtained detonation velocities for the firings with compositions Sats-30/13 and Sats-258/13. The obtained differences in detonation velocities between both compositions and parallels are within expected accuracy for the applied method.

Composition	Density (g/cm^3)	Time (μs)	Distance (mm)	Velocity (m/s)
Sats-230/13	1.776	17.684	150	**8482**
Sats-258/13	1.771	14.044	120	**8545**
	1.769	21.121	180	**8522**

Table 3.4 Summary of obtained detonation velocities for compositions Sats-230/13 and Sats-258/13.

3.3 Determination of detonation velocity for final compositions

Detonation velocity has been determined by use of ionization pins (5). All tested test items have been equipped with 4 or more ionization pins. For all three final compositions three test items have been tested, two made from pellets having diameter 18.6 mm and one from pellets having diameter 16.1 mm.

3.3.1 Sats-432/13

3.3.1.1 Firing No 1

The first firing of composition Sats-432/13 was with pellets having diameter 16.14 mm. The test item contained 20 pellets glued together to the charge shown in Figure 2.6. To measure the detonation velocity four ionization pins were placed as shown in Figure 3.12.

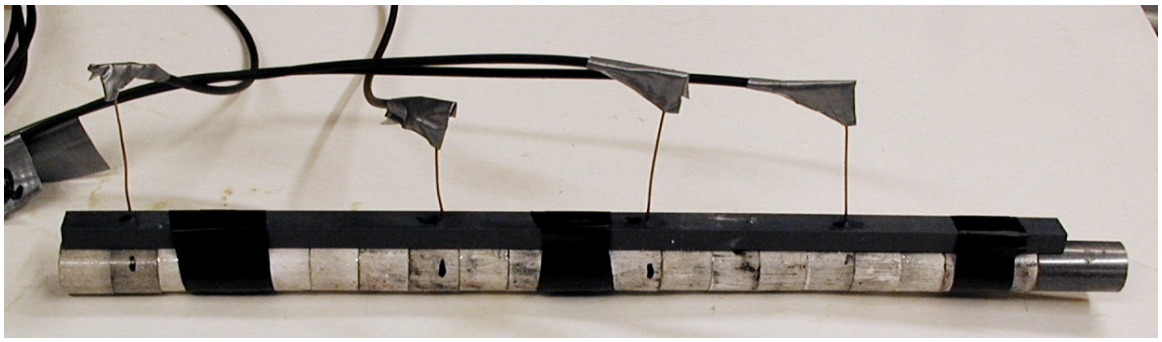


Figure 3.12 The figure shows the positions of the ionization pins.

The distance between ionization pin No 1 and pin No 2 were 60 mm, between pin No 2 and pin No 3 60 mm and finally between pin No 3 and pin No 4 90 mm. Total measuring distance 210 mm, Figure 3.12.

Figure 3.13 shows the test setup for the firing including the Dent witness plate to simultaneously measure the detonation pressure together with the detonation velocity. We did obtain registrations for all pins as shown in Figure 3.14. Figure 3.14 gives the arrival times of the detonation front at each ionization pin.

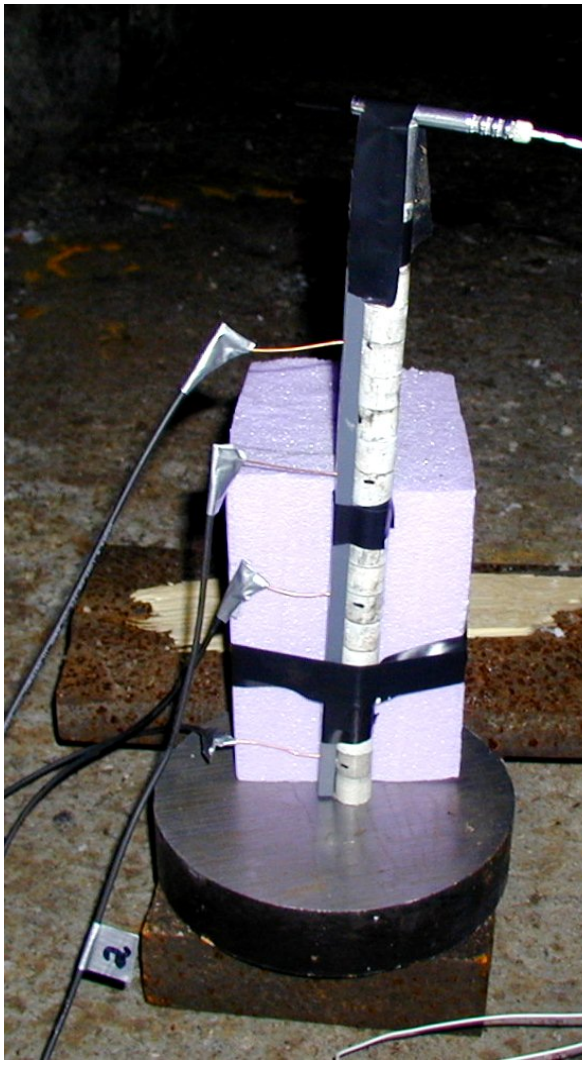


Figure 3.13 The picture shows test setup for firing No 1.

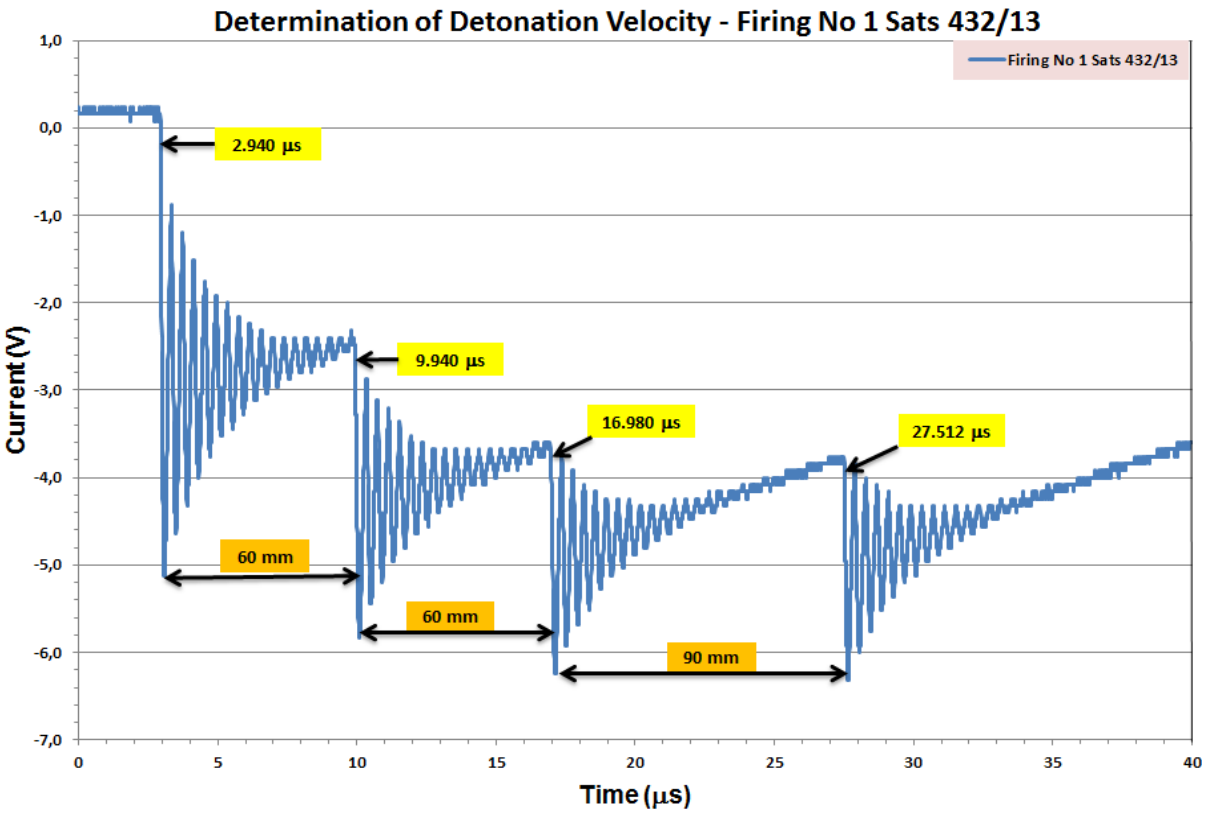


Figure 3.14 The figure shows arrival times for the detonation front and distances between the ionization pins.

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 1 containing Sats-432/13			
1	2.94			
2	9.94	7.000	60	8571
3	16.98	7.040	60	8523
4	27.512	10.532	90	8545
1-4		24.572	210	**8546**

Table 3.5 A summary of the results from the determination of the detonation velocity for Sats-432/13 firing No 1.

Table 3.5 gives a summary of obtained detonation velocities for different parts of the charge together with the overall detonation velocity of 8546 m/s. The differences in detonation velocities for the different parts of the test item are very small.

3.3.1.2 Firing No 2

The second firing with composition Sats-432/13 was with pellets having diameter 18.64 mm. The test item contained 17 pellets glued together to the charge shown at the top in Figure 2.6. The detonation velocity was measured with four ionization pins having positions as shown in Figure 3.15.

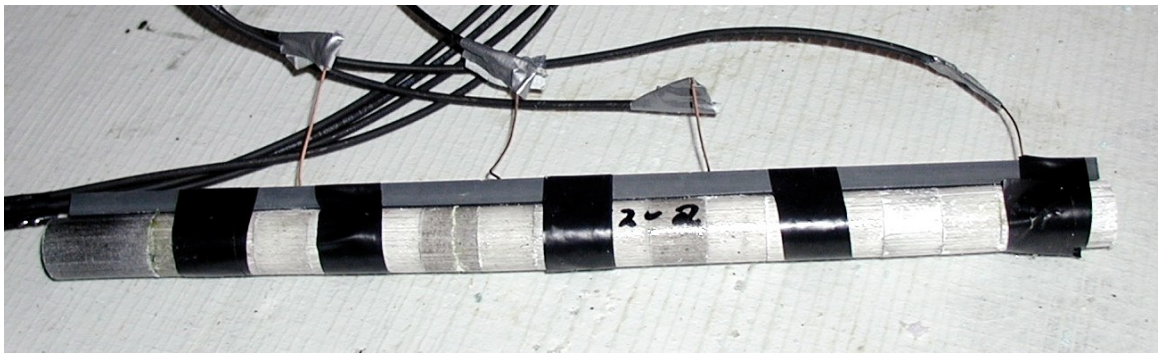


Figure 3.15 The figure shows the positions of the ionization pins.

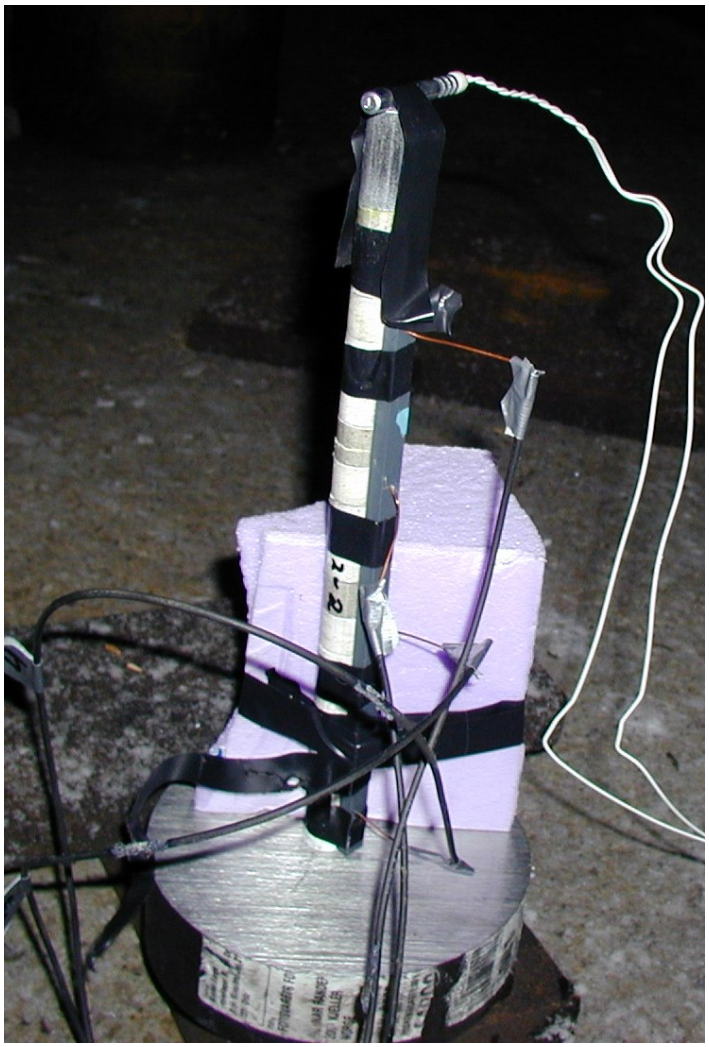


Figure 3.16 The picture shows test setup for firing No 2 with a test item of Sats-432/13.

