# What Influences the Shock Sensitivity of High Explosives?

**Dr. Werner Arnold, Dr. Helmut Muthig**

TDW Gesellschaft für verteidigungstechnische Wirksysteme mbH, Hagenauer Forst,
D-86529 Schrobenhausen, Germany
E-mail: werner.arnold@eads.com
helmut.muthig@eads.com

## Abstract

*Performance* and *Sensitivity* are the two most important features characterizing the properties of high explosives (HEs) and charges. Very often the performance of HEs has to be changed to meet specified, e. g. warhead requirements. But unfortunately, in most cases this means that also the sensitivity will be changed. Therefore the knowledge of the significant parameters influencing this sensitivity is not only useful but in fact crucial.

Many years ago, TDW has developed its own Gap Test which is in the meantime established as a very valuable tool to study the shock sensitivity of HEs. Even minor changes in the sensitivity caused by these parameters and not detected with simple tests like the friction or impact test can be measured with this Gap Test.

In the present paper a study on the investigation of the sensitivity trends will be presented while changing a broad field of the above mentioned significant parameters. In this way the study will deliver insight in the quantitative influence of parameters on the one hand important for high explosive formulations including different RDX- and HMX-crystals (e. g. also I-RDX) and binder systems. But it will on the other hand also describe parameters like voids or defects which might be caused during the manufacturing process or the application.

## 1 Introduction

In preceding papers [1-4] the motivation for these investigations were already indicated. Due to the broad spectrum of shock loads, especially for penetrator applications, the knowledge of high explosive (HE) shock sensitivity is of enormous importance (Figure 1). As already mentioned in [1] the HEs used in the Mephisto penetrator: KS22a and in the pre-charge: KS33 serve as baseline. As shown later, their shock sensitivities differ by an amount of 48 %.

The following questions came up: what are the reasons for this difference, how big are the influences by exchanging HMX with RDX, by using Aluminium or putting in a different binder instead of HTPB? In the context of hard target penetration, additional questions were of concern: how do voids or defects influence the shock sensitivity? Is there a risk of premature initiation of the high explosive (HE) due to voids while the penetrator perforates a target (Figure 1)? Are there even additional voids or defects provoked when perforating the first layer of the target which again could cause a premature initiation in the following layer(s)? And finally, are I-RDX or improved HMX really reducing the shock sensitivity and could this be helpful in applications like that? All these questions will be taken up in the following sections.

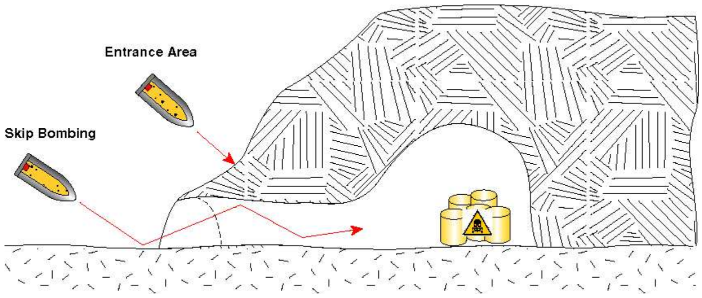

Figure 1: Multi spectral shock loading of a penetrator HE

A typical tool for measuring the shock sensitivity is the Gap Test. Many years ago TDW has developed its own Gap Test which is in the meantime established as a very valuable tool to study the shock sensitivity. The measurement of the “run distance to detonation” as a function of the “gap pressure” is carried out by a rotating mirror camera in streak technique. The test was already described in detail elsewhere [4].

## 2 Baseline

As mentioned above, the Mephisto HEs serve as the baseline. The formulations of these high explosives are:

| | | | |
|---|---|---|---|
| KS22a: | RDX / Al / HTPB | 67/18/15 | $\rho_0$ = 1.64 g/cc |
| KS33: | HMX / HTPB | 90 / 10 | $\rho_0$ = 1.71 g/cc |

The Gap Test results for these two HEs were taken from [1] and are graphically shown in Figure 2. Both curves will be used as references in the following to detect deviations while changing significant parameters. More sensitive HEs would be shifted to the lower left corner and less sensitive HEs to the upper right corner of the diagram. Arrows on the upper edge of the diagram mark trials where no detonation occurred within the 50 mm length of the acceptor charge. To quantitatively measure deviations, the Gap pressure at a 20 mm run distance to detonation is evaluated in Figure 2. For KS33, a value of 3.23 GPa and for KS22a one of 4.78 GPa can be ascertained. This is a difference of 1.55 GPa which means an increase in insensitivity of 48 % by changing the formulation from KS33 to KS22a. The question is now, what are the reasons for this change in insensitivity?

