INSENSITIVE ENHANCED BLAST FORMULATION

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Abstract

To select the most efficient enhanced blast formulations of the system Hexogen / Aluminium / HTPB, in a first step the heat of combustion, the heat of detonation and the difference of both the heat of afterburning were calculated. The quotient of the heat of afterburning and heat of detonation and a minimum of the heat of detonation was useful to limit the possible formulations. Experiments were done in a combustion chamber, results of pressure and temperature measurements are presented. The inert binder HTPB is compared with the energetic binder GAP. The results of the enhanced blast formulations were compared with TNT and PBXN-109.

Introduction

Enhanced blast explosives consist in general of a binder, high explosives and metal particles as fuels. The formulation can be optimised for high heat output, high blast output or a combination of both. For this study the system HTPB / Aluminium / HTPB was selected. To get a better understanding how much of each ingredient is necessary to get an optimized enhanced blast performance a simple model was used.

Modelling

To describe the reaction of an enhanced blast explosive after the ignition, a three phase model is suggested /1, 2/. After the detonation process and an anaerobic expansion, a combustion phase is followed. To examine these the phases, in a first step the detonation process is studied.

To describe the detonation process the CHEETAH code was used. The calculations were made over the maximum possible concentration range with 100% of the theoretical maximum density of the formulation. During the calculations the option Al was used instead of Al inert. In Figure 1 the results of the CHEETAH code computations concerning the heat of detonation are shown. For a heat of detonation greater than 4 kJ/g and at a constant mass fraction of binder, the greatest possible heat of detonation is reached for an Aluminium concentration between 10 and 30 mass percent.

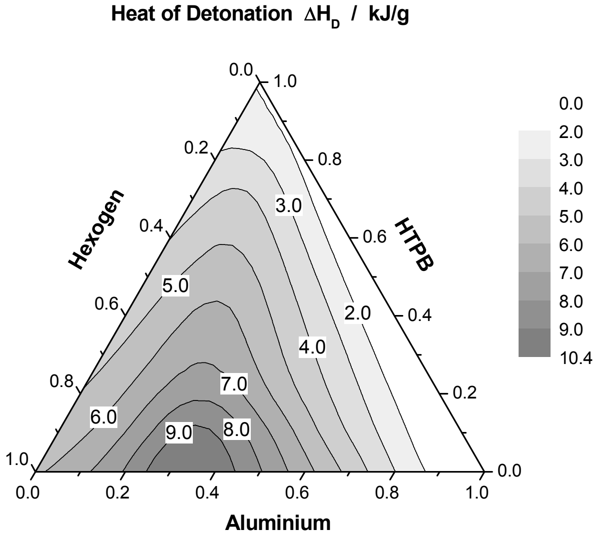

Figure 1: Heat of detonation ΔH_D for the system Hexogen / Aluminium / HTPB

For further calculations the heat of combustion is needed, which is plotted in Figure 2.

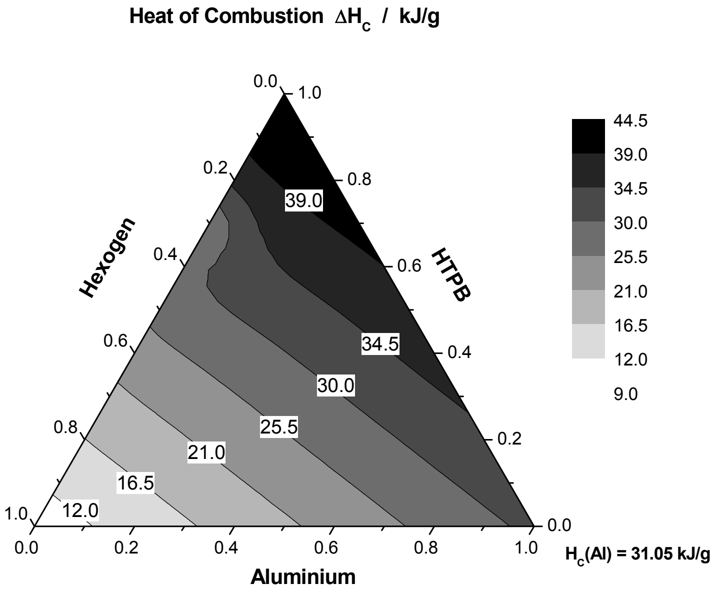

Figure 2: Heat of combustion ΔH_C for the system Hexogen / Aluminium / HTPB

With the heat of combustion and the heat of detonation, the heat of afterburning can be calculated according to equation (1).

$$\Delta H_{AB} = \Delta H_C - \Delta H_D \qquad (1)$$

In Figure 3 the heat of afterburning is divided by the heat of detonation. For efficient enhance blast formulations this mentioned relation should be at least greater than 1.