The distance between ionization pin No 1 and pin No 2 were 60 mm, between pin No 2 and pin No 3 60 mm and finally between pin No 3 and pin No 4 90 mm. Total measuring distance was 210 mm, Figure 3.15.

Figure 3.16 shows the test setup for the firing including the Dent witness plate to simultaneously measure the detonation pressure and the detonation velocity.
We did, for this firing, obtain registrations for all pins as shown in Figure 3.17. Figure 3.17 gives the arrival times of the detonation front for each ionization pin. In addition Figure 3.17 shows the distances between the ionization pins.

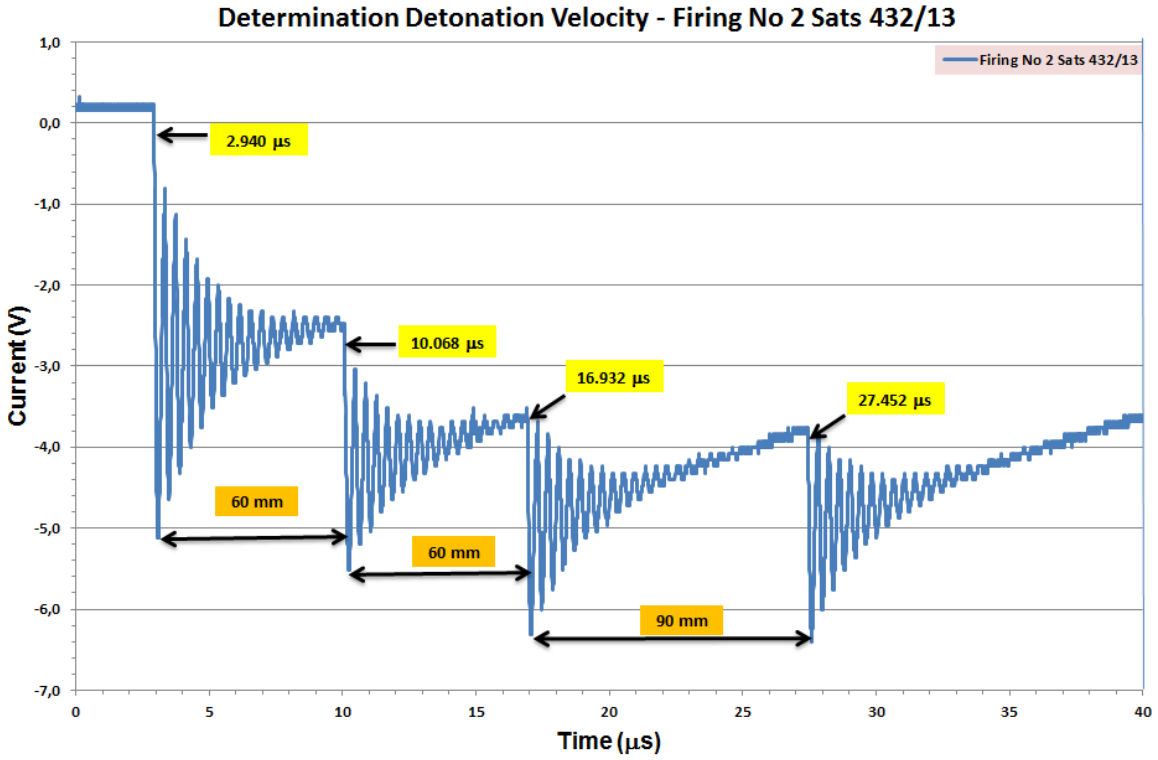


Figure 3.17 The figure shows arrival times and distances between each ionization pin.

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 2 containing Sats-432/13			
1	2.94			
2	10.068	7.128	60	8418
3	16.932	6.864	60	8741
4	27.452	10.52	90	8555
1-4		24.512	210	**8567**

Table 3.6 A summary of the results from the determination of the detonation velocity for Sats-432/13 firing No 2.

Table 3.6 gives a summary of obtained detonation velocities for the different parts of the charge together with the overall detonation velocity of 8567 m/s. Compared to 8546 m/s for the first firing the velocity for firing No 2 is 21 m/s higher. The differences in detonation velocities between the pins are moderate. The observed difference in detonation velocity between pins 1-2 and 2-3 may be due to a slightly wrong position of pin No 2. The pin was broken, but as Figure 3.17 shows it did function, but perhaps in a slightly wrong position.

3.3.1.3 Firing No 3

The third firing for composition Sats-432/13 contained pellets with diameter 18.64 mm. The test item contained 17 pellets glued together to the charge shown in the middle of Figure 2.6. This test item was equipped with five ionization pins to measure the detonation velocity. These pins were positioned as shown in Figure 3.18.

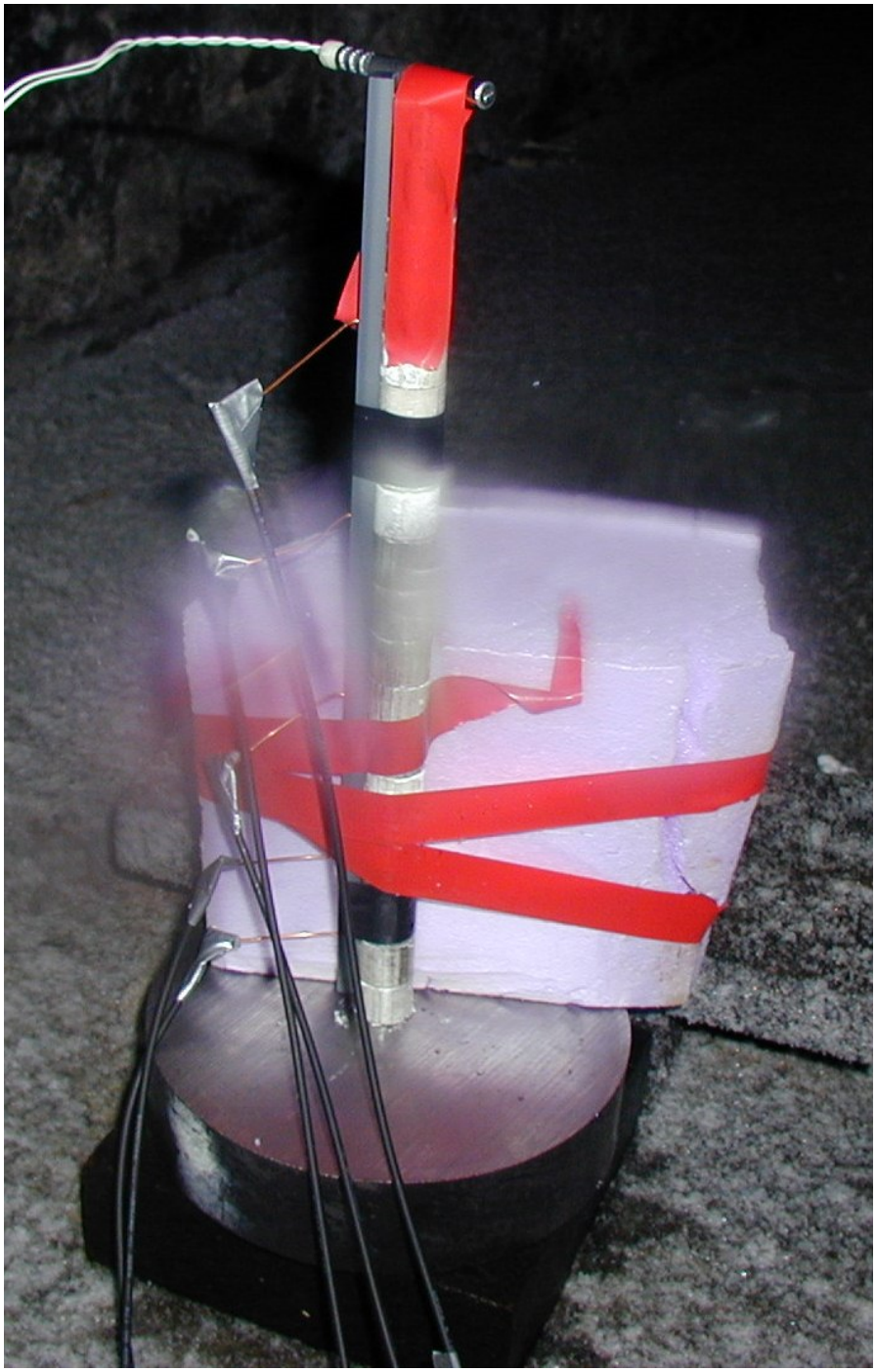


Figure 3.18 The picture shows test setup for firing No 3 with Sats-432/13.

The distance between ionization pin No 1 and pin No 2 was 60 mm, between pin No 2 and pin No 3 60 mm, between pin No 3 and pin No 4 60 mm and finally between pin No 4 and pin No 5 30 mm. Total measuring distance adds up to 210 mm, Figure 3.18.

Figure 3.18 shows the test setup for the firing including the Dent witness plate to simultaneously measure both detonation pressure and detonation velocity.

We obtained registrations for all pins as shown in Figure 3.19. Figure 3.19 shows the arrival times of the detonation front for each ionization pin. In addition the figure gives the distances between the ionization pins.

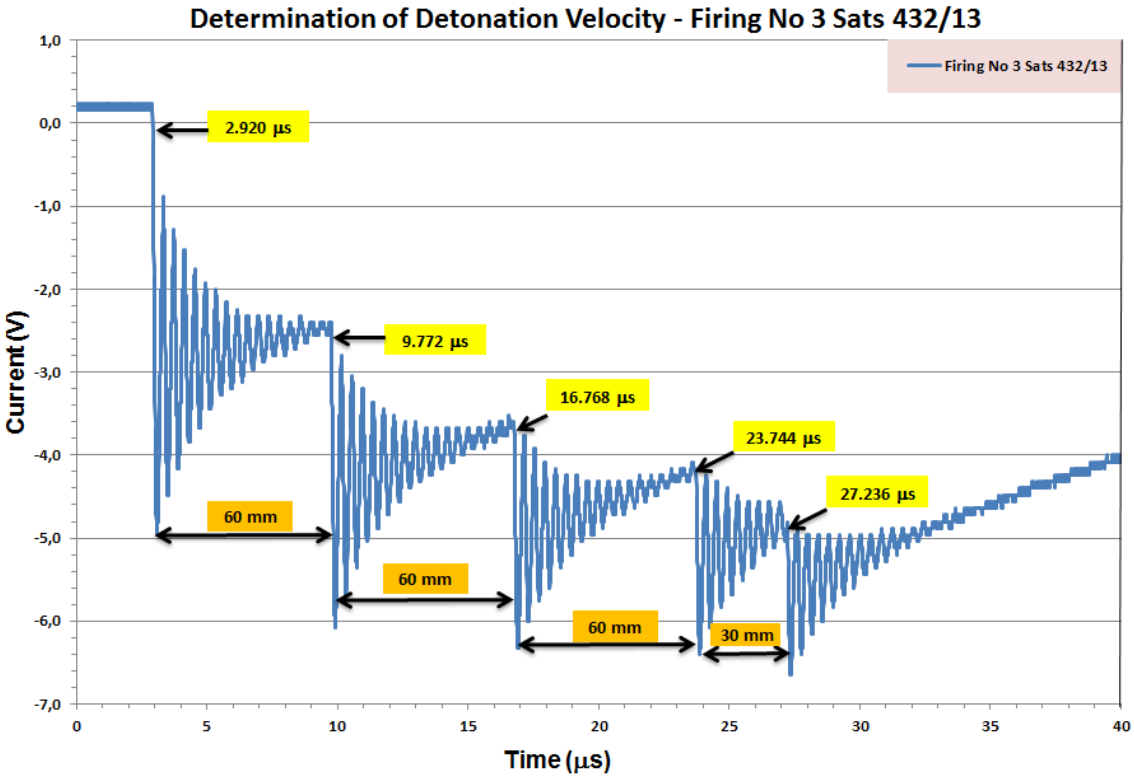


Figure 3.19 The figure shows arrival times for the detonation front and distances between ionization pins.