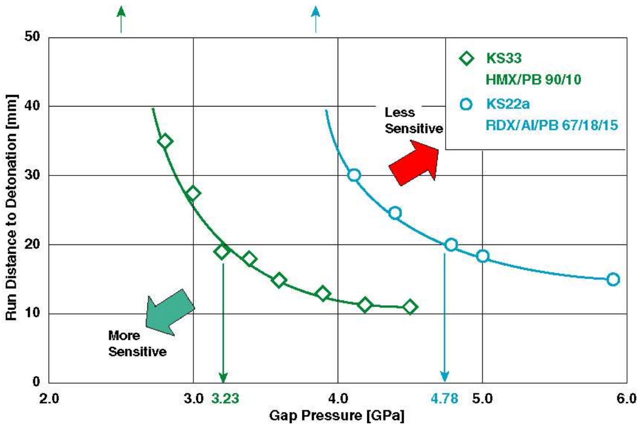

Figure 2: Gap Test results for KS22a and KS33 serve as baseline

## 3 Influence of Formulation

In this section, the formulation was changed step by step starting with KS33 to finally reach the formulation of KS22a. After each step, Gap Tests were carried out to investigate the corresponding change in shock sensitivity. Again, the gap pressure at a 20 mm run distance to detonation can be used as the measuring value for the sensitivity.

The performed stepwise changes in the formulation were as follows:

- Contents in Al powder (Figure 3):

| | | |
|---|---|---|
| HMX / Al / HTPB | 90 / 0 / 10 | (KS33, reference) |
| HMX / Al / HTPB | 80 / 10 / 10 | ( / ) |
| HMX / Al / HTPB | 70 / 20 / 10 | ( / ) |

- Contents in HMX / RDX / HTPB (Figure 4):

| | | |
|---|---|---|
| HMX / HTPB | 90 / 10 | (KS 33, reference) |
| HMX / HTPB | 85 / 15 | (KS32) |
| RDX / HTPB | 88 / 12 | (KS13) |
| RDX / HTPB | 85 / 15 | (KS11) |
| RDX / Al / HTPB | 67 / 18 / 15 | (KS22a, reference) |

