CHARACTERIZATION OF SIBEX IN 1,5m³ ICT DETONATION TANK

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Abstract

The 1.5m³ ICT detonation tank was recently upgraded, giving the opportunity to evaluate different SIBEXs and investigate the principals of detonation and combustion.
For this purpose the ICT detonation tank has been equipped with temperature and pressure sensors as well as spectrometers. Also a vacuum pump, a cyclone and gas supply has been added, which allows measurements in vacuum and in different atmospheres. Additionally the cyclone allows investigating particles suspended in air after the detonation.
During a series of experiments 16 different formulations of SIBEX have been tested. Ten of them were tested both in air and in argon to evaluate the influence of the atmosphere. Leftovers were taken and analyzed using EDX, REM and XRD, showing no oxidation of aluminum in argon.

Introduction

SIBEX (Shock Insensitive Blast Enhanced Explosive) have been investigated since WWII. During WWII they did not get ready for production. Nowadays SIBEX is very interesting for the use in MOUT (Military Operations in Urban Terrain). In such operations smaller charges are necessary.

In general SIBEX consists of a high explosive combined with a binder, a reactive metal, an oxidant and a plasticizer. This formulation leads to the SIBEX typical properties, which are higher temperature and longer duration of the positive pressure phase, resulting in a higher pressure impulse compared to high explosives. Both properties result from the burning metal. Metal combustion has a very high temperature and the gases resulting from the combustion prolong the positive pressure phase. SIBEX is most efficient in a confined or partly open volume like bunkers and caves. Due to run off of fumes, their performance decreases significantly in open field settings. Dependent on the scenario SIBEX can be optimized, though a profound knowledge of the occurring processes is necessary .Therefore working in a closed environment like the ICT detonation tank gives the advantage of having an air tight, constant volume. Consequently results can be described using quasistatic pressure (QSP) instead of pressure impulse. The combustion mechanism itself still needs a lot of

investigation to be understood. There is still a discussion, whether SIBEX needs additional oxygen to fully react or if the oxygen provided by the oxidant in the formulation is sufficient. One part of the presented experiments focuses on this question. Also the influence of particle size and the most efficient ratio of metal to explosive have not been determined yet.

Methods

Test charges were used, covering a broad range of modern SIBEX formulations. The 100g charges were produced in a cylindrical form with a diameter of 50mm. Length of the cylinders varied dependent on the density. The ignition chain consisted of a cylindrical 11g HWC-Booster (l/d=1) with hole and inserted detonator. It was centrally positioned on top of the charge. Main focus of the experiments was the thermobaric effect in the first two seconds after initiation. For this purpose pressure, temperature, heat flux and spectroscopic measurements have been carried out inside the detonation tank. In addition the charges were initiated in an inert argon atmosphere, to evaluate the influence of oxygen in air on the combustion of the metal particles.

The detonation tank

The detonation tank was designed and constructed at ICT. Its dimensions are shown in Figure 2. It is built of stainless steel, has a volume of 1,5 m^3 and can withstand static pressures up to 30 bar. To mount measurement instrumentations different flanges have been added to the tank (see Figure 2). Underneath the port of the tank is an additional flange to adapt extraction or a vacuum pump.