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 Sats-432/13			
1	2.92			
2	9.772	6.852	60	8757
3	16.768	6.996	60	8576
4	23.744	6.976	60	8601
5	27.236	3.492	30	8591
1-5		24.316	210	**8636**

Table 3.7 A summary of the results from the determination of the detonation velocity for Sats-432/13 firing No 3.

Table 3.7 gives a summary of obtained detonation velocities for different parts of the test item together with the overall detonation velocity of 8636 m/s. The differences in detonation velocities between the different pins are moderate.

3.3.1.4 Summarizing results for Sats-432/13

Table 3.8 gives the overall results for the three firings carried out with Sats-432/13. For the three firings an average detonation velocity of 8583±47 m/s is obtained.

Firing No	Pin	Time between Pin No 1 and 4(5) (μs)	Distance from Pin 1 to Pin 4 (5) (mm)	Detonation Velocity (m/s)
	Firings containing Sats-432/13			
1	1-4	24.572	210	8546
2	1-4	24.512	210	8567
3	1-5	24.316	210	8636
	Average			**8583±47**

Table 3.8 Summary of the detonation velocities for the three firings performed with composition Sats-432/13.

3.3.2 Sats-430/13

3.3.2.1 Firing No 4

The first firing with composition Sats-430/13 was firing No 4 with pellets having diameter 16.14 mm. The test item contained 20 pellets glued together to the charge shown at top of Figure 2.5. The test item was equipped with four ionization pins positioned as shown in Figure 3.20.

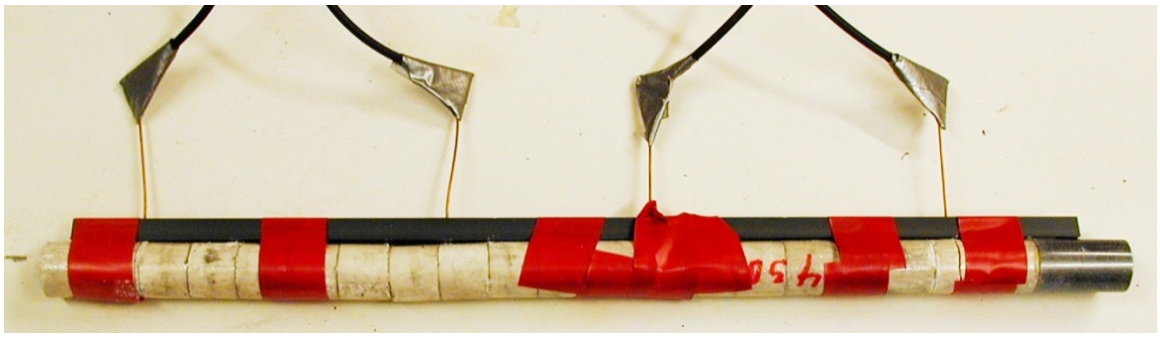


Figure 3.20 The figure shows the positions of the ionization pins.

The distance between ionization pin No 1 and pin No 2 was 90 mm, between pin No 2 and pin No 3 60 mm and finally between pin No 3 and pin No 4 90 mm. Total measuring distance adds up to 240 mm, Figure 3.20.

Figure 3.21 shows the setup for the firing including the Dent witness plate to measure simultaneously both detonation pressure and detonation velocity.

We did obtain registrations only on 3 ionization pins as shown in Figure 3.22. For pin No 1 we did not obtain registration. Figure 3.22 shows the arrival times of the detonation front for each ionization pin.

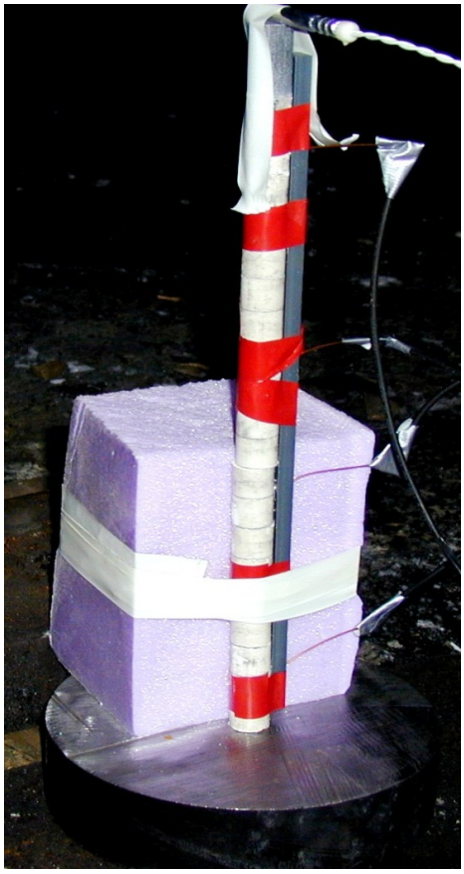


Figure 3.21 The picture shows test setup for firing No 4 with Sats-430/13.

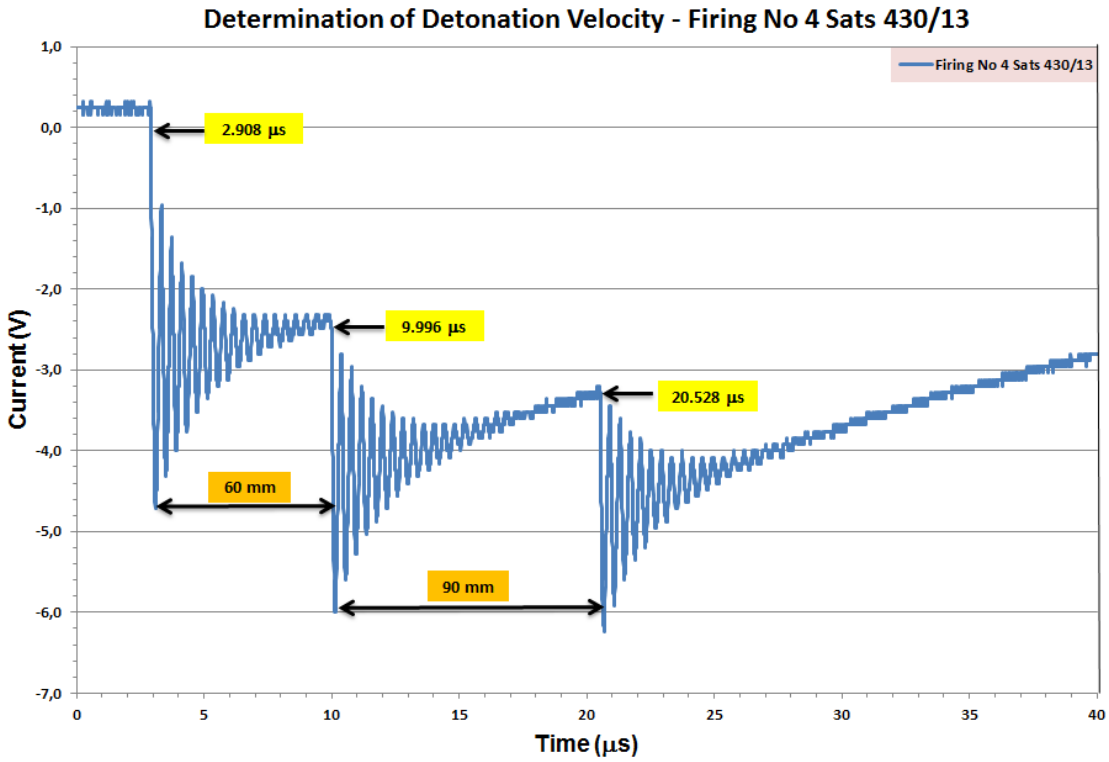


Figure 3.22 The figure shows arrival times of the detonation front for each ionization pin and the distances between pins.

Table 3.9 gives a summary of obtained detonation velocities for different parts of the charge together with the overall detonation velocity of 8513 m/s. The difference in detonation velocity between the two parts of the charge is 80 m/s.

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 4 containing Sats-430/13			
1	No registration			
2	2.908			
3	9.996	7.088	60	8465
4	20.528	10.532	90	8545
2-4		17.62	150	**8513**

Table 3.9 A summary of the results from the determination of the detonation velocity for Sats-430/13 firing No 4.

3.3.2.2 Firing No 6

The second firing with composition Sats-430/13 was firing No 6 with pellets having diameter 18.66 mm. The test item contained 16 pellets glued together to the charge shown at the center of Figure 2.5. To measure the detonation velocity the test item was equipped with four ionization pins positioned as shown in Figure 3.23.

Figure 3.23 The figure shows the positions of the ionization pins.

The distance between ionization pin No 1 and pin No 2 was 50 mm, between pin No 2 and pin No 3 100 mm and finally between pin No 3 and pin No 4 50 mm. Total measuring distance adds up to 200 mm, Figure 3.25.

Figure 3.24 shows the setup for the firing including the Dent witness plate to simultaneously measure detonation pressure and detonation velocity.

We did as Figure 3.25 shows obtain registrations for all ionization pins. Figure 3.25 gives the arrival times of the detonation front for each ionization pin. In addition the figure shows the distances between ionization pins.

Figure 3.24 The picture shows test setup for firing No 6.

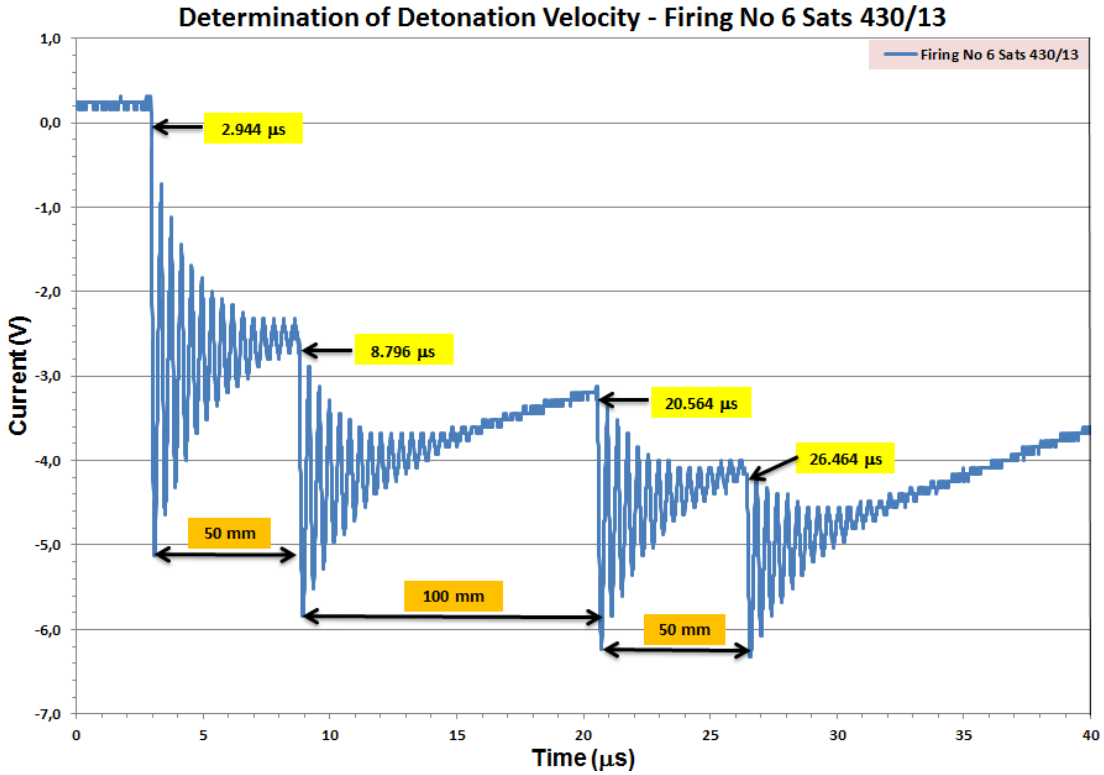


Figure 3.25 The figure shows arrival times of the detonation front for each ionization pin and the distances between the ionization pins.