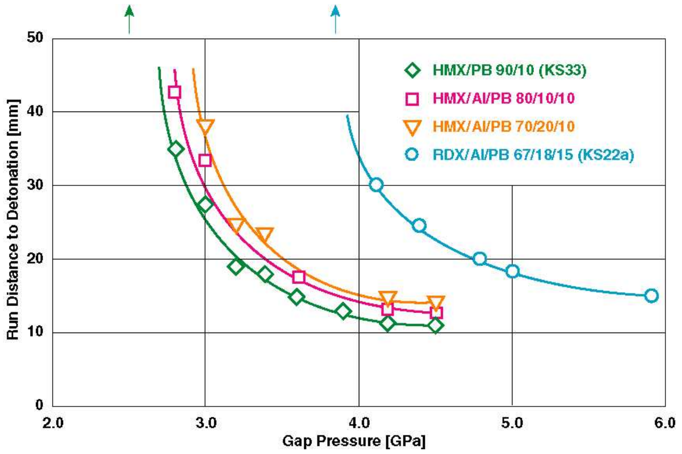

Figure 3: Changes in sensitivity due to Al Powder

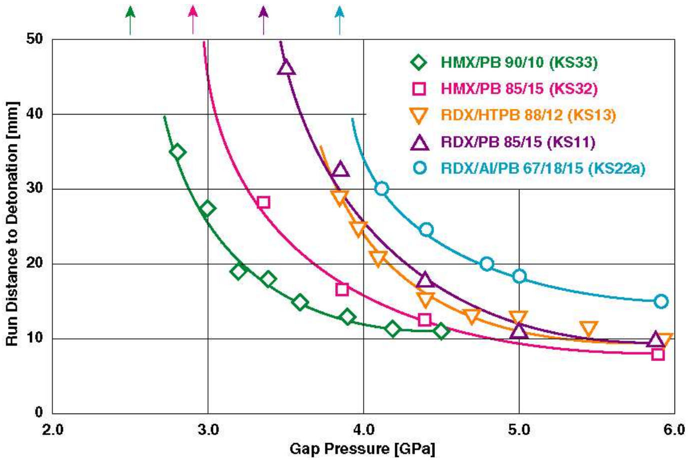

Figure 4: Changes in sensitivity due to HMX / RDX / HTPB content

Qualitatively it can be said that all three parameters: Al powder, HMX / RDX exchange and HTPB content respectively influence the sensitivity roughly likewise. But quantitatively, differences between these three parameters can be ascertained. Comparing KS32 (85 % HMX) and KS11 (85 % RDX) especially the exchange of HMX by RDX delivers a big step in insensitivity. This advantage was taken in KS22a as a very insensitive HE for penetrator applications [1]. The additional 18 % Al powder further decreases the sensitivity and increases the blast effect which is useful in hard target defeat requirements.

## 4 Influence of Binder

In section 3, only HTPB was used as a binder. Now also the influence of the binder should be investigated. As an alternative binder for HTPB, silicon was used. Two HE formulations were chosen from section 3, with a relatively large amount of binder (15 %) and with RDX and HMX respectively: KS22a and KS32. HEs with silicon binder are indicated with the letter “s”.

The Gap Test results for KS22s and KS32s are shown in Figures 5 and 6 respectively. The already very insensitive KS22a is influenced only a little bit. The “no go range” is becoming even more insensitive whereas the “go range” is shifted to higher sensitivities. Contrary to these results, KS32s is affected much more by the silicon binder. The whole curve is shifted to the higher sensitivity range. This even resulted in a higher sensitivity than KS33 (HMX / HTPB 90 / 10).

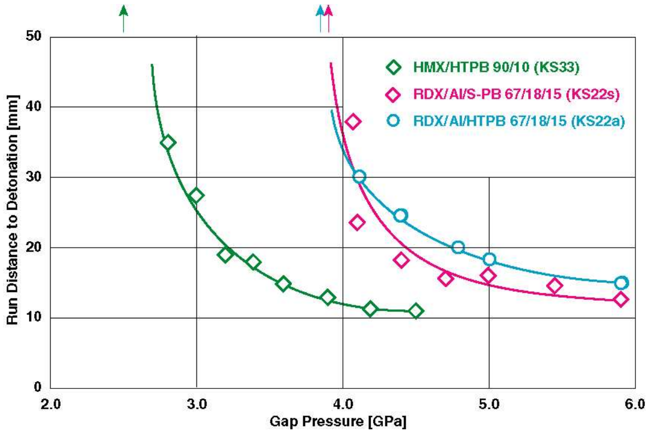

Figure 5: Gap Test results for KS22s with silicon binder

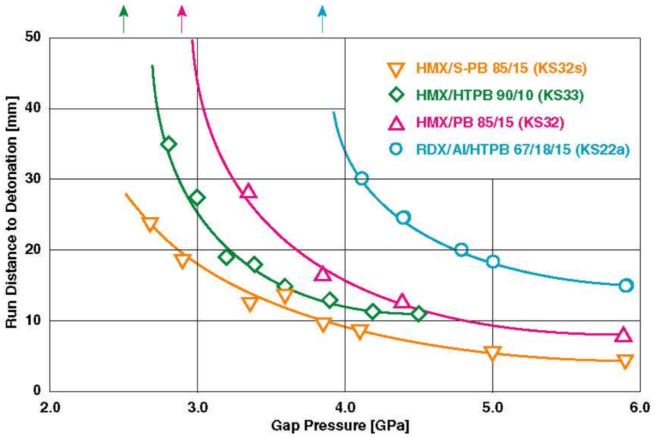

Figure 6: Gap Test results for KS32s with silicon binder.

## 5 Influence of Voids

The influence of voids on the sensitivity should be investigated. In [5], the collapse of a macroscopic void with 6 mm diameter was numerically simulated. The graphs shown in Figure 7 are taken from this paper. A PMMA projectile was shot with 2 mm/µs against an Ammonium Nitrate cylinder and caused a shock pressure of 43 kbar at the interface. The history of the collapse can be seen on the right side. Due to the impact of the marked point # 1 on point # 2, a much higher pressure of 85 kbar is caused for a short time. The temperature rises to values up to 1900 K (“hot spot”). Due to the short duration it is not clear if a premature initiation would take place at this hot spot.