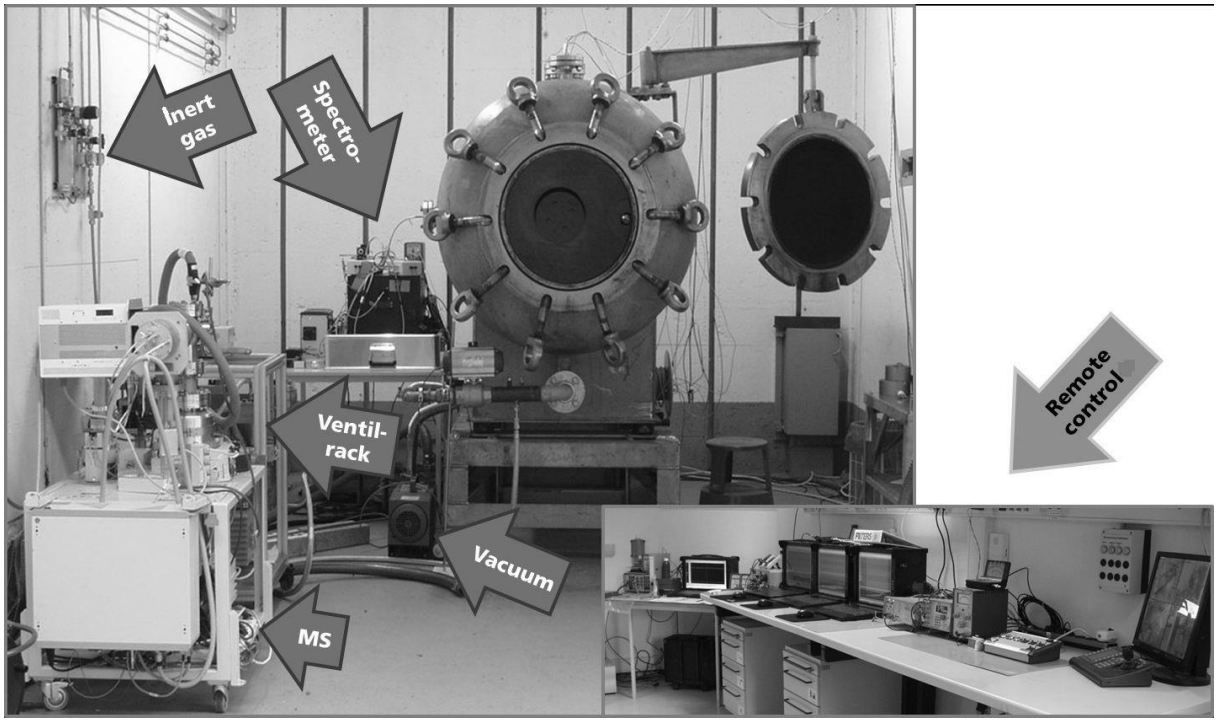

Figure 1: Detonation tank and set up of measurement equipment

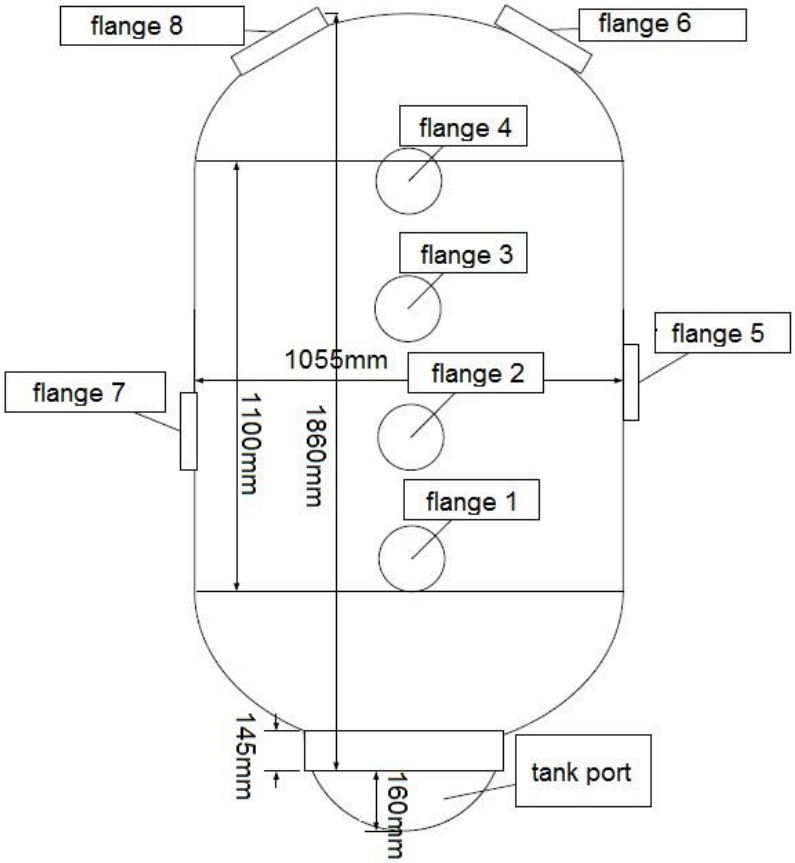

Figure 2: Dimensions of detonation tank and names of flanges

Pressure and temperature measurement equipment

All data was recorded by a computer-based transient recording system with a sampling rate of 1 µs and a resolution of 16 Bit resulting in a recording time of 4 s. To get a well-defined t_0 a trigger sensor has been used. The pressure history was recorded using piezoresistive absolute pressure sensors (P1-P3) Type 4043 of Kistler. To record the temperature history Type K mantle thermocouples (T1-T3) with a diameter of 0,5 mm were used. The sensors were adapted in the tank according to Table 1.

