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Influence of Initiation Strength, Ambient Inert Gas, Al-Content and Polymeric Binder on the Detonation Products of High Explosives

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1. Introduction

The knowledge of the reaction products of detonation processes is important for different reasons:

- in order to learn more in the field of kinetics of fast reaction processes, especially with regard to equilibrium or non-equilibrium reactions
- in order to evaluate the completeness of detonation reactions of energetic organic substances or of metallic ingredients such as aluminium (Al), especially as a function of the confinement and the oxygen balance of the explosive charge
- In all of these cases, the detonation products together with the heat output are capable of qualifying the reaction under different conditions.

It is the aim of this investigation to analyze the detonation products of different explosive charges, which were initiated with different initiation stimuli and under different confinements. Confinement influences reaction in so far as it adds resistances to the expansion of the gaseous detonation products and maintains high pressures and temperatures for a longer period of time before lateral rarefactions quench reaction ¹⁾

In addition, the following points have been investigated:

- the influence of ambient gas and of glass confinement
- and the influence of the Al content and of different polymeric binder systems on the detonation products.

3. Experiments

The experiments were conducted in a stainless steel containment with a volume of 1.5 m³. The cylindrical high explosive charge had a mass of about 300 g with 50 mm in diameter and 80 to 90 mm in length.²⁾ For the initiation, different boosters were used:

- 1) A booster with a weak initiation strength which consisted of 10 g RDX (Type I). The cylindrical shape of this booster had a diameter of 20 mm and a length of also 20 mm.

- 2) The second booster type consisted of 18 g explosive sheets (Type II) with the same diameter as the main explosive charge. It is expected that both boosters, type I together with type II, give rise to a more complete detonation reaction resulting in complete detonation products in such a way that no more explosive components can be identified in the post-blast residue.⁴⁾

4. Results

4.1 Different Initiation Stimuli

The results of the examination of the initiation strength of the two different boosters (type I and type I + type II) can be seen in table 1.

Table 1: Influence of a different booster strength on the initiation reaction

Initiating Booster		High Explosive Charge	TNT in Residue (wt%)
Type I 10 g RDX	Type II 18 g Expl. Sheets		
+	-	40% TNT/60% RDX (Compound B)	-
+	-	60% TNT/40% NQ	1.5
+	-	50% TNT/30% NQ/20% Mg	6.0
+	-	50% TNT/50% AN	2.0
+	+	60% TNT/40% NQ	-
+	+	50% TNT/50% NQ	-
+	+	50% TNT/50% TATB	-

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In table 1 it is shown that compound B, which is much more easily to be initiated, reacts completely also by using booster type I alone. On the contrary, nitroguanidine (NQ) and ammonium nitrate (AN) containing high explosive charges, which need a stronger initiation stimulus, leave unreacted TNT in the post blast residue, which was analyzed by High Performance Liquid Chromatography (HPLC). The same holds for the charge containing magnesium (Mg). On the other side, a complete detonation reaction is shown by using both types of boosters together: No more TNT could be analyzed.

4.2 Influence of Ambient Gas and Glass Confinement on the Detonation Products

When detonating high explosives in different atmospheric conditions, it is of interest to know if the detonation products or the energy out-put will change. In order to investigate this behavior, charges containing 45 % TNT and 55 % Nitroguanidine (NQ) were initiated in the containment under different pressures of argon and in vacuum. In addition, the same charges were conducted which had a glass confinement. In this case, the glass tube exhibited a wall thickness of 9 mm. The results of the unconfined and the glass-tube confined charges are in table 2 and 3.

Table 2: Influence of vacuum and of different argon pressures on the detonation products

Sample No.	1450/1c	1450/2c	1450/3c
Ar pressure [MPa]	Vac.	0.05	0.1
Composition	45% TNT/55% NQ		
O ₂ -Balance [%]		-47.6	
Charge Weight [g]	331	332	331
ΔH_f [kJ/kg]	-661	-662	-657
<i>Products [mol %]</i>			
H ₂	20.7	8.3	5.0
CH ₄	0.04	0.1	0.24
CO	32.1	17.9	14.3
CO ₂	3.7	7.9	10.3
N ₂	27.5	26.1	25.6
NO	0.1	0.1	0.13
HCN	0.3	3.2	3.6
NH ₃	0.5	3.0	4.9
C ₂ H ₂	0.02	0.03	0.1
H ₂ O	10.7	19.6	20.0
C _s	4.4	13.8	15.9
ΔH_{det} [kJ/kg]	2999	3653	3763
C in Residue [% of total C]	10.8	32.2	35.7
Gas formation [mol/kg]	44.5	37.9	35.7