Table 3.10 gives a summary of obtained detonation velocities for different parts of the test item together with the overall detonation velocity of 8503 m/s. The differences in detonation velocities between the different parts of the test item are as expected.

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 6 containing Sats-430/13			
1	2.944			
2	8.796	5.852	50	8544
3	20.564	11.768	100	8498
4	26.464	5.900	50	8475
1-4		23.52	200	**8503**

Table 3.10 A summary of the results from the determination of the detonation velocity for Sats-430/13 firing No 6.

3.3.2.3 Firing No 8

The third and last firing with composition Sats-430/13 was firing No 8 with pellets having diameter 18.66 mm. The test item consisted of 19 pellets glued together to the charge shown at the bottom in Figure 2.5. To lengthen the charge two pellets with diameter 16.14 mm was glued

to the top. To measure the detonation velocity four ionization pins were positioned as shown in Figure 3.26.

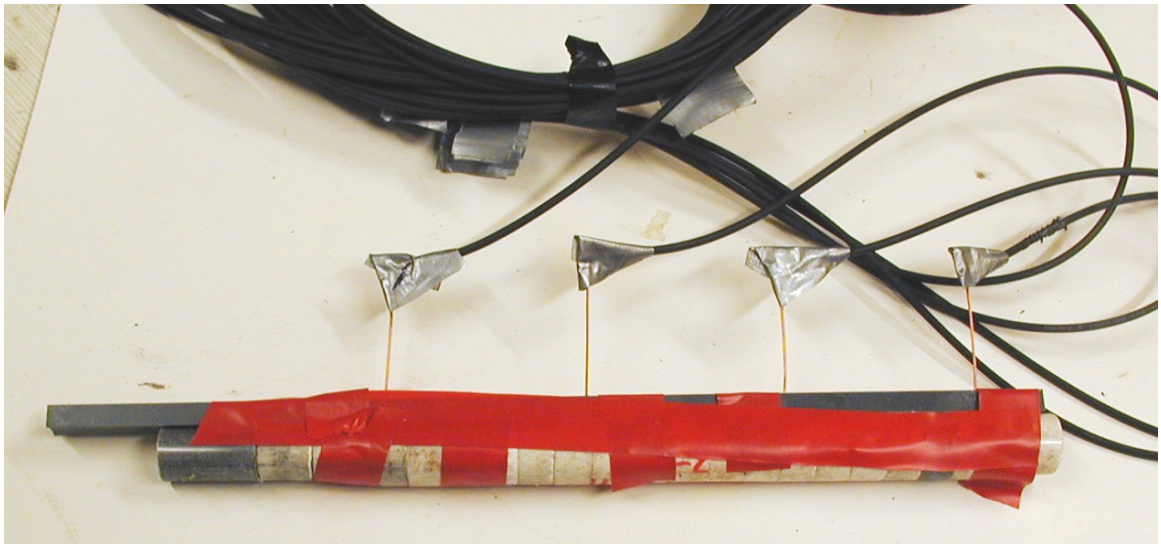


Figure 3.26 The figure shows the positions of the ionization pins for firing No 8 with Sats-430/13.

The distance between ionization pin No 1 and pin No 2 was 60 mm, between pin No 2 and pin No 3 60 mm and finally between pin No 3 and pin No 4 60 mm. Total measuring distance adds up to 180 mm, Figure 3.28.

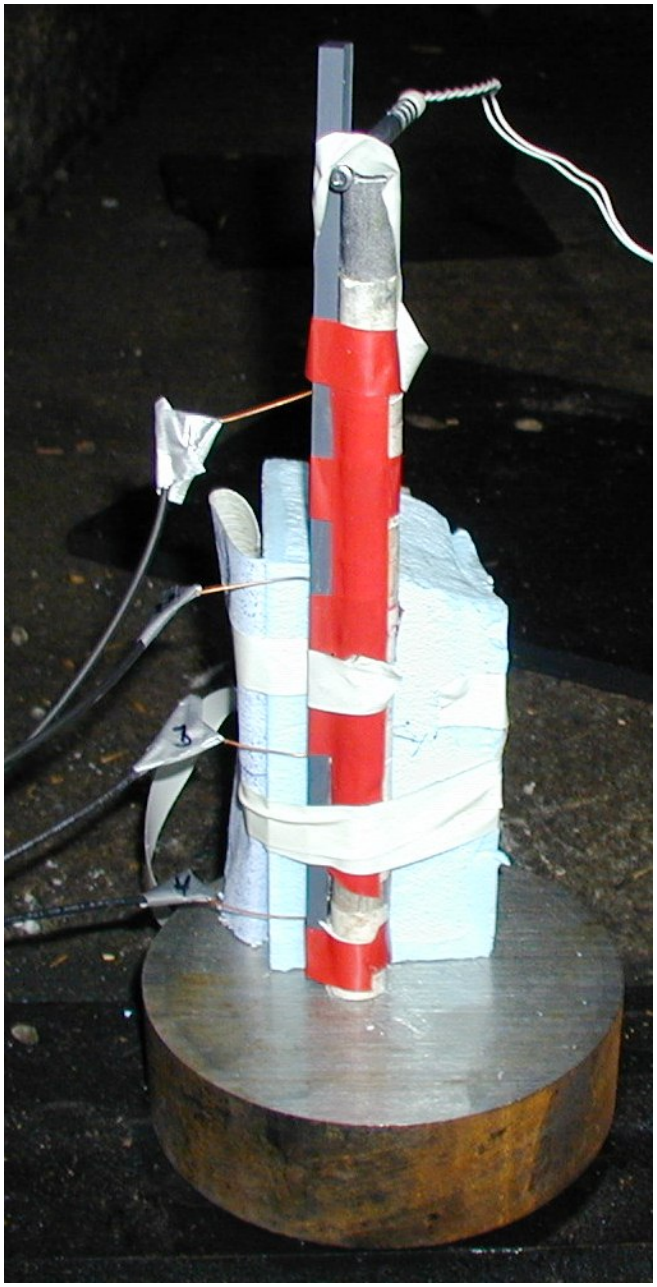


Figure 3.27 The picture shows test setup for firing No 8 with Sats-430/13 composition.

Figure 3.27 shows the setup for the firing including the Dent witness plate to simultaneously measure detonation pressure and detonation velocity.

We did obtain registrations for all pins as shown in Figure 3.28. Figure 3.28 gives the arrival times of the detonation front for each ionization pin. In addition the figure shows the distances between all ionization pins.

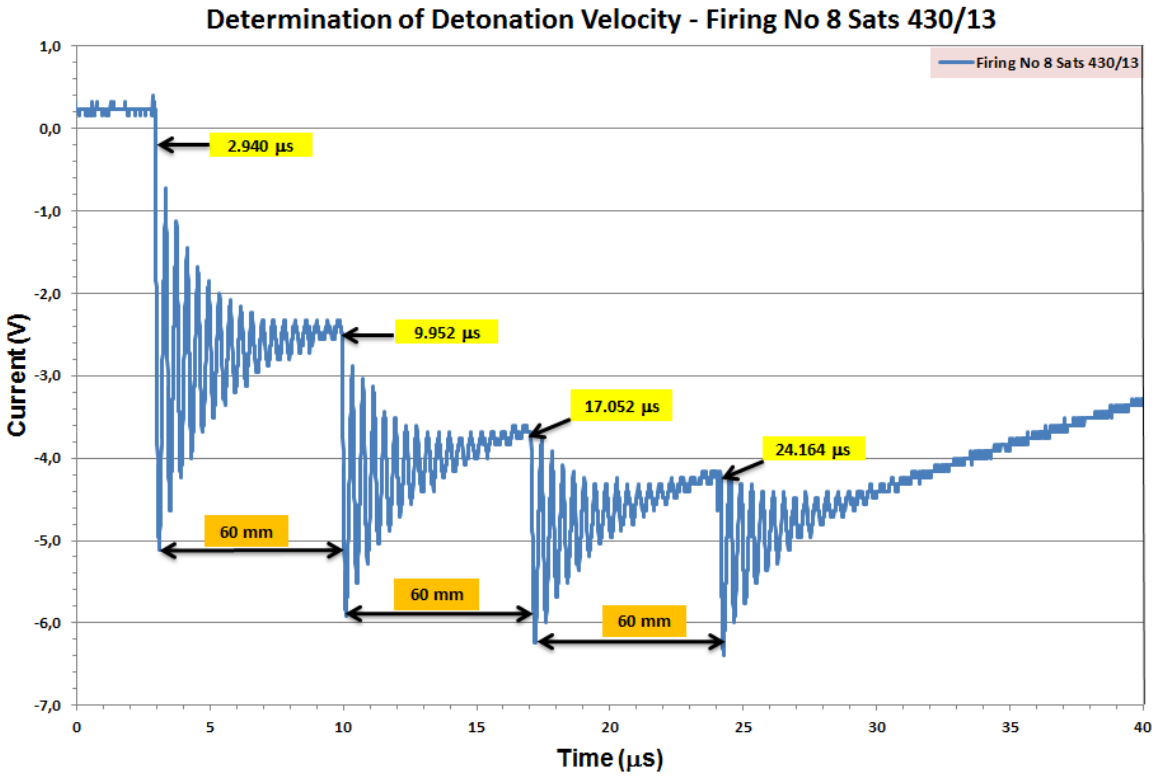


Figure 3.28 The figure shows arrival times of the detonation front for each ionization pin and distances between ionization pins.

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 8 containing Sats-430/13			
1	2.994			
2	9.952	6.958	60	8623
3	17.052	7.100	60	8451
4	24.164	7.112	60	8436
1-4		21.17	180	**8503**

Table 3.11 A summary of the results from the determination of the detonation velocity for Sats-430/13 firing No 8.

Table 3.11 gives a summary of obtained detonation velocities for different parts of the test item together with the overall detonation velocity of 8503 m/s. The differences in detonation velocities between the different pins are within expected range.

3.3.2.1 Comparison of the results for Sats-430/13

In Table 3.12 the overall results obtained for the three firings carried out with Sats-430/13 are given. For the three firings an average detonation velocity of 8506±6 m/s is obtained. The standard deviation of ±6 m/s is low indicating that the charges are homogenous. Differences in

measurements of single test items must be ascribed to inaccuracy in positioning of the ionization pins.

Firing No	Pin	Time between Pin No 1 and 4(5) (μs)	Distance from Pin 1 to Pin 4 (5) (mm)	Detonation Velocity (m/s)
	Firings containing Sats-430/13			
1	2-4	17.620	150	8513
2	1-4	23.520	200	8503
3	1-4	21.170	180	8503
	Average			**8506±6**

Table 3.12 Summary of the detonation velocities for the three firings performed with composition Sats-430/13.

3.3.3 Sats-400/13

3.3.3.1 Firing No 5

The first firing of composition Sats-400/13 was firing No 5 with pellets having diameter 16.17 mm. The test item contained 19 pellets glued together to the charge shown in Figure 2.4. To measure the detonation velocity the test item was equipped with four ionization pins positioned as shown in Figure 3.29.