Table 1: Equipment of the detonation tank

Flange	Equipment	Distance to charge [cm]
1	Initiation and trigger sensor	69
2	blind	
3	P2, T2 und T-WFS2	55
4	blind	
5	P4 (piezoelectric)	53
6	P1, T1 und T-WFS1	87
7	Spectroscopy	55
8	P3, T3 und T-WFS3	87
9	Extraction/ vacuum pump	

To record peak pressure a piezoelectric sensor (P4) Type 603B also from Kistler was used. Heat flux was recorded with coaxial thermocouples Type MCT31 (T-WFS1- T-WFS3) of Dr.Müller Instruments, Oberursel. Due to their complexity, results of heat flux measurements will not be discussed in this publication.

Evaluation of pressure and temperature transients

The transients of the piezoresistive pressure and temperature sensors were treated in the same manner. A mean pressure history P_{av} was calculated from the three signals. The initial pressure P_0 in the tank was calculated from the pressure signal between -100 ms and t_0 and subtracted from P_{av}. To compensate oscillations the curves were smoothed by using a moving average in the interval from 0 to 100 ms with 500 points. The piezoelectric signal was evaluated by using a linear fit for the data before t_0 and another one for the slope. The flank was fitted with a 1/e-function. The value of the peak pressure is obtained as the intersection of the 1/e function and a line parallel to the y-axis through the intersection of the two linear fits.

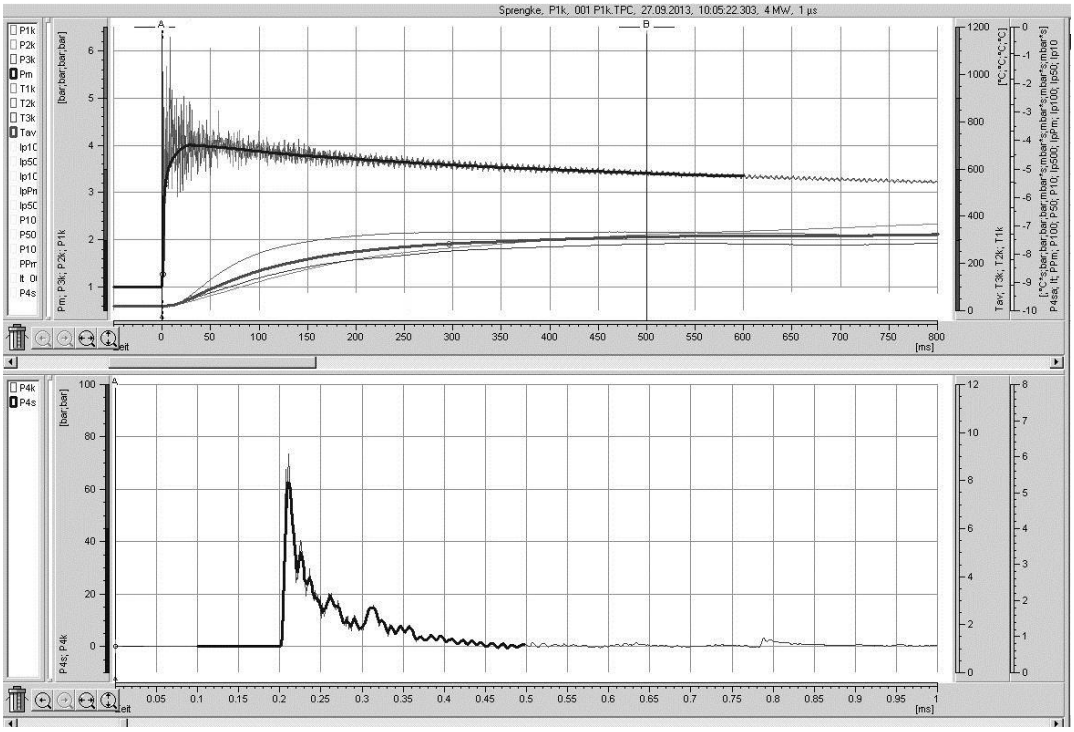

Figure 3: Example for a graph of temperature and pressure transients. The upper section shows QSP and temperature transients. The lower section shows the peak pressure.