**Table 3: Influence of glass confinement
on the detonation products**

Composition		45% TNT / 55% NQ		
Sample No.	1451/1	1451/2	1451/3	
Ar pressure (Mpa)	Vacuum	0.05	0.1	
Oxygen balance (%)	-47.6	-47.6	-47.6	
Charge weight (g)	332	335	332	
ΔH_f (kJ/kg)	-656	-658	-658	
Products (mol%)				
H ₂	8.7	4.2	3.1	
CH ₄	0.2	0.4	0.44	
CO	15.9	10.2	9.3	
CO ₂	7.9	11.9	12.7	
N ₂	27.3	26.0	25.6	
NO	0.06	0.05	0.14	
HCN	1.35	2.4	1.1	
NH ₃	1.15	4.7	5.3	
C ₂ H ₂	0.07	0.1	0.13	
H ₂ O	20.5	20.7	21.0	
Cs	16.8	19.2	21.3	
ΔH_{det} (kJ/kg)	3779	3960	4003	
C in residue (% of total C)	39.8	43.3	47.2	
Gas formation (mol/kg)	37.1	34.4	33.0	

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From table 2 we see that the detonation products change strongly when going from vacuum to 1,0 bar argon (0.1 MPa) of the unconfined charge. The concentration of H₂ und CO decrease, whereas CO₂, H₂O and carbon formation increase in the same manner as the detonation heat increases. This means that a detonation under a pressure of 1 bar is much more powerful with regard to the energy output than in vacuum.²⁾

On the other hand, the glass confined charge exhibits already in vacuum detonation products which are similar to those at 0.1 MPa argon of the unconfined charge, as we see comparing table 2 with 3. But the heat output increases also with higher ambient pressure of 0.05 and 0.1 MPa, but not in the same magnitude as before regarding the unconfined charges. As a conclusion we can say that ambient argon of one bar behaves as a confinement. Experiments conducted with 2,0 und 3,0 bar argon exhibited nearly no more further improvement of the confinement.²⁾

Composite explosives consisting of polybutadien binder and RDX have shown the same behavior as TNT/NQ when using different ambient pressures of argon as we see in table 4.

Also here increases the heat of detonation very strongly from vacuum to 0.05 MPA argon, because of the increase of H_2O and CO_2 and of carbon via the exothermal Boudouard-reaction

Table 4: Detonation products of PBX - charges

Sample No.		HX 72/1	HX 72/2	HX 72/3
Ar pressure [MPa]		Vacuum	0.05	0.1
Composition		20% PB/80% RDX (10 μm)		
O_2 -Balance [%]			-73.3	
Charge Weight [g]		329	328	330
ΔH_f [kJ/kg]		-94	-90	-95
<i>Products [mol %]</i>	H_2	33.5	15.0	12.3
	CH_4	0.1	0.7	2.9
	CO	34.4	17.3	13.1
	CO_2	1.2	3.5	6.6
	N_2	18.8	18.0	18.8
	NO	0.05	0.03	0.02
	HCN	0.1	0.8	0.9
	NH_3	0.5	2.9	2.8
	C_2H_2	—	0.06	0.5
	H_2O	4.8	19.6	19.9
	C_s	6.6	22.2	22.2
ΔH_{det} [kJ/kg]		2949	4214	4440
C in Residue [% of total C]		15.7	49.9	47.3
Gas formation [mol/kg]		52.1	42.0	39.7

4.3 Influence of Al Content on the Detonation Products

It is very interesting that the detonation of Al containing PBX-charges with Polybutadiene (PB) binders exhibit a different detonation behavior as to be seen in table 5. In this PBX-charge, consisting of 15 % PB, 15 % Al and 70 % RDX, we cannot more find the strong influence of vacuum on the detonation products compared with one bar argon (0.1 MPa). The same holds also for the detonation enthalpy, which is not very different for the vacuum shot compared with that of one bar argon.

Table 5: Detonation products of Al - containing PBX - charges

Sample No.	HXA 123/1	HXA 123/3
Ar pressure [MPa]	Vacuum	0.1
Composition	15% PB/15% Al Alcan 400 56% RDX Class C/14% RDX (10 μ m)	
O ₂ -Balance [%]		-69.3
Charge Weight [g]	331	331
ΔH_f [kJ/kg]	-73	-71
<i>Products</i> [mol %]		
	H ₂	29.5
	CH ₄	0.04
	CO	26.1
	CO ₂	0.01
	N ₂	16.9
	NO	0.07
	HCN	0.1
	NH ₃	2.2
	C ₂ H ₂	0.04
	C ₂ H ₄	0.03
	H ₂ O	4.2
	Al ₂ O ₃	4.6
	Al	1.6
	C _s	14.6
		14.3
K _p (T)	?	2.018
Freeze out Temp. [K]		1365
ΔH_{det} [kJ/kg]	5143	5066
C in Residue		
[% of total C]	35.6	34.5
Unreacted Al [%]	15.0	28.0
Gas formation		
[mol/kg]	38.6	37.0