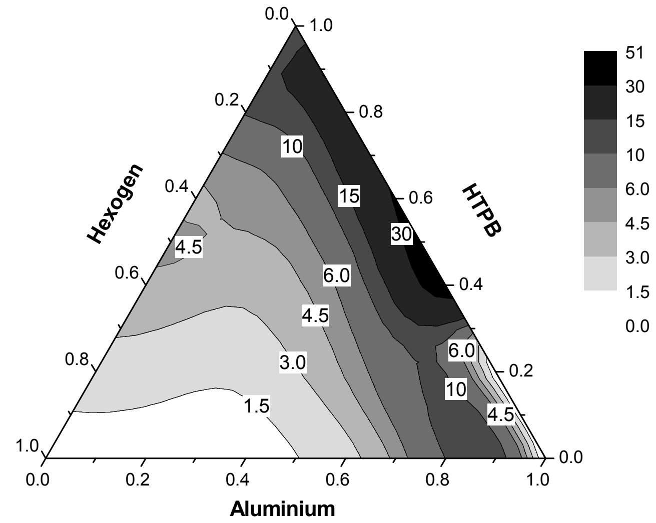

Figure 3: ΔH_{AB} / ΔH_D for the system Hexogen / Aluminium / HTPB

Not only a high value of ΔH_{AB} / ΔH_D is recommended, a minimum of blast in free field applications is recommended as well. In Figure 4 possible formulations are marked in grey which meet the requirements of ΔH_{AB} / ΔH_D is greater than 2 and the heat of detonation ΔH_D is greater than 4 kJ/g.

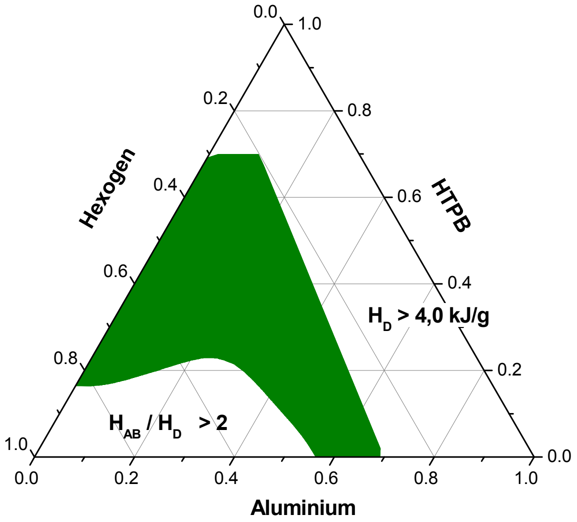

Figure 4: **Heat of detonation for the system Hexogen / Aluminium / HTPB**

Experimental Setup

More than 70 experiments were done in free field and in the detonation chamber. The closed Fraunhofer ICT detonation chamber has a free inner gas volume of 45m³. The mass of the charge was selected to 2000 g explosives for all experiments. All formulations were castable; no results of heterogeneous formulations were studied.

Additionally a booster charge of 160 g of pressed HWC with a composition of Hexogen /Wax/Graphite (94.5%/ 4.5%/1%) was used. The limit of 2.16 kg of charge mass leads to a maximum of static overpressure which fits the design criteria of the detonation chamber. The total amount of atmospheric oxygen in the chamber is suitable to enable completely oxidised reaction products.
The pressure was measured using piezoresistive pressure gauges with extended temperature range. Temperature-time histories of the gas phase were detected with 0.5 mm type K thermocouples. To receive the Impulse, the pressure-time histories were integrated over 0.5 seconds. The temperature curves were integrated between 0 ms and 2000 ms. The diagrammatic view of the octagonal detonation chamber and the application of the charge in the detonation chamber is shown in Figure 5. More details of the test setup were already published /4/.