Setting up and evaluation of argon atmosphere

After mounting the explosive charge the detonation tank was evacuated down to 100 mbar and then filled with Argon up to a slight overpressure. This overpressure was relieved to atmospheric pressure in order to ensure identical initial pressure conditions for argon and air tests. To evaluate the created atmosphere mass spectrometry (MS) measurements have been carried out two times without explosive charges. According to the obtained data the atmosphere consisted of 2,32% Oxygen, 12,5% Nitrogen and 85,18% Argon.

Experimental procedure

For the experiments in air the charges were mounted hanging in the tank. After applying the trigger sensor and the initiator the detonation tank was closed. Following the detonation the tank was first relieved and then distressed to 3 bar with compressed air and relieved again before opening. Leftovers were taken with a brush to be evaluated using REM, EDX and XRD. After finishing the experiments in air the experiments in Argon followed. The atmosphere was obtained as described previously and the procedure after the reaction remained the same.

Results

The following graphs give only qualitative data. Heat flux, temperature, pressure and spectroscopic data have been recorded; presented data focuses on effect on QSP and PP. The samples contained several different amounts of metal, with approximately the same particle size. Remembering that blast enhanced explosives consist of high explosive, binder, oxidant and metal, it is obvious that with increasing metal content the content of high explosive has to decrease. With decreasing high explosive content the peak pressure is expected to decrease as well. This dependency could be proofed in the experiments and is shown in Figure 4. Additionally this figure shows that there is no effect of the atmosphere on the peak pressure, which confirms that the high explosive component itself does not need oxygen from the air to fully react.

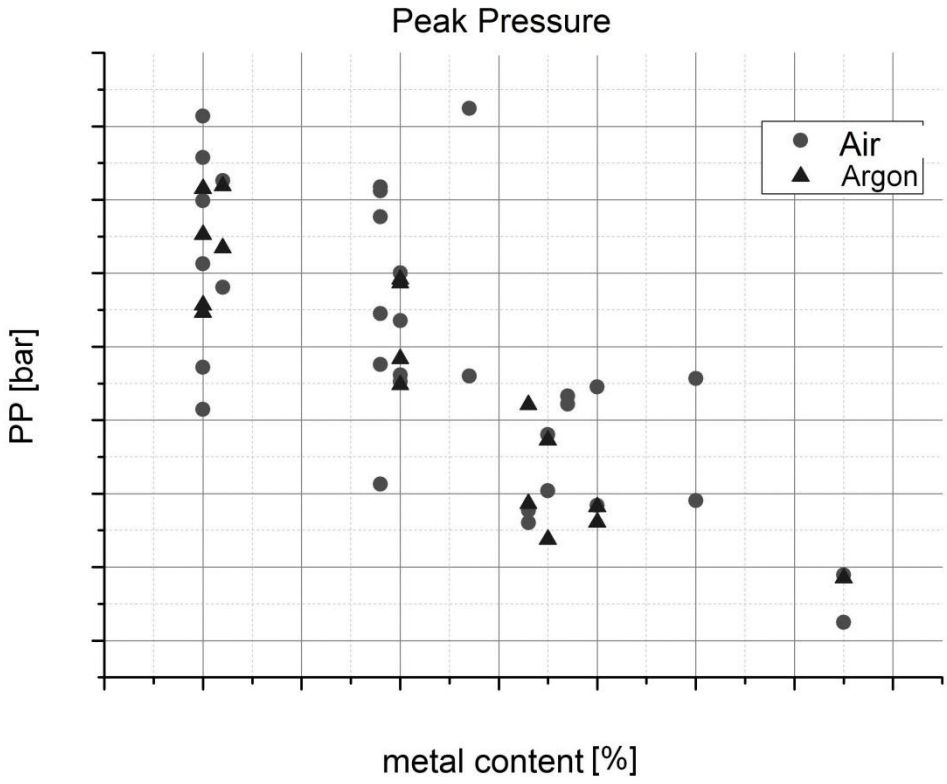

Figure 4: Peak Pressure plotted against metal content. Initiations in air are shown as dots and initiations in Argon as triangles