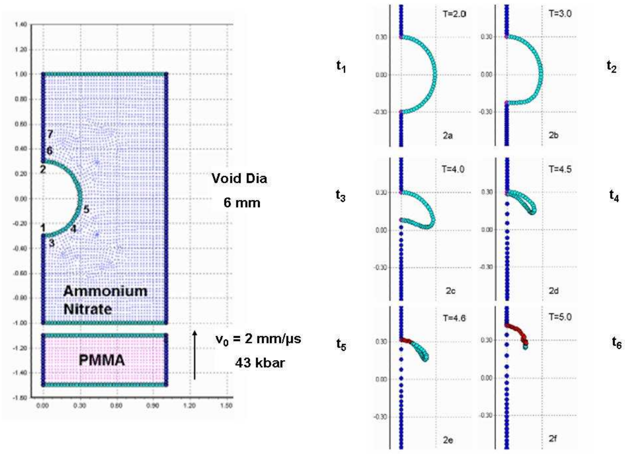

Figure 7: Numerical simulation of the collapse of a macroscopic void with 6 mm diameter (from [5])

Concluding from scaling laws, we know that macroscopic voids are the worst case situation compared to small pores. Therefore, both baseline HEs should be tested with macroscopic voids in the Gap Test. The dimensions of the acceptor charge sample are shown in Figure 8. Christmas tree balls with 15 and 20 mm diameters each were used to get an exactly specified void in the test samples. The acceptor charges were prepared in two steps. In the first step, the balls were glued on a 10 mm thick HE disk, closing the opening of the ball with a tape. In a second step, the sample was cast with the HE under vacuum.

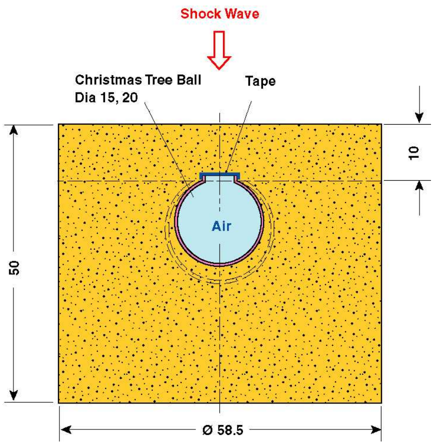

Figure 8: Voids of 15 and 20 mm diameter (Christmas tree balls) in the Gap Test acceptor

The Gap Test results are shown in Figures 9 and 10 for KS22a and KS33 respectively. As already shown in [1], KS22a is a very robust and insensitive HE, ideal for hard target defeat applications. Even the exchange of HTPB by a silicon binder has changed the sensitivity values only to a small degree. The same is the case for both void diameters, 15 and 20 mm, which are inserted in the two figures for illustration reasons. KS22a (Figure 9) shows no change in its sensitivity within scattering level, indicated with dashed lines. Because the gap pressures correspond to very high supersonic impact velocities, there is no risk for a premature initiation with KS22a.

Different results are obtained with the more sensitive KS33 (Figure 10). Here, a distinct shift of the run distance curve can be identified depending on the void diameter. The larger the void is the more sensitive is the charge to shock waves, as expected from scaling laws. Pores and some kind of defects never can be completely excluded in HEs, therefore only very insensitive HEs should be used for HTD applications.