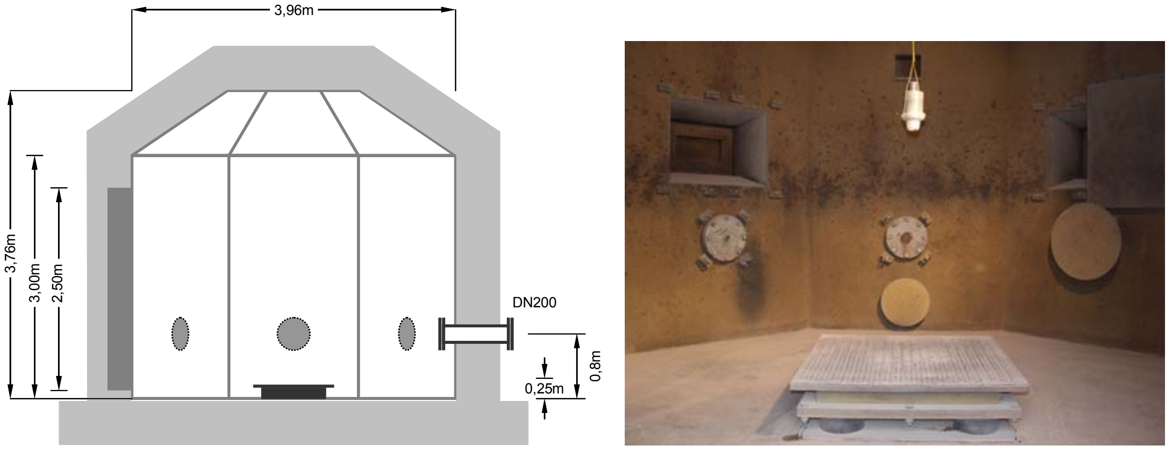

Figure 5: **Diagrammatic view and suspension of the charge in the detonation chamber**

Results

In this study the HTPB binder is compared with Glycidylazidpolyer-diol. The GAP-idol is crosslinked with Desmodur N100 in absence of plasticizer. In the literature /5/ the energetic binder GAP is proposed as a suitable binder for enhanced blast formulations.
For every binder type six experiments were done in the detonation chamber. The highest measured pressure for each formulation is pointed out in Figure 6. Concerning HTPB formulations, the highest detected pressure was found at the lowest Aluminium and Hexogen content. At constant mass percentage of Hexogen, the pressure decreases with increasing the Aluminium mass percentage. At a constant mass percentage of binder, the pressure decrease slightly. GAP based formulation show in general a lower pressure level than HTPB based formulations. With decreasing Hexogen, the pressure is rising. In contrast to HTPB formulations the pressure increases with increasing Aluminium content. The reason could be the higher heat of detonation of GAP based formulations.