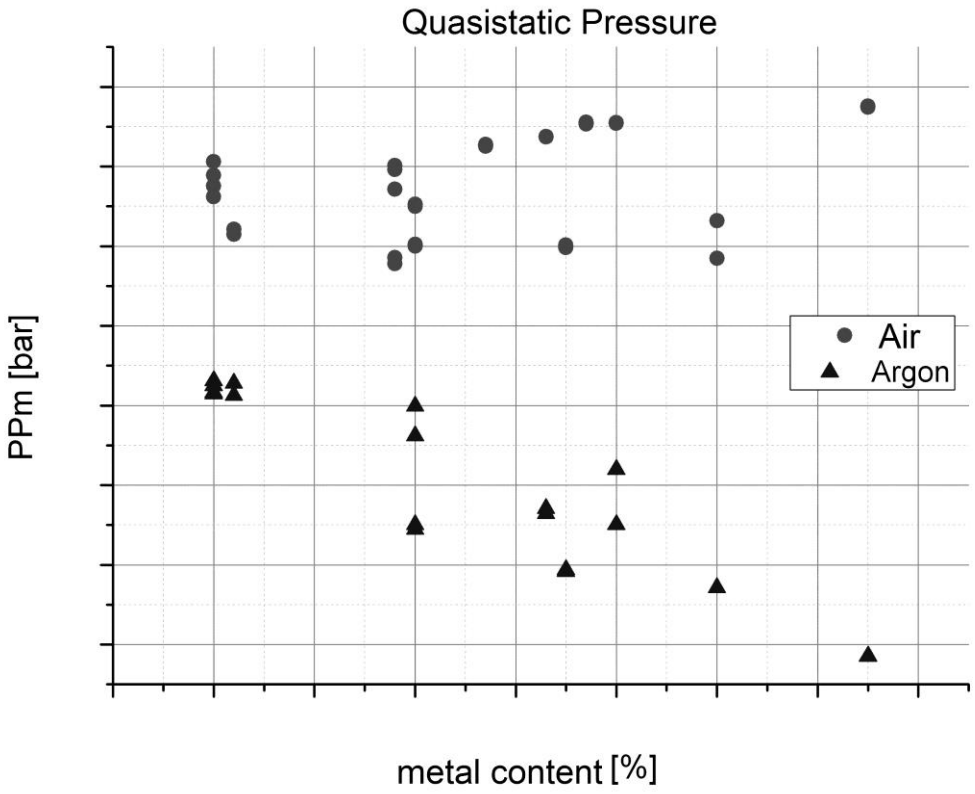

Figure 5: Quasistatic Pressure plotted against metal content. Initiations in Air are plotted as dots and initiations in Argon as triangles

QSP on the other hand, which correlates with the burning of metal particles, decreases significantly in Argon. At the same time it seems to be rising slightly with increasing metal content in air. Taking both observations into account the conclusion, that the metal in the formulation needs oxygen from the air could be drawn. Also the assumption that QSP rises with increasing metal content could be made. Although taking a closer look at the data, it seems that after an extreme QSP decreases again. Data for both observations is not significant enough to give a proper conclusion. So far it is a mere tendency that needs to be proofed by getting further data.

The experiments with different particle size are shown in Figure 6 and Figure 7. Particle size seems not to have an influence on the peak pressure. The decrease in peak pressure with increasing metal content was not observed.