**Table 6: Detonation products of HMX / Al / PIB charges
with different Al - content**

Sample No.:	PHXA-81	PHXA-82
Composition, %	65 HMX/25 Al/10 PIB	60 HMX/30 Al/10 PIB
Ar pressure (MPa)	0.1	0.1
Oxygen balance (%)	-63.45	-66.05
Charge mass (g)	220.0	221.5
ΔH_f (kJ/kg)	-96.2	-119.7
Products (mol%)		
H ₂	26.1	28.9
CH ₄	1.7	1.4
CO	21.3	22.3
CO ₂	3.2	2.5
N ₂	20.1	18.9
HCN	3.2	2.6
C ₂ H ₄	1.7	1.4
H ₂ O	3.6	2.6
C _s	7.1	6.9
Al ₂ O ₃	7.9	9.4
Al	4.1	4.9
ΔH_{det} (kJ/kg)	6583	7027
Al in residue (% of total Al)	20.8	20.6
C in residue (% of total C)	17.7	18.0
Gas formation (mol/kg)	31.3	29.8

Table 7: Detonation products of charges with different binders

Composition, %	65 HMX/25 Al/10 PIB	60 HMX/25 Al/15 GAP
Ar pressure (MPa)	0.1	0.1
Oxygen balance (%)	-63.45	-54.40
Charge mass (g)	220.0	328.7
ΔH_f (kJ/kg)	-96.2	-141.8
Products (mol%)		
H ₂	26.1	30.0
CH ₄	1.7	0.1
CO	21.3	26.5
CO ₂	3.2	0.2
N ₂	20.1	21.6
NO	?	0.1
HCN	3.2	1.9
C ₂ H ₄	1.7	0.05
H ₂ O	3.6	1.0
C _s	7.1	7.7
Al ₂ O ₃	7.9	10.7
Al	4.1	0.12
ΔH_{det} (kJ/kg)	6583	7481
Al in residue (% of total Al)	20.8	0.6
C in residue (% of total C)	17.7	21.2
Gas formation (mol/kg)	31.3	30.1

We assume that an increase of CO_2 and H_2O with increased pressure is prevented by the reaction of these components with Al. This can be explained by the fact that especially H_2O decreases dramatically with increase of Al, as we see in table 6, where the detonation products of two plastic bonded explosive charges containing 25 % and 30 % Al are described. In this case HMX as explosive component and polyisobutylene (PIB) as a polymeric binder have been used.

4.4 Influence of the Polymeric Binder on the Detonation Products

In order to evaluate the influence of different binder systems on the detonation reaction, we investigated two explosive charges containing polyisobutylene (PIB) on the one side, and Glycidylazide polymer (GAP) on the other side.³⁾

The two compositions were as follows:

Charge A: 65 % HMX, 25 % Al, 10 % PIB

Charge B: 60 % HMX, 25 % Al, 15 % GAP

The main difference between the two charges is the oxygen balance, which is better in the GAP-containing charge (- 54,4 %) compared with - 63,45 % in the PIB containing charge, see table 7.

Although the enthalpy of formation is less negative and therefore more energetic in Charge A because of the higher HMX content, the better O_2 -balance of Charge B is responsible for a more complete reaction of Al.

In Charge B with the energetic binder we found only 0,6 % of unreacted Al, compared with 20,8 % in Charge A.

The more complete Al-reaction leads to a much higher energy output:

Charge B: 7481 kJ/kg

Charge A: 6583 kJ/kg

This means that the O_2 -balance is very important especially for Al-containing high explosives.

This behavior of different binder systems is easily to understand when we compare the O_2 -balances of HMX with GAP, Polybutadien (HTPB) and Polyisobutylen (PIB) as to be seen in table 8.

Table 8: Oxygen balance and enthalpy of formation of different binder systems

	Oxygen balance (%)	ΔH_f (kJ/kg)
GAP	-121.1	1179
R 45M (HTPB)	-323.0	-380
PIB	-342.2	-1568
80 RDX / 20 GAP	-41.5	457.4
80 HMX / 20 GAP	-41.5	438.5
80 HMX / 20 HTPB	-81.9	126.9
80 HMX / 20 PIB	-85.7	-110.8

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5. Conclusion

The influence of different boosters on the initiation of explosive charges containing TNT and nitroguanidine has been investigated. It was found, that a complete detonation was only observed after placing an additional booster sheet with the same diameter as the explosive charge on the front side of the cylindrical charge.

The investigation of Al-containing charges exhibited a very different behavior compared with the charges without Al. No more influence of vacuum or of different ambient gas pressure could be observed.

By comparing two charges with different oxygen balances it was found a great influence on the reaction of Al. The PBX charge with the better O_2 -balance containing the energetic GAP-binder reacted nearly complete with the Al, opposite to the charge containing the Polyisobutylene (PIB) binder system.

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