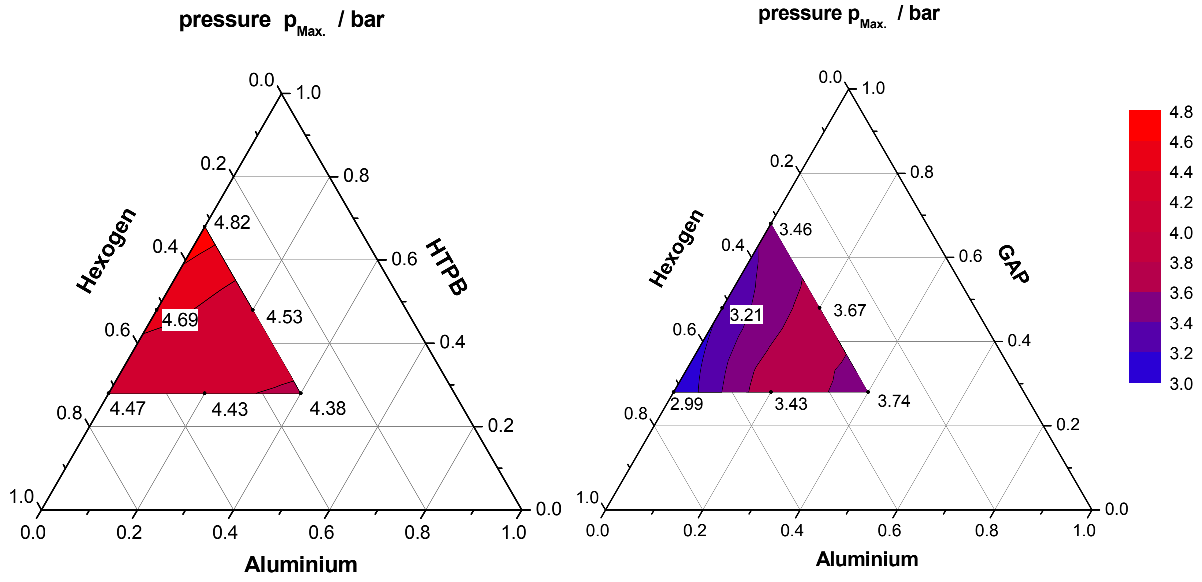

Figure 6: Maximum pressure $p_{Max.}$ for HTPB and GAP based formulations

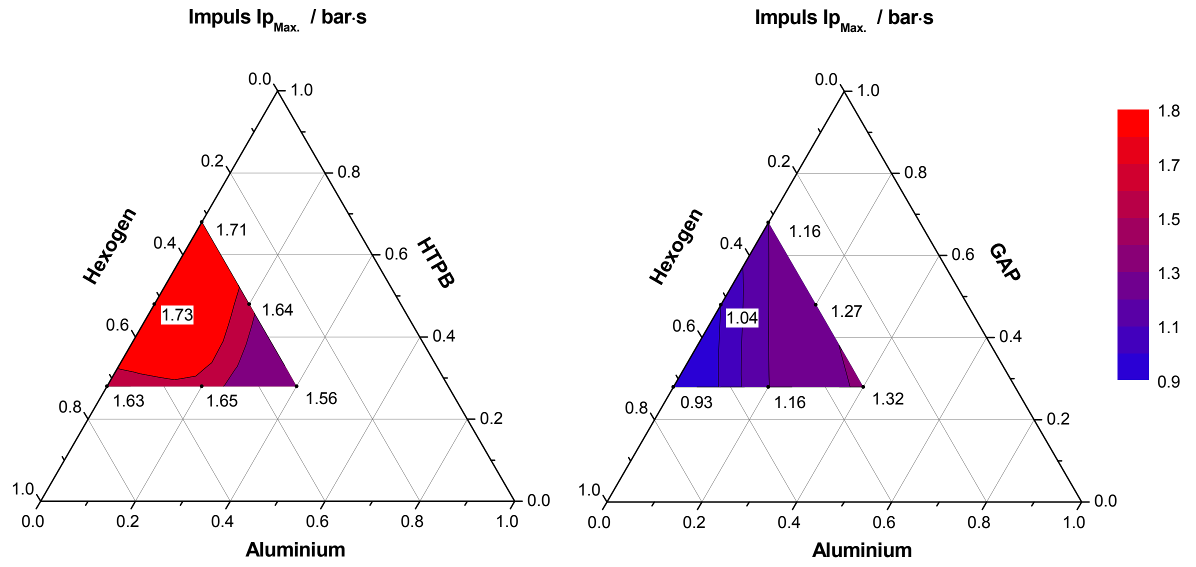

Figure 7: Impulse Ip for HTPB and GAP based formulations

The impulse in Figure 7 is the integral of pressure over 0.5 seconds. The impulse shows the same trend as the pressure in Figure 6. The impulse for HTPB based formulations is higher compared to GAP based formulations.

Arnold and Rottenkolber /2/ show with Hydrocode simulations that the pressure equilibrium is reached much earlier than the temperature equilibrium in the detonation chamber. Even when the turbulent combustion is finished, it takes time that the gases reached an equilibrium temperature. The result is a higher fluctuation in the temperature.

In Figure 8 the maximum measured temperature is shown. HTPB based formulations displayed the highest temperature with no aluminium at the lowest Hexogen content. As a result of increasing the mass percentage of RDX in formulations, lower temperatures are measured. At constant mass percentage of binder there is no significant change in the measured temperature.