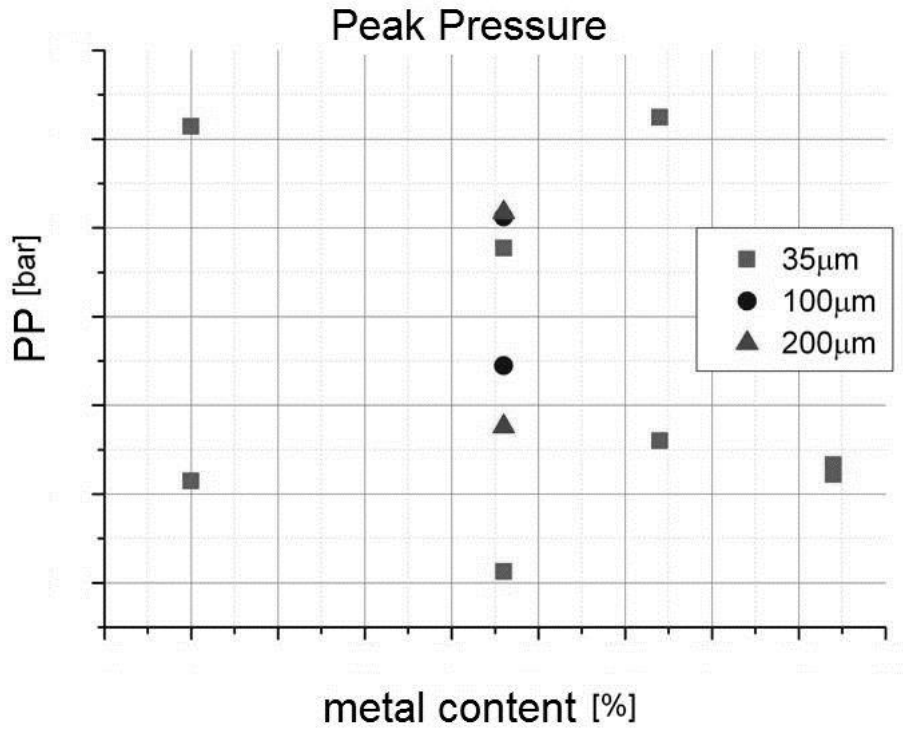

Figure 6: Peak Pressure plotted against metal content for different particle sizes

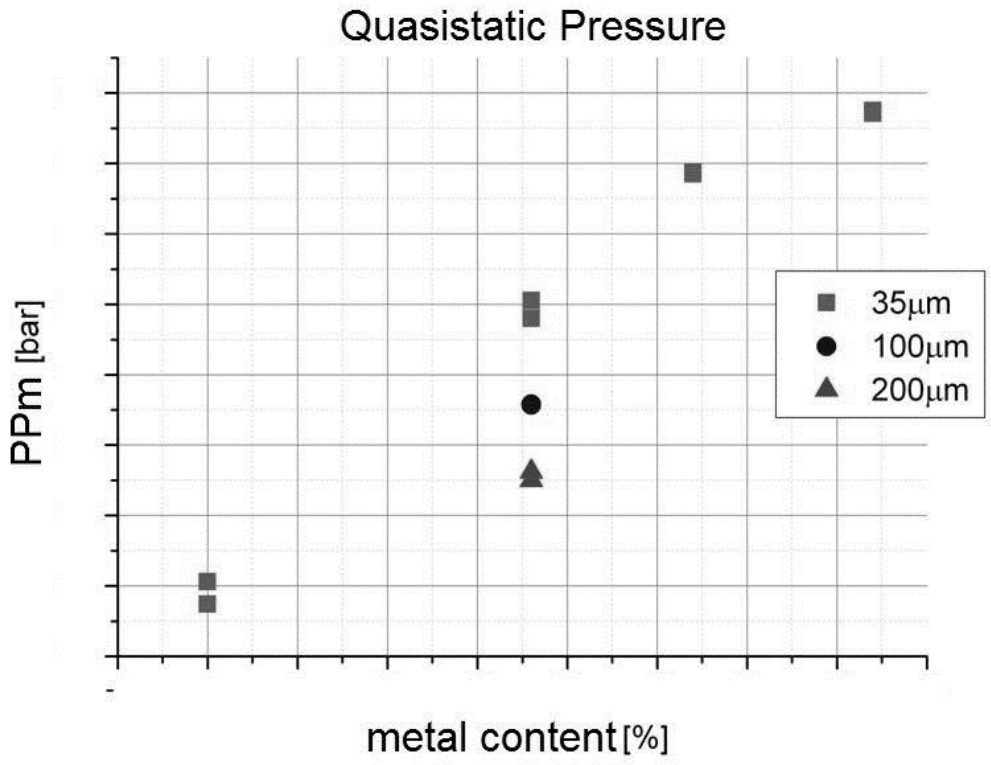

Figure 7: Quasistatic Pressure plotted against metal content for different particle sizes

As was expected, particle size shows a distinct influence on QSP. Bigger particles have smaller surface to volume ratio; therefore it takes more time for them to combust. Figure 57 shows a definite decrease of pressure with increasing particle size, so the assumption that those particles do not combust completely can be made.

To corroborate the conclusion of metal particles not combusting in an Argon atmosphere X-ray diffraction (XRD) measurements have been carried out on some samples. Two of the graphs resulting are shown in Figure 8 and Figure 9. Whereas in Figure 8, which shows the reaction products from air, there are several peaks, indicating the presence of two types of Al_2O_3 as well as Al, there are only some peaks, all showing Al in Figure 9. This supports the theory of SIBEX needing additional oxygen to fully react.