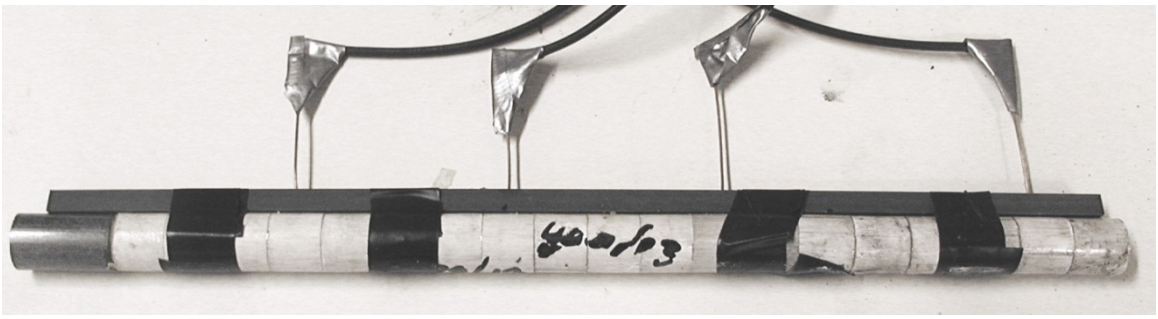


Figure 3.29 The figure shows the positions of the ionization pins.

The distance between ionization pin No 1 and pin No 2 was 60 mm, between pin No 2 and pin No 3 60 mm and finally between pin No 3 and pin No 4 90 mm. Total measuring distance added up to 210 mm, Figure 3.31.

Figure 3.30 shows the setup for the firing including the Dent witness plate to simultaneously measure detonation pressure and detonation velocity.

We did obtain registrations for all ionization pins as shown in Figure 3.31. Figure 3.31 shows the arrival times of the detonation front for each ionization pin. In addition it shows the distances between the ionization pins.

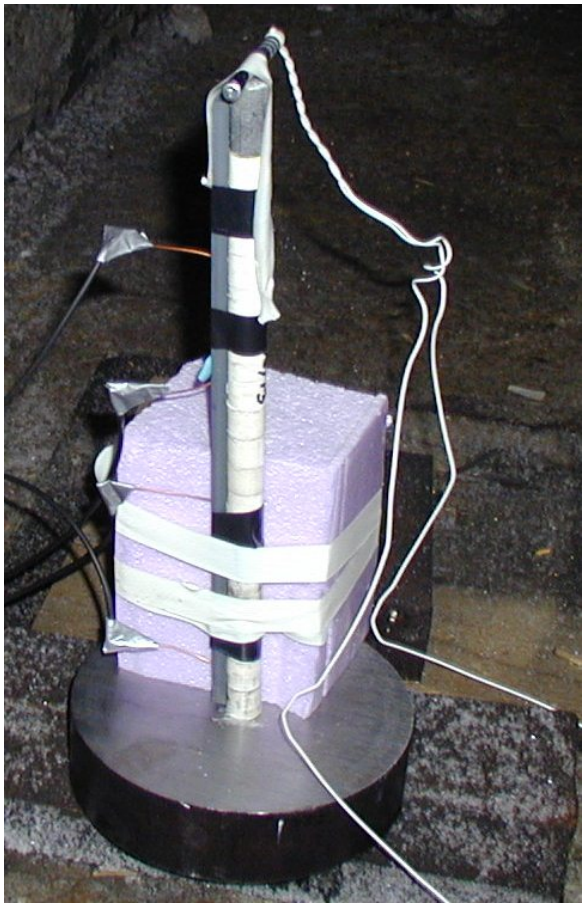


Figure 3.30 The picture shows the test setup for firing No 5 with Sats-400/13 composition.

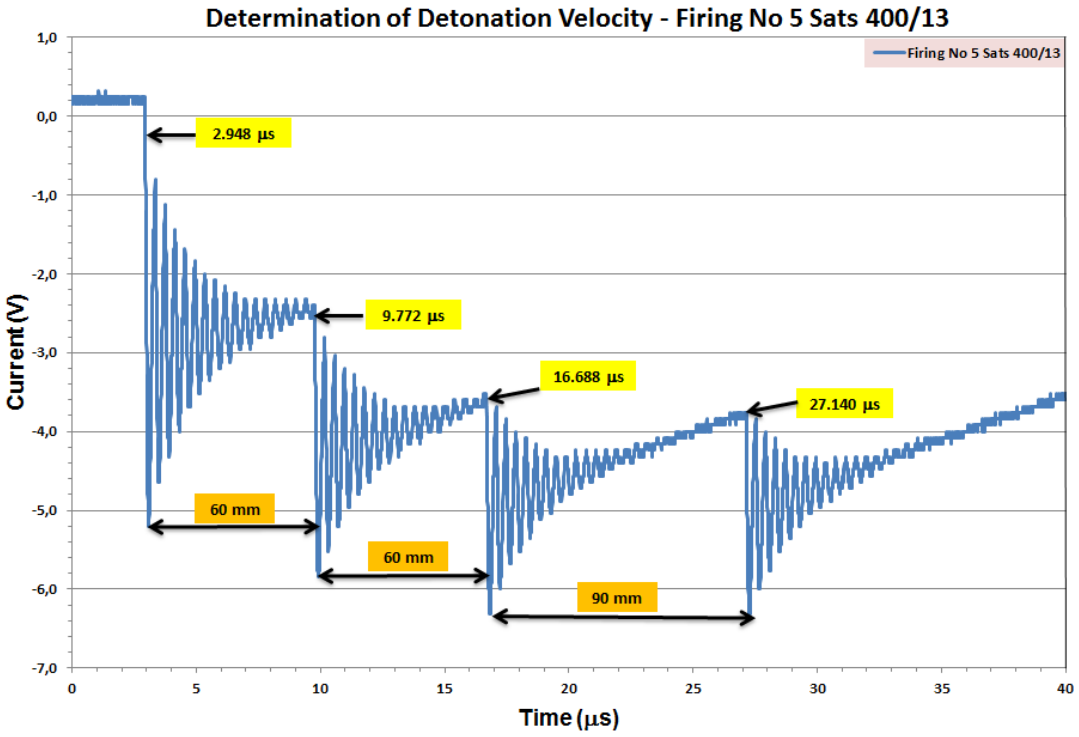


Figure 3.31 The figure shows arrival times of the detonation front at each ionization pin and the distances between the ionization pins.

Table 3.13 gives a summary of obtained detonation velocities for different parts of the test item together with the overall detonation velocity of 8681 m/s. The differences in detonation velocities between the different pins are as expected.

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 5 containing Sats-400/13			
1	2.948			
2	9.772	6.824	60	8792
3	16.688	6.916	60	8676
4	27.14	10.452	90	8611
1-4		24.192	210	**8681**

Table 3.13 A summary of the results from the determination of the detonation velocity for Sats-400/13 firing No 5.

3.3.3.2 Firing No 7

The second firing for composition Sats-400/13 was firing No 7 with pellets having diameter 18.67 mm. The test item contained 17 pellets glued together to the charge shown at the top in Figure 2.4. The detonation velocity was measured with four ionization pins positioned as shown in Figure 3.32.

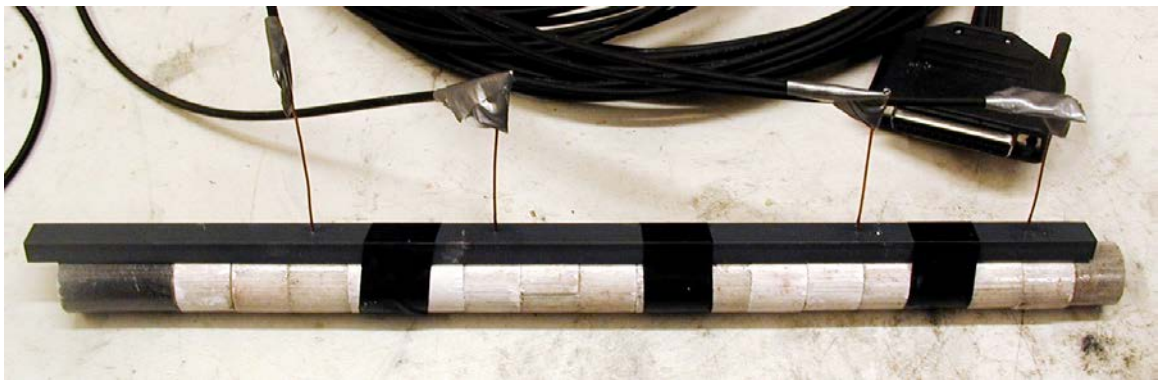


Figure 3.32 The figure shows the positions of the ionization pins for firing No 5 with Sats-400/13.

The distance between ionization pin No 1 and pin No 2 was 50 mm, between pin No 2 and pin No 3 100 mm and finally between pin No 3 and pin No 4 50 mm. Total measuring distance adds therefore up to 200 mm, Figure 3.34.

Figure 3.33 shows the setup for the firing including the Dent witness plate to simultaneously measure detonation pressure and detonation velocity.

For this firing we obtained registrations for only 3 pins as shown in Figure 3.34. Ionization pin No 4 gave no registration. Figure 3.34 shows the arrival times of the detonation front for the three ionization pins with registrations. In addition it shows the distances between the ionization pins.

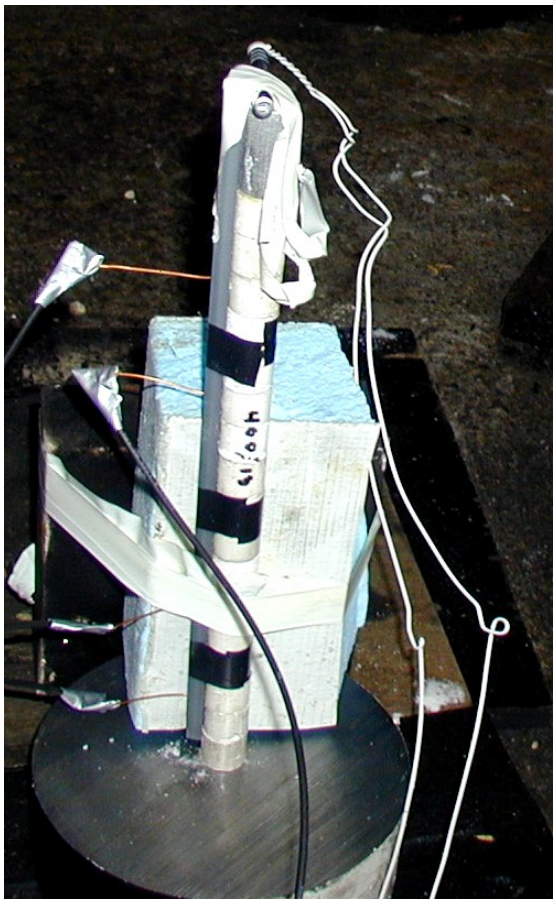


Figure 3.33 The picture shows test setup for firing No 7 with composition Sats-400/13.

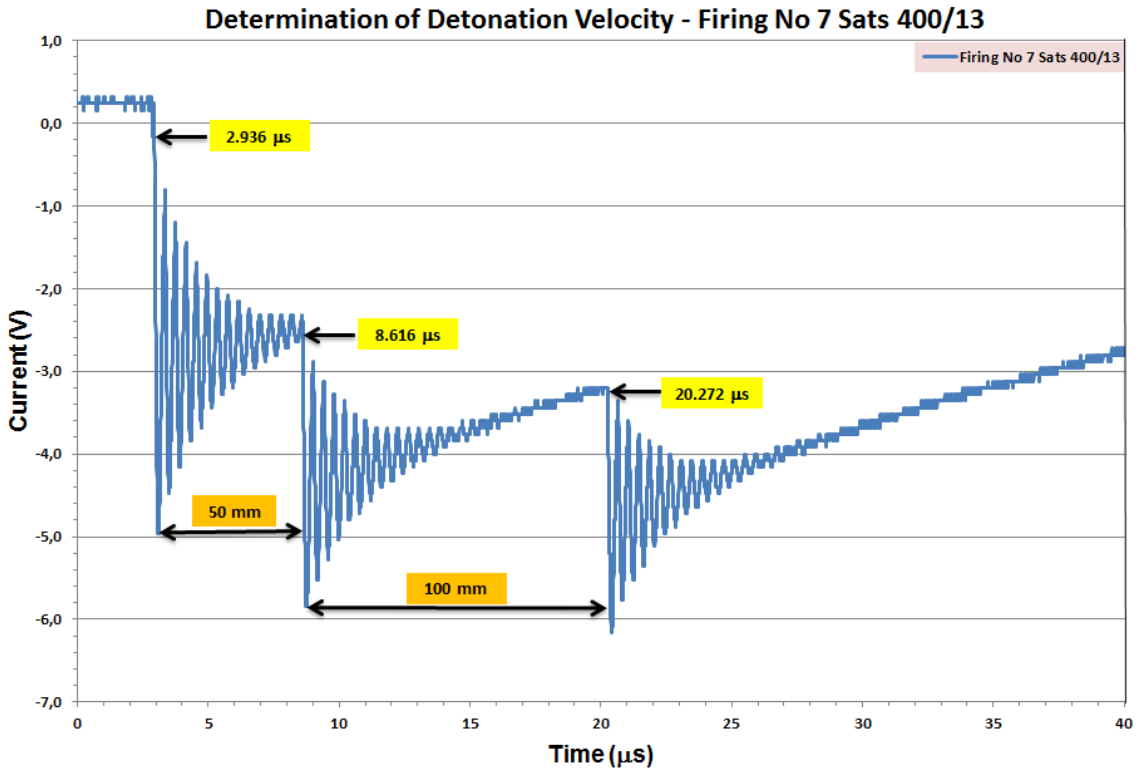


Figure 3.34 The figure shows arrival times of the detonation front at all ionization pins in addition to the distances between the ionization pins.