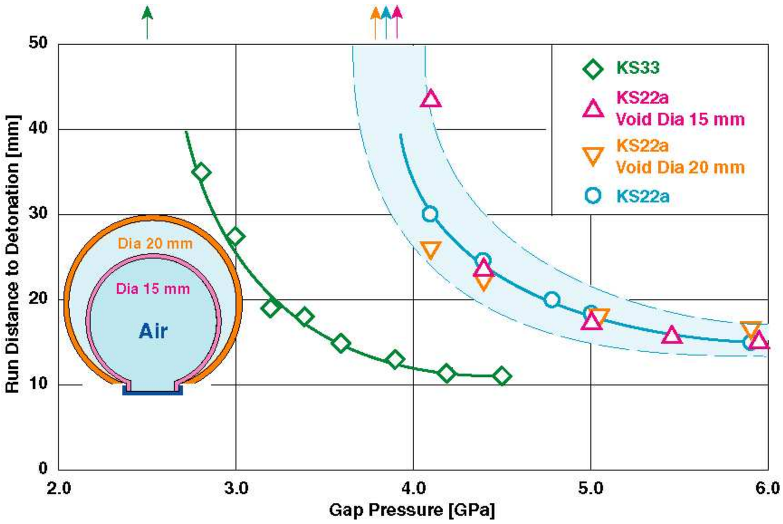

Figure 9: Gap Test results for KS22a with 15 mm and 20 mm diameter voids

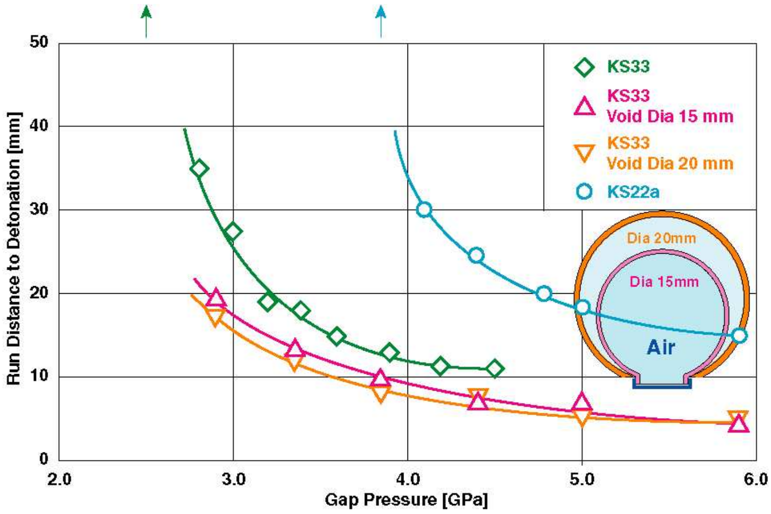

Figure 10: Gap Test results for KS33 with 15 mm and 20 mm diameter voids

## 6 Influence of Defects

As already mentioned above, defects in a HE could be caused by the penetration / perforation process itself (Figure 1). Quasi-static pressure loadings up to about 2 kbar led to an increasing number of cracks in HMX grains with increasing pressure values [6]. In [7], scaled penetrators were shot against concrete targets up to velocities of 1100 m/s causing dynamic pressures up to about 4 kbar in the HE specimens. These loadings caused defects like mechanical debonding and/or localized reactions.

KS22a samples were loaded under quasi-static and dynamic conditions by the author [3]. For the first time, the change in shock sensitivity due to the defects caused in this way was measured with the help of the TDW Gap Test. The results taken from [3] are summarized in Figure 11. Despite the fact that KS22a is a very robust and insensitive HE, defects produced during the perforation of hard targets at high velocities (≥ 300 m/s) caused a shift of the curves to higher sensitivities. This demonstrates the necessity for further investigations if deeper target penetrations shall be achieved by increasing the velocities into supersonic ranges.

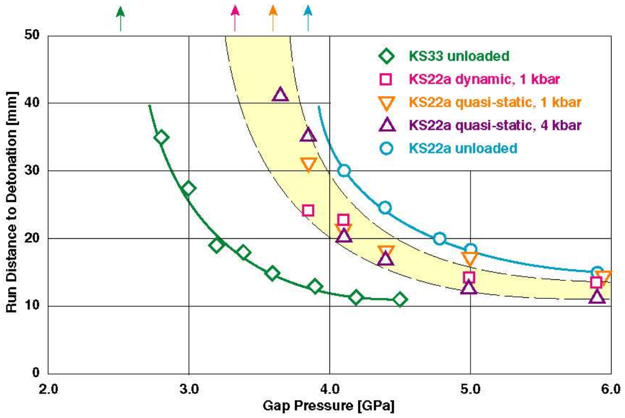

Figure 11: Gap Test results for KS22a samples quasi-statically and dynamically loaded with pressures up to 4 kbar (from [3]).