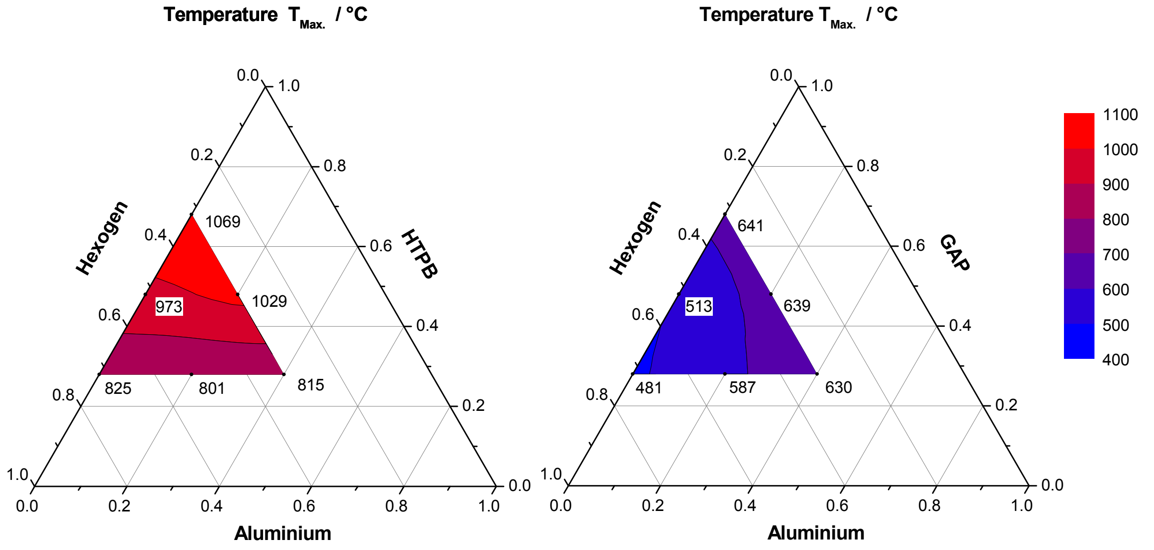

Figure 8: Temperature $T_{Max.}$ for HTPB and GAP based formulations

GAP based formulations indicate a different behaviour. The highest temperature is observed at the lowest aluminium and RDX content. In contrast to HTPB based formulations an increase of the temperature is observed with increasing the aluminium mass percentage. Nevertheless, the highest measured temperature of GAP based formulations is more than 150 °C lower than the lowest measured temperature of HTPB based formulations.