Table 3.14 gives a summary of obtained detonation velocities for different parts of the test item together with the overall detonation velocity of 8653 m/s.

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 7 containing Sats 400/13			
1	2.936			
2	8.616	5.68	50	8803
3	20.272	11.656	100	8579
4	No registration			
1-3		17.336	150	**8653**

Table 3.14 A summary of the results from the determination of the detonation velocity for Sats-400/13 firing No 7.

3.3.3.3 Firing No 9

The last firing of composition Sats-400/13 was firing No 9 with pellets having diameter 18.67 mm. The test item contained 17 pellets glued together to the charge shown in Figure 2.4. To measure the detonation velocity the test item was equipped with four ionization pins positioned as shown in Figure 3.35.

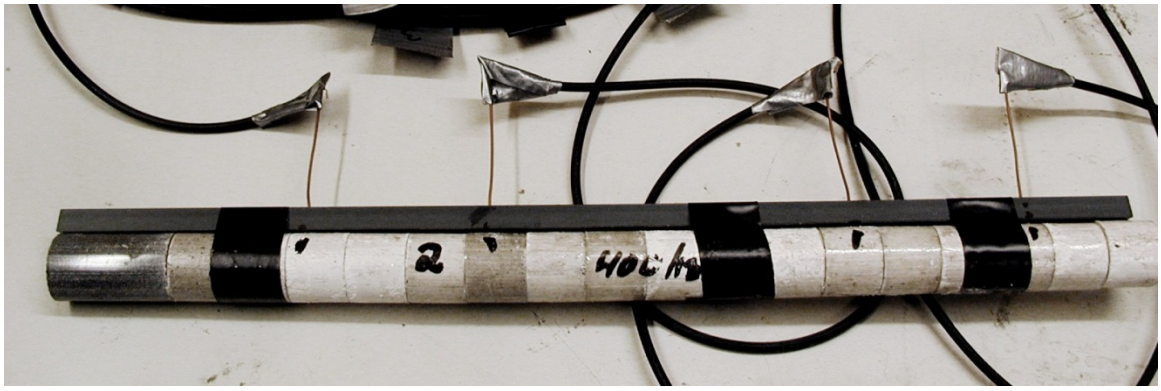


Figure 3.35 The figure shows the positions of the ionization pins.

The distance between ionization pin No 1 and pin No 2 was 50 mm, between pin No 2 and pin No 3 100 mm and finally between pin No 3 and pin No 4 50 mm. Total measuring distance therefore adds up to 200 mm, Figure 3.35.

Figure 3.36 shows the setup for the firing including the Dent witness plate to simultaneously measure detonation pressure and detonation velocity.

We did obtain registrations for all four pins as shown in Figure 3.37. Figure 3.37 gives the arrival times of the detonation front for each ionization pin. In addition it shows the distances between ionization pins.

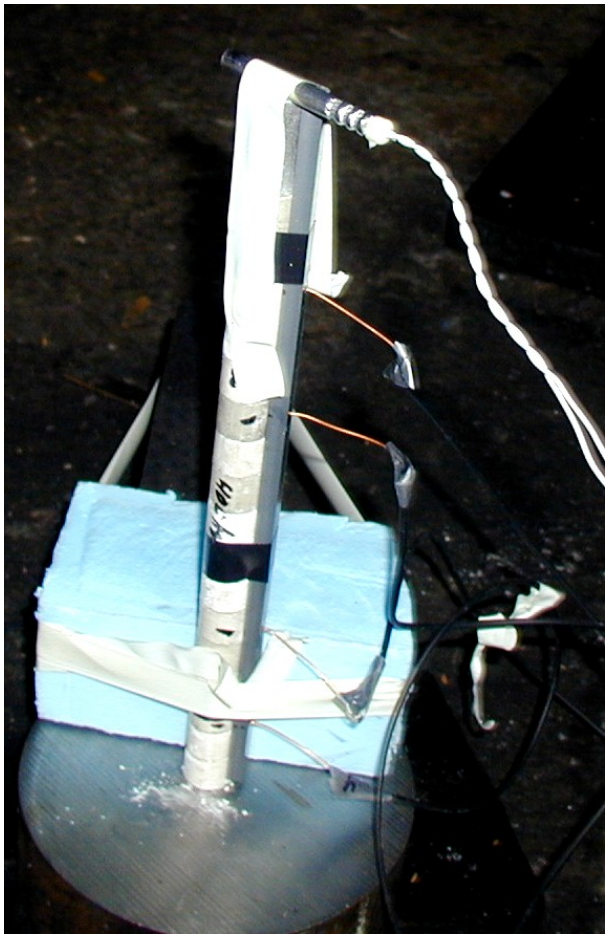


Figure 3.36 The picture shows test setup for firing No 9 with composition Sats-400/13.

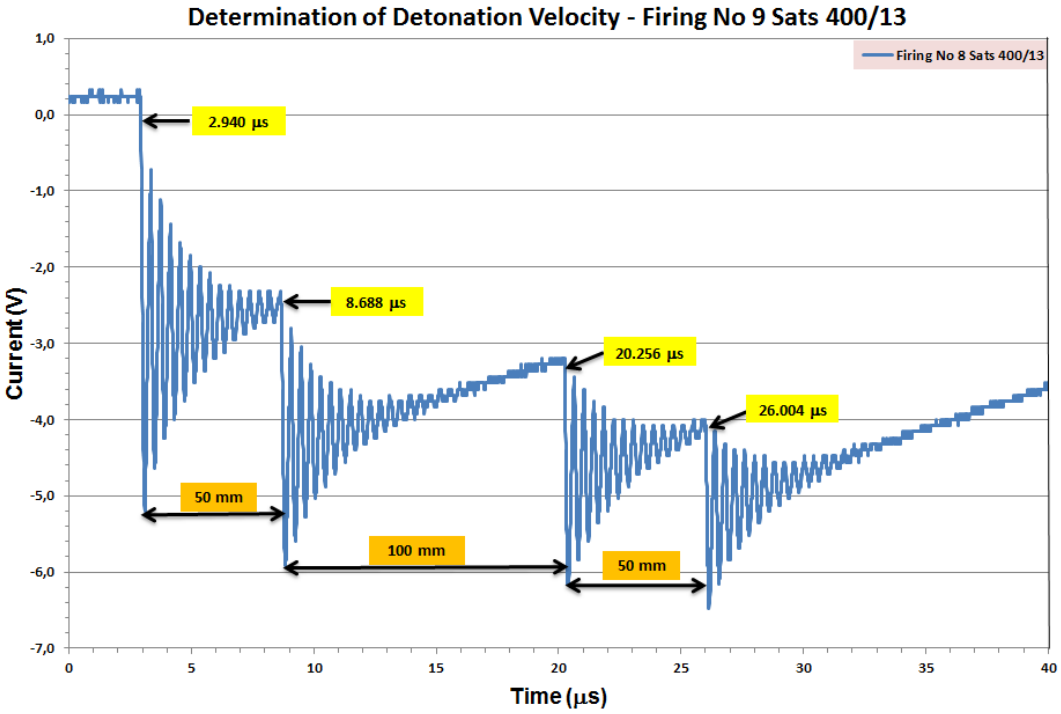


Figure 3.37 The figure shows arrival times of the detonation front at each ionization pin and distances between ionization pins.

Table 3.15 gives a summary of obtained detonation velocities for different parts of the test item together with the overall detonation velocity of 8673 m/s. The differences in detonation velocities between the different parts of the charge are very small.

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 9 containing Sats-400/13			
1	2.944			
2	8.688	5.744	50	8705
3	20.256	11.568	100	8645
4	26.004	5.748	50	8699
1-4		23.06	200	**8673**

Table 3.15 A summary of the results from the determination of the detonation velocity for Sats-400/13 firing No 9.

3.3.3.4 Comparison of the results for Sats-400/13

In Table 3.16 the average results for the three firings carried out with Sats-400/13 are given. For the three firings an average detonation velocity of 8669±14 m/s is obtained.

Firing No	Pin	Time between Pin No 1 and 4(3) (μs)	Distance from Pin 1 to Pin 4 (3) (mm)	Detonation Velocity (m/s)
	Firings containing Sats-400/13			
5	1-5	24.192	210	8681
7	1-3	17.336	150	8653
9	1-4	23.060	200	8673
	Average			**8669±14**

Table 3.16 Summary of the detonation velocity measurements for the three firings performed with composition Sats-400/13.

3.4 Plate Dent test

The Plate Dent test has been used to determine the detonation pressure for the five compositions studied in this report. First the two compositions in the initial pressing study were tested followed by the final three compositions. For all compositions except for Sats-230/13 three tests have been carried out. For Sats-230/13 only one test was performed. For the three final compositions the first firing was with a test item composed of pellets having diameter 16.1 mm. The last two firings were performed with test items of pellets with diameter of 18.6 mm.

The Dent depth has been measured with the tool described in 2.4. Calculations of detonation pressure have been performed with the equation in reference 6.

3.4.1 Sats-230/13

The setup for testing of composition Sats-230/13 is shown in Figure 3.3. The depth in the Dent witness plate shown in Figure 3.38 is 2.92 mm corresponding to a detonation pressure of 262 kbar.

Figure 3.38 Picture of the Dent witness plate for the test item of composition Sats-230/13.

3.4.2 Sats-258/13

3.4.2.1 Firing No 1

For Sats-258/13 three test items were tested in the Plate Dent test. The first firing was with a test setup as shown in Figure 3.6. Figure 3.39 shows a picture of the witness plate after firing. The depth in the witness plate was measured to 3.02 mm for this test item having a diameter of 16.14 mm. This depth corresponds to a detonation pressure of 270 kbar.

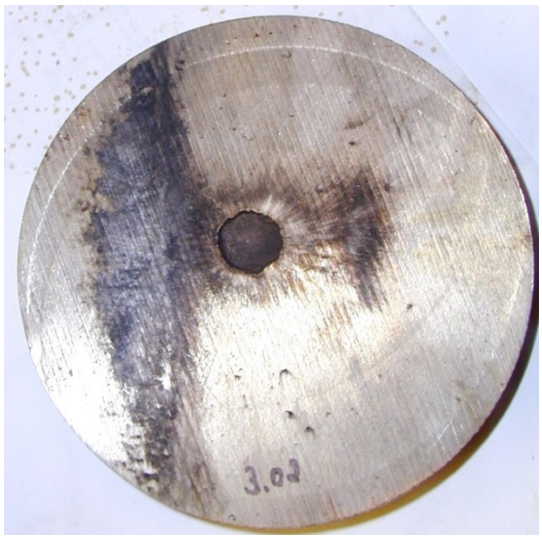


Figure 3.39 The Figure shows a picture of the witness plate from firing No 1 with a test item containing composition Sats-258/13.

3.4.2.2 Firing No 2

The second firing of Sats-258/13 was with a test setup as shown in Figure 3.7. Figure 3.40 shows a picture of the witness plate after firing. The depth in the witness plate was measured to 3.22 mm. This test item had a diameter of 16.13 mm. The Dent depth corresponds to a detonation pressure of 287 kbar.