## 7 Influence of I-RDX

The RDX of the baseline KS22a was already taken from a batch of insensitive RDX (I-RDX). The question occurred if the difference between regular RDX and I-RDX could be measured with the Gap Test. To answer this question, KS22a acceptor samples with two different RDX qualities were tested: I-RDX and a so-called medium insensitive MI-RDX. In addition, different KS22a samples with the I-RDX quality were prepared: samples with different times of preparation (03/2001 and 02/2004 respectively), producing the fine part of grains by grinding the coarse grains at TDW or having it manufactured by the supplier. Altogether four different kinds of acceptor charges were prepared, summarized in Table 1.

| Sample | RDX quality | Part of Fine Grains | Preparation Time |
|---|---|---|---|
| Baseline | I-RDX | Milling by TDW | 03 / 2001 |
| 1 | I-RDX | Milling by TDW | 02 / 2004 |
| 2 | I-RDX | Supplier | 02 / 2004 |
| 3 | MI-RDX | Supplier | 06 / 2004 |

Table 1: Parameters of Gap Test KS22a samples

The only difference between the baseline KS22a and the sample #1 is just the date of preparation (test of reproducibility of I-RDX and casting process of KS22a). The difference between sample #1 and sample #2 is the milling of coarse grains to fine grains by TDW.

The Gap Test results of the three charges with I-RDX and different preparation times are presented in Figure 12. No distinct trend in the sensitivity behaviour of these samples can be observed. The deviations from the baseline (circles) lie within the statistical scatter indicated by dashed lines. That means, the reproducibility of both the I-RDX and the casting process of KS22a is quite well.

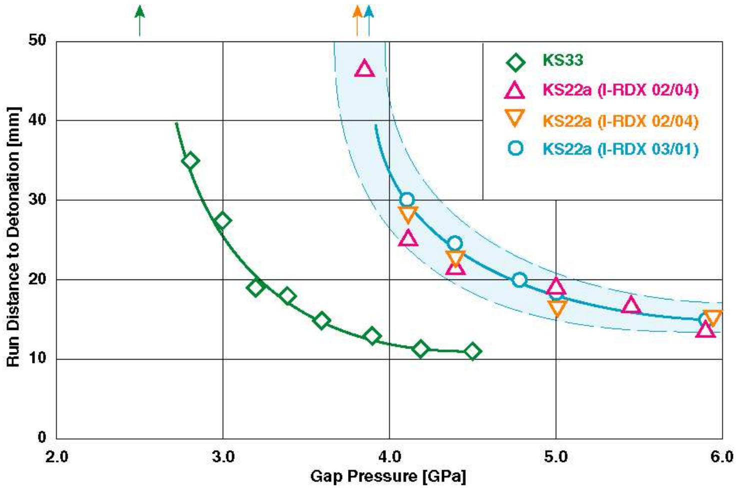

Figure 12: Gap Test results for the KS22a samples with I-RDX

Now, the results for the MI-RDX quality are presented. The sensitivity curve in Figure 13 clearly shifted to higher sensitivity behaviour. If we use the 20 mm run distance to detonation as a quantitative measure we get a value of 4.78 GPa for the baseline KS22a and one of 4.22 GPa for the sample with MI-RDX that means an insensitivity increase of 0.56 GPa or 13 %. Especially for penetrator applications, the highest possible insensitivity should be strived for and therefore the I-RDX quality is recommended.

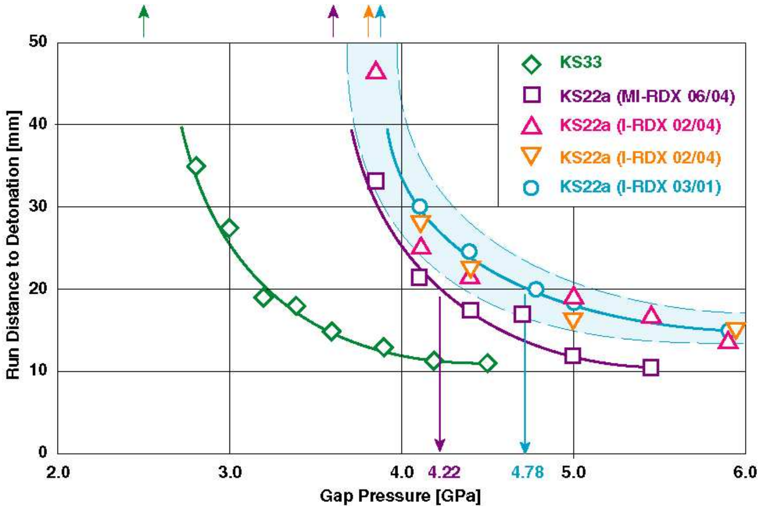

Figure 13: Comparison of Gap Test results for KS22a samples with I-RDX and MI-RDX