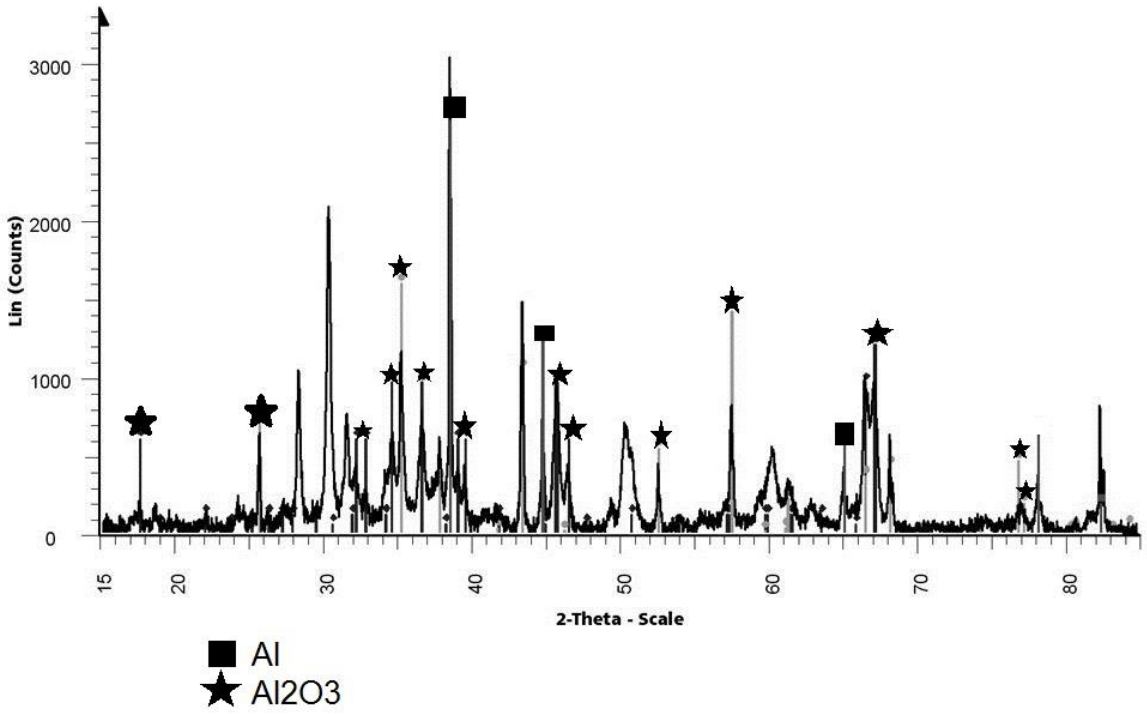

Figure 8: XRD measurement of SIBEX reaction leftovers in air

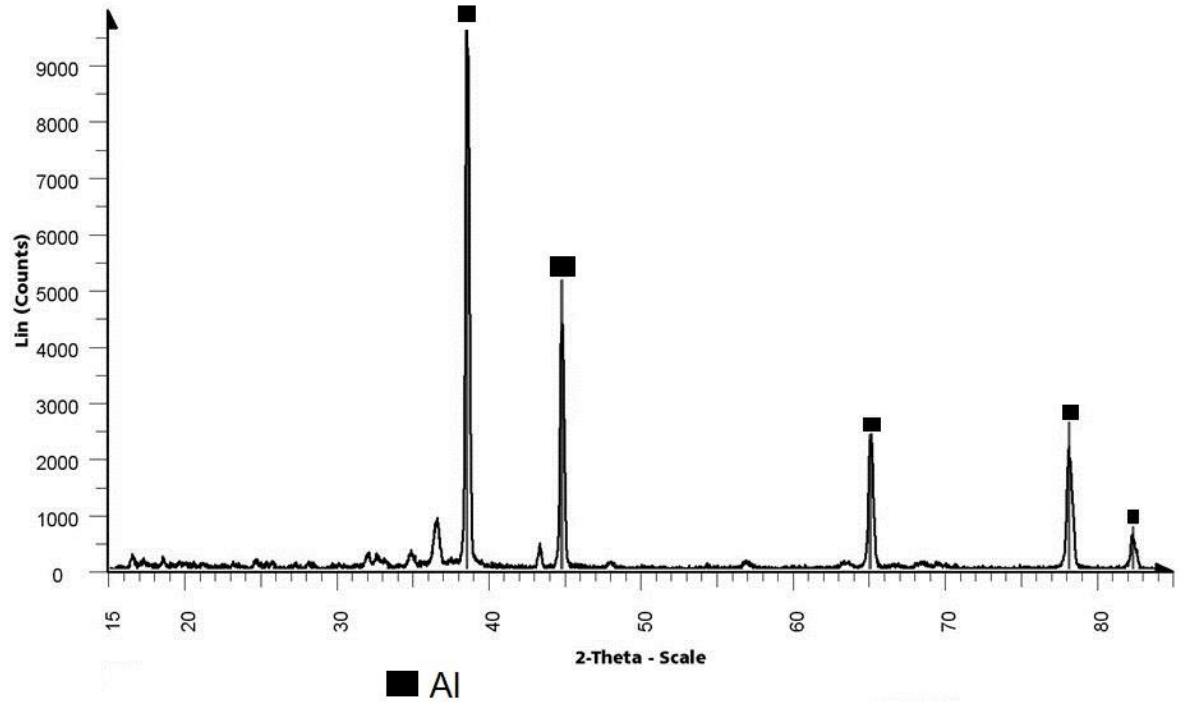

Figure 9: XRD measurement of the same leftovers as shown in Figure 7 in Argon

EDX measurements have been carried out and REM images have been taken as well. EDX measurements show similar results as the XRD measurements, but on a more local area. REM images can be seen in Figure 10. The particles in the first image had a size of 200 µm before the reaction; the other particles were a mixture of 6 µm and 60 µm particles. In both images particles are smaller and agglomerated or molten after the reaction. The section shown has a size of 60 µm.

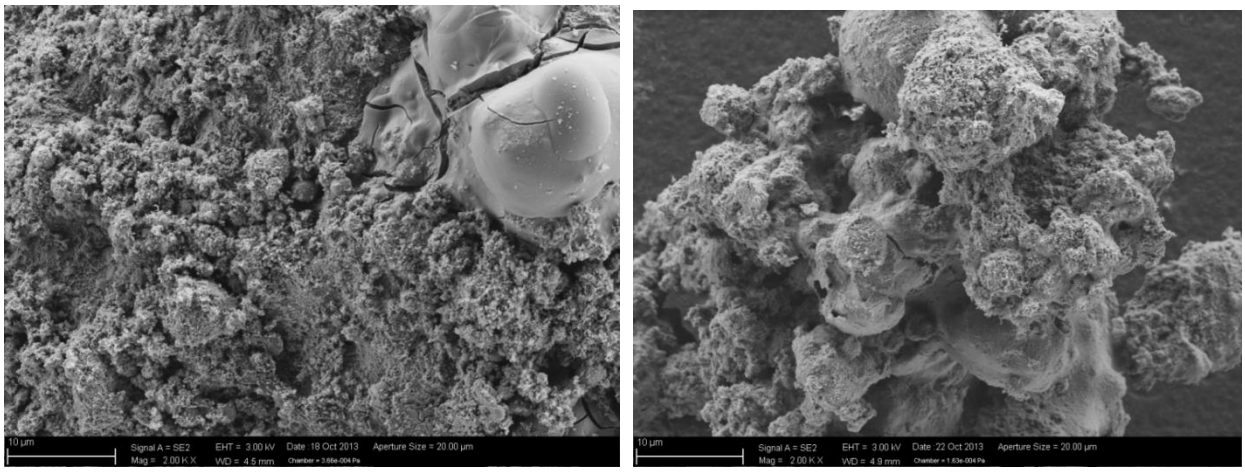

Figure 10: REM images of leftovers of SIBEX in air

Conclusion

The carried out experiments showed a slight increase in QSP with increasing metal content. Likewise QSP decreases for bigger particles at constant metal ratio. Experiments in Argon confirmed that SIBEX needs additional oxygen to fully react. This was shown in a lower QSP compared to initiations in Argon and by XRD measurements, where no Al_2O_3 could be detected in leftovers of Argon experiments. Further research is necessary to characterize the particle behavior in and after a detonation front. Moreover scaling effects are of interest, especially considering MOUT scenarios. Scaling effects can be tested in the 45m³ ICT bunker, where tests with up to 2 kg NEM are possible. In addition to scaling effects more finely graduated metal contents should be tested as well as other metals. All results put together should help to deepen the understanding of mechanisms in SIBEX and help produce a broader range of SIBEX better suitable for special tasks.