Figure 3.40 The Figure shows a picture of the witness plate from firing No 2 with a test item containing composition Sats-258/13.

3.4.2.3 Firing No 3

Figure 3.41 gives a picture of the Dent witness plate after firing with Sats-258/13. A picture of the test setup is shown in Figure 3.10. The depth in the Dent witness plate was measured to 3.34 mm which corresponds to a pressure of 298 kbar.

Figure 3.41 Dent witness plate from firing No 3 with a test item of composition Sats-258/13.

3.4.2.4 Summary Dent test results for Sats-230/13 and Sats-258/13

Table 3.17 gives detonation pressures determined by the Plate Dent test for the four firings performed in the initial testing of the GA/BAMO (IPDI) pressed compositions. On average the Sats-258/13 composition gives higher detonation pressure than the Sats-230/13 composition. However the differences in detonation pressures are within expected range.

Shot No/Composition	Charge Diameter (mm)	Density (g/cm^3)	Dent Depth (mm)	Pressure (kbar)
1/Sats-258	16.13	1.756	3.02	**270**
2/Sats-258	16.14	1.764	3.22	**287**
3/Sats-258	16.13	1.768	3.34	**298**
4/Sats-230	16.03	1.775	2.92	**262**

Table 3.17 The Table shows the Plate Dent results for initial testing of pressed compositions.

3.4.3 Sats-432/13

3.4.3.1 Test item No 1

Sats-432/13 firing No 1 test item contained pellets with diameter 16.14 mm. Table 2.10 gives all information about the pellets. Figure 3.13 shows a picture of the test setup and Figure 3.42 gives a picture of the Dent witness plate. The Dent depth was measured to 3.14 mm, which corresponds to a detonation pressure of 280.1 kbar. The results are summarized in Table 3.18.

Figure 3.42 The witness plate from firing No 1 with a test item of Sats-432/13.

3.4.3.2 Test item No 2

The second firing with pressed pellets of Sats-432/13 was performed with a test item composed of of pellets having a diameter of 18.64 mm. Figure 3.16 shows the test setup and Figure 3.43 shows the Dent witness plate. The Dent depth was measured to 3.76 mm which corresponds to a detonation pressure of 290.5 kbar.

Figure 3.43 The witness plate from firing No 2 with a test item of Sats-432/13.

3.4.3.3 Test item No 3

The last firing with composition Sats-432/13 contains pellets with diameter 18.64 mm (pellets 18-34 in Table 2.11). The setup for the firing is shown in Figure 3.18 and the Dent witness plate is shown in Figure 3.44. The measured Dent depth was 3.65 mm which corresponds to a detonation pressure of 282.0 kbar.

Figure 3.44 The witness plate from firing No 3 with a test item of Sats-432/13.

3.4.3.4 Summary of Dent results for Sats-432/13.

Table 3.18 summarizes Plate Dent results for composition Sats-432/13. The average detonation pressure is 284.2 kbar.

Shot No	Charge diameter (mm)	Density (g/cm^3)	Dent Depth (mm)	Detonation pressure (kbar)
1	16.14	1.777	3.14	**280.1**
2	18.64	1.782	3.76	**290.5**
3	18.64	1.778	3.65	**282.0**
	Average			**284.2±5.5**

Table 3.18 The Table shows the Plate Dent results for Sats-432/13.

3.4.4 Sats-430/13

3.4.4.1 Test item 1

The first firing with composition Sats-430/13 firing No 4 was with pellets having diameter 16.14 mm. Table 2.8 gives the properties of the pellets for this test item, and Figure 3.21 shows the setup for the firing. The Dent witness plate is given in Figure 3.45. The Dent depth was measured to 3.38 mm. Converted to pressure this Dent depth is equal to a detonation pressure of 301.6 kbar.

Figure 3.45 The witness plate from firing No 4 with a test item of Sats-430/13.

3.4.4.2 Test item 2

The second firing with composition Sats-430/13 was firing No 6 containing pellets with diameter 18.66 mm. Table 2.9 gives the properties of the pellets (1-16) that the test item was made of. Figure 3.24 shows the setup for the firing. Figure 3.46 shows a picture of the Dent witness plate with a Dent depth of 3.80 mm. Converted to pressure this Dent depth is equal to 293.2 kbar.

Figure 3.46 The witness plate from firing No 6 with Sats-430/13.

3.4.4.3 Test item No 3

The third firing with composition Sats-430/13 was firing No 8 having pellets with diameter 18.66 mm. Table 2.9 gives the properties of the pellets (17-35) used to build the test item. Figure 3.27 shows the setup for the firing. Figure 3.47 shows a picture of the Dent witness plate with a Dent depth of 3.61 mm. Converted to pressure this Dent depth is equal to 278.6 kbar.

Figure 3.47 The witness plate from firing No 8 with a test item of Sats-430/13.

3.4.4.4 Summary of Dent results for Sats-430/13

Table 3.19 summarizes Plate Dent results for composition Sats-430/13. The average detonation pressure is 291.1 kbar. It's the first two firings that give the highest detonation pressures but these two also have the test items with the highest densities.

Shot No	Charge diameter (mm)	Density (g/cm^3)	Dent Depth (mm)	Detonation pressure (kbar)
4	16.14	1.789	3.38	**301.6**
6	18.66	1.783	3.80	**293.2**
8	18.66	1.779	3.61	**278.6**
	Average			**291.1±11.6**

Table 3.19 The Table shows the Plate Dent results for Sats-430/13.

3.4.5 Sats-400/13

3.4.5.1 Test item No 1

The third composition to be tested was Sats-400/13. The first firing, No 5, was with pellets having diameter 16.17 mm. Table 2.6 gives the properties of the pellets and Figure 3.30 shows the setup for the firing. The witness plate is given in Figure 3.48 with a measured Dent depth of 3.16 mm. Converted to pressure this Dent depth is equal to 281.4 kbar.

Figure 3.48 The witness plate from firing No 5 with a test item of Sats-400/13.

3.4.5.2 Test item No 2

The second firing with composition Sats-400/13 was firing No 7 containing pellets with diameter 18.66 mm. Table 2.7 gives the properties of the pellets (1-17) and Figure 3.33 shows the setup for the firing. Figure 3.49 shows a picture of the witness plate with a Dent depth of 3.68 mm. Converted to pressure this Dent depth is equal to 283.8 kbar.

Figure 3.49 The witness plate from firing No 7 with a test item of Sats-400/13.

3.4.5.3 Test item No 3

The third firing with composition Sats-400/13 was firing No 9 having pellets with diameter 18.67mm. Table 2.7 gives the properties of the pellets (17-34), and Figure 3.36 shows the setup for the firing. Figure 3.50 shows a picture of the witness plate with a Dent depth of 3.62 mm. Converted to pressure this Dent depth is equal to 279.2 kbar.

Figure 3.50 The witness plate from firing No 9 with a test item of Sats-400/13.

3.4.5.4 Summary of Dent results of Sats-400/13

Table 3.20 summarizes Plate Dent results for composition Sats-400/13. The average detonation pressure is 281.5 kbar. There are no significant differences in detonation pressure between the three firings. The average result for Sats-400/13 is slightly below the average result for all compositions.

Shot No	Charge diameter (mm)	Density (g/cm^3)	Dent Depth (mm)	Detonation pressure (kbar)
5	16.17	1.785	3.16	**281.4**
7	18.67	1.778	3.68	**283.8**
9	18.67	1.778	3.62	**279.2**
	Average			**281.5±2.3**

Table 3.20 The Table shows the Plate Dent results for Sats-400/13.

3.4.6 Summary of Plate Dent results for final compositions

Table 3.21 summarizes the Dent results for the 9 firings with the three final compositions. Average detonation pressure for all firings is 285.6±7.8 kbar. The test items with diameter 16.14 mm have a detonation pressure of 287.7±12.1 kbar and the test items with diameter 18.67 mm 284.6±6.0 kbar.

The results show no clear trends except that high charge density gives high detonation pressure. There is no indication that different charge diameters give different densities or detonation pressures. Figure 3.51 shows a plot of detonation pressures as function of charge density. Compositions with approximately the same binder content, 5.7 wt. %, fall in the same part of the figure. The composition with only 3 wt. % binder, Sats-258/13, has lower charge density and is different from the other 4 compositions.

Firing No	Charge diameter (mm)	Density (g/cm^3)	Dent Depth (mm)	Detonation pressure (kbar)
1	16.14	1.777	3.14	**280.1**
2	18.64	1.782	3.76	**290.5**
3	18.64	1.778	3.65	**282.0**
	Average Sats-432/13			**284.2±5.5**
4	16.14	1.789	3.38	**301.6**
6	18.66	1.783	3.80	**293.2**
8	18.66	1.779	3.61	**278.6**
	Average Sats-430/13			**291.1±11.6**
5	16.17	1.785	3.16	**281.4**
7	18.67	1.778	3.68	**283.8**
9	18.67	1.778	3.62	**279.2**
	Average Sats-400/13			**281.5±2.3**

Table 3.21 The table shows a summary of Plate Dent results for all firings of the final compositions.

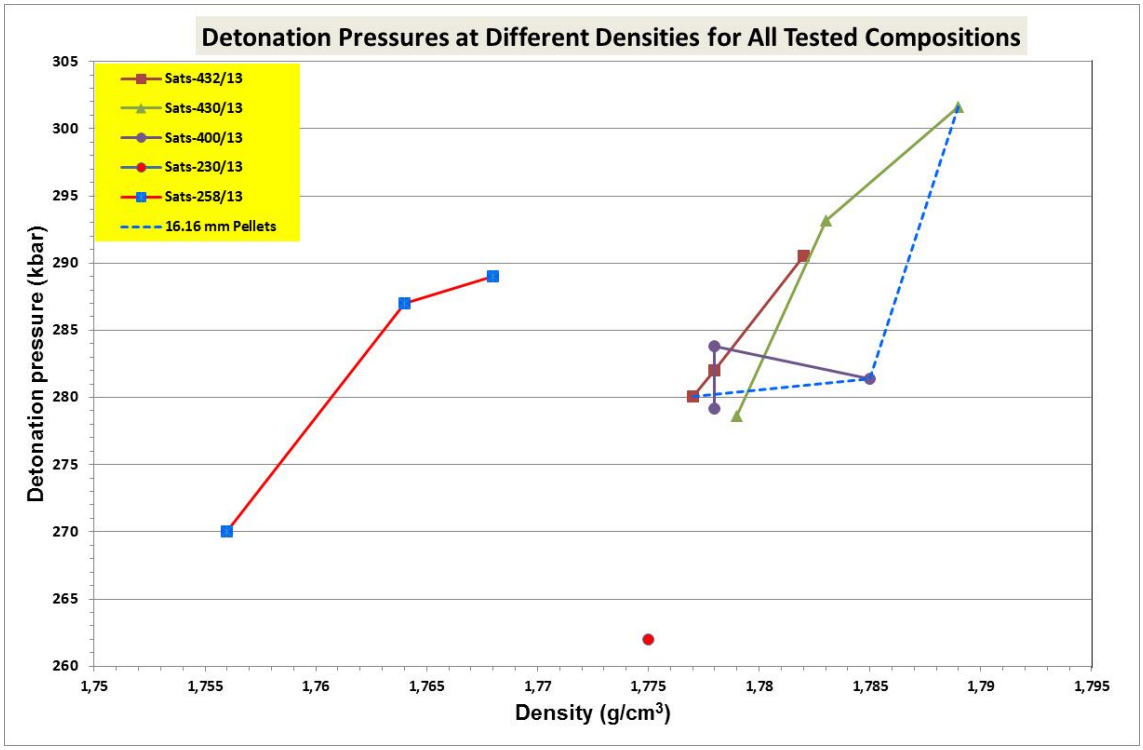


Figure 3.51 The Figure shows measured detonation pressures as function of density of all test items.