## 8 Influence of different HMX qualities

Finally also different HMX qualities were tested. The HE formulation of KS 32 (HMX/PB 85/15) served as a baseline. Three different suppliers delivered the HMX-crystals (HMX1-3) which were used. HMX-1 served as a baseline and the Gap Test results were already shown in Figure 4 and 6 respectively. The two additional tested HMX-crystals were HMX-2 also from a new delivery like HMX-1 and HMX-3 from an older batch.

The results for these three KS32 samples are shown in Figure 14. There is no difference in sensitivity in the “go range” but a significant one in the “no go range”. The KS32 curve with the older HMX-3 shows distinctively more sensitivity than HMX-1 (baseline) or HMX-2 which is rather close. Analogous to RDX and I-RDX it seems that the production processes were improved during the last couple of years with the result of more insensitive RDX- and HMX-crystals.

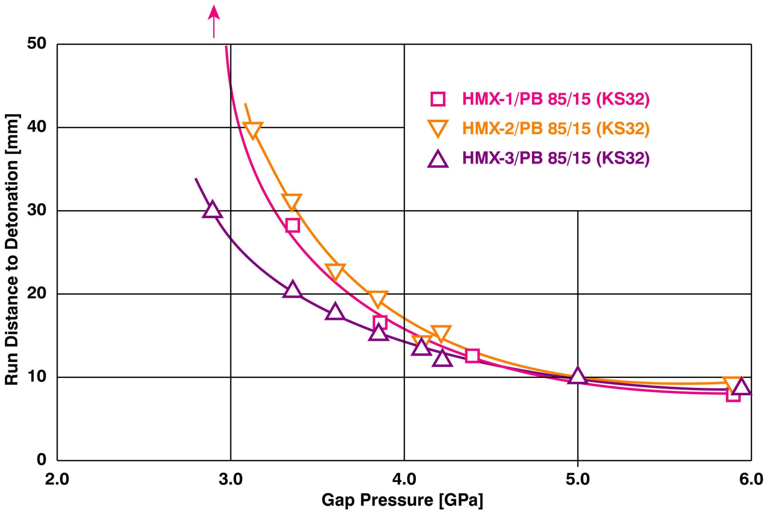

Figure 14: Comparison of Gap Test results for KS32 samples with three different HMX lots

## 9 Conclusion

Especially in hard target defeat (HTD) applications it is necessary to know the significant parameters influencing the shock sensitivity of HEs. The TDW Gap Test was used to measure this sensitivity behaviour while varying different parameters. In the first part of this paper, HE formulations and binders were investigated. The stepwise increase of insensitivity was studied by adding Al powder, exchanging HMX by RDX and increasing the amount of binder. Exchanging HTPB binder by a silicon binder demonstrated a partial change in the mechanical behaviour. This influenced KS32s in its sensitivity to a certain amount but showed only a small shift of the sensitivity curve for KS22s.

The influence of voids and defects on the shock sensitivity of the HE samples was investigated in the second part. In addition, different RDX (MI-RDX and I-RDX) and HMX qualities were studied. Macroscopic voids with diameters of 15 mm and 20 mm caused no shift in the sensitivity of the robust KS22a formulation. A different behaviour was observed with the more sensitive KS33 samples. Macroscopic voids tended to an increasing sensitivity with increasing void diameters – according to scaling laws. Despite the fact that KS22a is a very robust and insensitive HE for penetrator applications, defects like debonding, grain cracks and local reactions caused by quasi-static or dynamic shock loads led to a distinct shift to higher sensitivities. This shift increases the risk of premature initiation in hard target defeat penetrators (layered targets) with high velocities.

Finally, the lower shock sensitivity of I-RDX compared to MI-RDX could be shown. No influence of the time of preparation and of the milling of coarse grains by TDW was observed. Furthermore, various HMX batches showed differences in shock sensitivity. Together with the results of I-RDX it seems that improved production processes during the last years have led to more insensitive HE crystals.

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