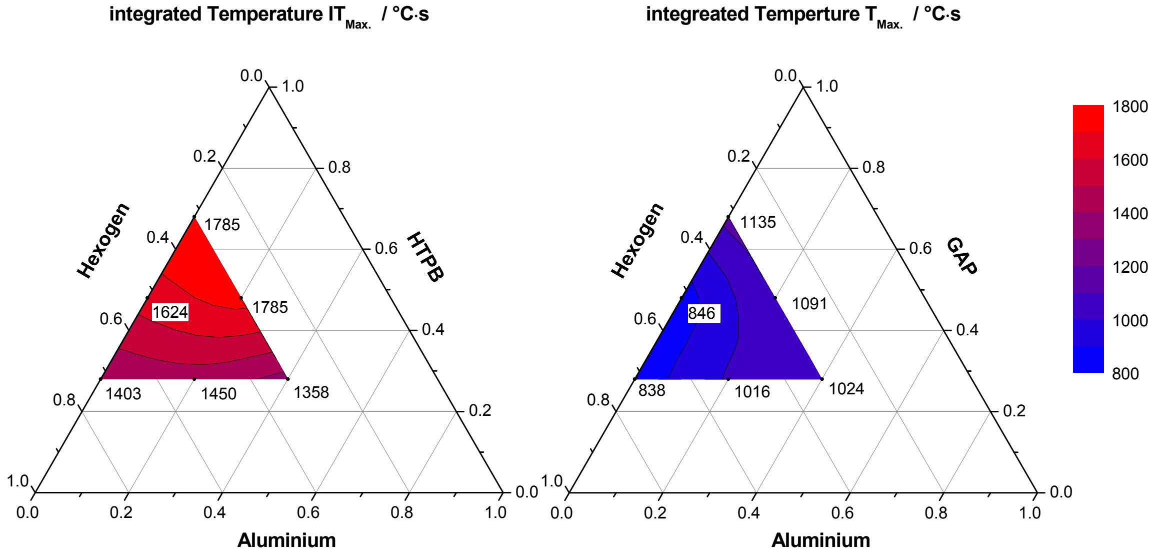

Figure 9: Integrated Temperature $IT_{Max.}$ for HTPB and GAP based Formulations

The integrated temperatures in Figure 9 confirm the above formulated trends of the temperature. The highest integrated temperatures were detected with HTPB based formulations.

To compare the results of the new enhanced blast formulations, in the Fraunhofer ICT combustion chamber standard formulations were tested. The mass of the charge was kept constant for all tests. The results are listed in Table 1. TNT shows the lowest measured pressure. PBXN-109 indicates a slightly higher pressure in the combustion chamber, compared to TNT. The new enhanced blast formulation EBX 26 has an impulse I_P which is more than 50% higher than TNT, and a measured maximum temperature which is twice as much as TNT. Compared to TNT, the EBX 47 formulation doubles approximately the impulse as well as the integrated temperature.

Table 1: Comparison of different formulations

Formulation	$p_{Max.}$ / bar	I_p / bar·s	$T_{Max.}$ / °C	I_T / °C·s
TNT	3.26	1.06	548	939
PBXN-109	3.51	-	-	-
EBX 26 (2008)	4.85	1.67	1139	1828
EBX 47 (2009)	5.47	2.08	1099	1850

To determine the insensitive properties 50 mm PMMA Gap-Tests were made. The length of the charge amount to 100 mm. A pressed HWC Donor Charge was used.

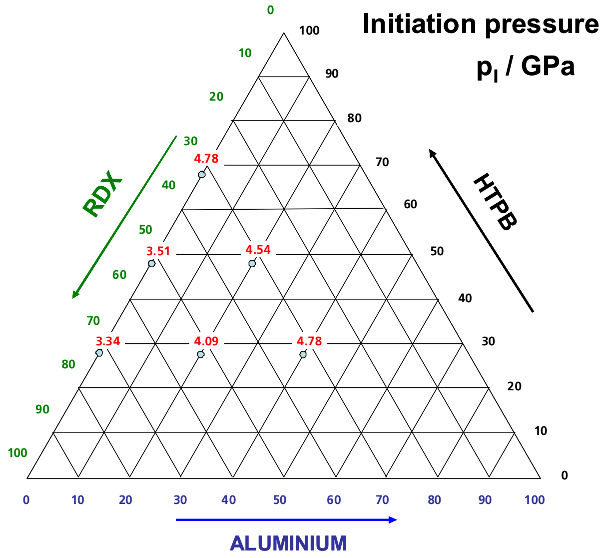

Figure 10: 50 mm Gap-Test results of RDX / Aluminium / HTPB based Formulations

As you can see from Figure 10 the initiation pressure increases with increasing the Hexogen content. At constant filler content the Initiation pressure increases with increasing the amount of aluminium. For all tested formulations the initiation pressure is greater than 2.5 GPa. This is according to the WIWEB handbook /6/ necessary of an insensitive behaviour of the formulation.

Conclusion

The proposed limitation of ΔH_{AB} / ΔH_D greater than 2 and the restriction of ΔH_D is greater than 4 kJ/g, is a useful tool to select efficient enhanced blast explosives. The formulation system Hexogen / Aluminium / HTPB was compared with Hexogen / Aluminium /GAP based formulations. Experiments in a combustion chamber were made. The highest pressure was measured for HTPB based formulations at the lowest Aluminium and Hexogen content. The pressure decreases slightly with increasing the aluminium content. GAP based formulations shown lower pressure and temperature values compared to HTPB based formulations. In contrast to HTPB based formulations the pressure increases with increasing the Aluminium content.

References

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6 Handbuch der Prüfvorschriften zur Ermittlung der sicherheitstechnischen Eigenschaften von Explosivstoffen, WIWEB, 2002