3.5 Detonation pressure and velocity summary

Tables 3.22 to 3.26 summarize the experimentally obtained detonation pressures and detonation velocities for all firings. Figure 3.52 shows a plot of the same results. There are no clear trends between these two properties other than that they all fall within the same range. Use of different press tools and the fact that the compositions have some different contents may explain this observation. One should expect that high detonation pressure is obtained in combination with high detonation velocity. However, that is not observed as a general trend. For charges with diameter18.6x mm, for two of the compositions the opposite trend is observed, high velocity is combined with low detonation pressure. For two of the firings with Sats 430/13 identical detonation velocities give different detonation pressures. For the composition Sats 258/13 pressed only in the 16.1x mm tool the highest detonation velocity gives the lowest detonation pressure.

Firing No	Charge Diameter (mm)	Density (g/cm^3)	Dent Depth (mm)	Detonation Pressure (kbar)	Detonation Velocity (m/s)
	Firings containing Sats-230/13				
1	16.03	1.775	2.92	**262**	8422
	Average			**262**	**8422**

Table 3.22 The table shows detonation velocity and pressure for Sats-230/13.

Firing No	Charge Diameter (mm)	Density (g/cm^3)	Dent Depth (mm)	Detonation Pressure (kbar)	Detonation Velocity (m/s)
	Firings containing Sats-258/13				
1	16.13	1.756	3.02	**270**	
2	16.14	1.764	3.22	**287**	8545
3	16.13	1.768	3.34	**298**	8522
	Average			**284±14**	**8534±16**

Table 3.23 The table shows detonation velocities and detonation pressures for Sats-258/13.

Firing No	Charge Diameter (mm)	Density (g/cm^3)	Dent Depth (mm)	Detonation Pressure (kbar)	Detonation Velocity (m/s)
	Firings containing Sats-432/13				
1	16.14	1.777	3.14	**280.1**	8546
2	18.64	1.782	3.76	**290.5**	8567
3	18.64	1.778	3.65	**282.0**	8636
	Average			**284.2±5.5**	**8583±47**

Table 3.24 The table shows detonation velocities and detonation pressures for Sats-432/13.

Firing No	Charge Diameter (mm)	Density (g/cm^3)	Dent Depth (mm)	Detonation Pressure (kbar)	Detonation Velocity (m/s)
	Firings containing Sats-430/13				
4	16.14	1.789	3.38	301.6	8513
6	18.66	1.783	3.80	293.2	8503
8	18.66	1.779	3.61	278.6	8503
	Average			**291.1±11.6**	**8506±6**

Table 3.25 The table shows detonation velocities and detonation pressures for Sats-430/13.

Firing No	Charge Diameter (mm)	Density (g/cm^3)	Dent Depth (mm)	Detonation Pressure (kbar)	Detonation Velocity (m/s)
	Firings containing Sats-400/13				
5	16.17	1.785	3.16	281.4	8681
7	18.67	1.778	3.68	283.8	8653
9	18.67	1.778	3.62	279.2	8673
	Average			**281.5±2.3**	**8669±14**

Table 3.26 The table shows the Plate Dent results and corresponding detonation velocities for Sats-400/13.

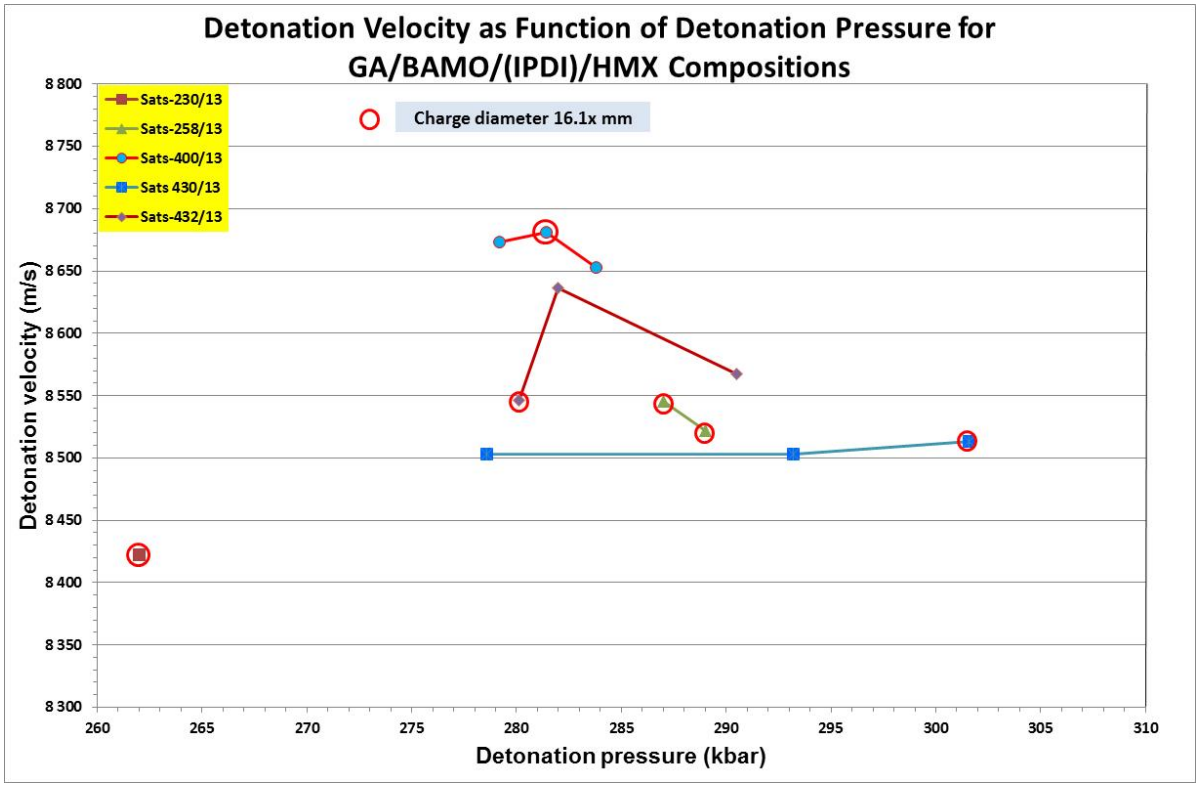


Figure 3.52 The Figure shows detonation velocity as function of detonation pressure for tested compositions.

Composition	Content			Detonation Pressure (kbar)	Detonation Velocity (m/s)
	Binder	GA/BAMO	Wt. %		
Sats-230/13	GA/BAMO	40/60	5.72	**262**	**8422**
Sats-258/13	GA/BAMO/IPDI (I)	40/60	3.0	**284±14**	**8534±16**
Sats-400/13	GA/BAMO/IPDI (II)	40/60	5.3	**281.5±2.3**	**8669±14**
Sats-430/13	GA/BAMO	30/70	5.7	**291.1±11.6**	**8506±6**
Sats-432/13	GA/BAMO/IPDI	50/50	5.7	**284.2±5.5**	**8583±47**

Table 3.27 Summary of obtained properties of tested compositions with regard to detonation velocity and pressures.

4 Summary

Five compositions containing 5 different GA/BAMO binders with HMX as filler have been studied in pressing. The obtained pressed pellets have been glued together to get test items with required length for determination of detonation velocity and detonation pressure.

The obtained densities for the majority of the pellets were 97 % of TMD or higher, an acceptable density for these compositions containing granulates with small diameter. The lowest pellet density compared to TMD was obtained for Sats-258/13. This composition contains less binder

than the 4 other compositions. Sats-258/13 has only 3.0 wt. % binder and this gives a dryer powder. For this composition the density of the pellets was on average 1.77 g/cm^3 or 95.2 % TMD. This is approximately 2% lower TMD than for the 4 other compositions. However the density of the pellets is not far from the density of the pellets from the other compositions.

For the three final compositions, which all contain 5.3-5.7 wt. % binder, we obtained more or less the same pellet density. From the pressing experiments where different press pressures, diameters of tool and amount of powder (height of pellet) were used we concluded that Sats-400/13 and Sats-432/13 should be selected for the final fragmentation study.

For all five compositions detonation velocity and detonation pressure were determined. Except for composition Sats-230/13 three tests were performed for all compositions. For Sats-230/13 only one test was performed. This test showed lower detonation velocity and detonation pressure than for the four other compositions. For the four remaining compositions the variations in detonation velocity and detonation pressure between the three parallels and between the different compositions were moderate. Sats-400/13 gave highest average detonation velocity of 8669$\pm$14 m/s and lowest detonation pressure with 281.5$\pm$2.3 kbar.

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

Appendix A Certificate Plate Dent Plates

Below is given the certificate for the steel used as witness plate in the Plate Dent test.

Item #	Charge #	Lot	Piece ID	Cust.art.#	Art #	Qty	Description
	16348				200480	1	Rundtstål S355J2/520M

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RUUKKI

OVAKO IMATRA

Inspection certificate **EN 10204 3.2 DNV** **1/ 2**

26.9.2013 **357406** **DNV HEL 13-2183**

Customer's order number W2270	Manufacturer's order number 100721 3
Customer/consignee Ruukki Norge A/S Prof. Birkelandsvei 21 1062 Oslo Norway	Buyer Ruukki Norge A/S Postboks 140 Furuset 1001 Oslo Norway
Customer reference number RUUKKI NORGE W2270	
Product Round bar As rolled Hot rolled, reeled	Steel grade S355J2/520M Specification EN10025-2:2004/IS2721.01.

Charge	Diameter/dimensions	Reduction ratio	Weight
16348	160 mm	5,71	7 880 KG

CAST ANALYSIS

	C %	SI %	MN %	P %	S %	CR %	NI %	MO %
Min					0,020			
Result	0,12	0,33	1,24	0,018	0,029	0,20	0,15	0,03
Max	0,20	0,55	1,60	0,025	0,040			

	V %	CU %	CEV %
Min			
Result	0,06	0,23	0,41
Max	0,09	0,30	0,54

CHARPY V2/-20 C (J)

	KV1 J	KV2 J	KV3 J	KV AVER J
Min				27
Result	65	100	105	90
Max				

TENSILE TEST FROM 1/3 RADIUS

	REH MPa	RM MPa	A 5 %	Z %
Min	350	490	20,0	
Result	403	548	24,6	57
Max		630		

The products supplied are in compliance with the requirements of the order

The coverage and the acceptance criteria of the UT of the bars
fulfils the requirements of SEP 1920 coverage 1/quality class A.

Ovako Imatra Oy Ab
Quality control
FI-55100 Imatra
Tel. +358 (0)5 68021
Fax. +358 (0)5 6802 211

Ovako Imatra Oy Ab
Teollisuuskuja 1
FI-14200 Turenki
Tel. +358 (0)5 68021
Fax. +358 (0)3 6334032

Certified Quality System to
ISO/TS 16949 by DNV
Business ID 2067276-0
Domicile Imatra

OVAKO IMATRA

Inspection certificate **EN 10204 3.2 DNV** **2/ 2**

26.9.2013 **357406** **DNV HEL 13-2183**

Customer's order number W2270	Manufacturer's order number 100721 3
Customer/consignee Ruukki Norge A/S Prof. Birkelandsvei 21 1062 Oslo Norway	Buyer Ruukki Norge A/S Postboks 140 Furuset 1001 Oslo Norway
Customer reference number RUUKKI NORGE W2270	
Product Round bar As rolled Hot rolled, reeled	Steel grade S355J2/520M Specification EN10025-2:2004/IS2721.01.

Charge	Diameter/dimensions	Reduction ratio	Weight
16348	160 mm	5,71	7 880 KG

The bundle labels are stamped

One end of each bar is hardstamped with cast number 16348
This is to certify that the material described above has been manufactured in conformance with the steel grade and specification mentioned on this inspection certificate and has been tested with satisfactory result according to requirement.
This certificate is issued by the manufacturer under the authorization of the Manufacturing Survey Arrangement No. R-1448, with Det Norske Veritas which is controlled by regular auditing.

Rolled steel bars used as substitute for forgings. Rules for Classification of Ships Pt. 2 Ch. 2 Sec.5.

Ovako Imatra Oy Ab
Matti Happonen
Authorized Inspector
Quality Control Laboratory

For certification/MSA
Ilpo Lehtola
Station Manager,Helsinki Office

DET NORSKE VERITAS ESTABLISHED 1864
MSA R-1447

Appendix B Control report HWC

The figure below shows the control report for the HWC composition used to press boosters for initiation of the different test items. 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.