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Influence of Ageing on the Properties of IHE

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Introduction

In the last decades, operation areas of NATO partners have drastically changed. The times when ammunition was kept in air-conditioned bunkers for long-term storage until immediately before use are over. In practice, the ammunition is often stored in hot regions and in provisional rooms or containers under various conditions. In some cases, the ammunition may even be exposed to direct sun radiation without any protection. For example, in the next picture fully loaded vehicles and practice shooting in Afganistan are shown:

Figure 1: fully loaded vehicles and practice shooting in Afganistan

Accordingly, ammunition may experience extreme weather conditions and temperature loads. For example, in Kandahar (Afganistan) the typical average temperature in the summer is 86°F (30°C). Maximum temperatures of over 105°F (40°C) are often measured in June.

To assess the possible impact of extreme climate conditions on the ammunition - especially on the explosive charge - lab scale samples of two explosive types were aged and afterwards various investigations were performed with stressed and unstressed samples.

Investigations were carried out with respect to the mechanical properties, the shore A hardness, friction and impact sensitivity and thermal properties. Additionally, GAP tests were performed.

Samples

Three different high explosives used in tank and/or artillery munition were tested. Two of the three main charges are polymer bonded explosives based on RDX with an HTPB-Matrix. The third explosive charge is a TNT based explosive including RDX and NTO called MC-1.

All explosives were qualified as insensitive high explosive according STANAG 4170.

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The samples were produced as cylinders, Janaf-samples and other geometries. After production the samples were stored at different temperatures for up to 12 months to simulate ≈ 25 years under depot conditions. The storage temperatures were:

- +21°C, up to 12 months (reference)
- +63°C, up to 12 months
- +71°C, up to 6 months

Parts of the PBX samples were stored packed (no interaction with the environment) and unpacked. The melt cast samples were stored only packed.

Investigations

The investigations were planned in different steps:

1. Determination of the properties of unaged explosives
2. Ageing of explosive samples
3. Determination of the properties of aged explosives
4. Comparison with unaged samples

Results

Change in Geometry

The biggest effects of changing the geometry, the weight and the density, were measured of the unpacked PBX samples.

After 6 months at +71°C a weight loss of nearly 4% was measured. At a temperature of +63°C the maximum weight loss after 12 months was 2.5%. It can be assumed that the weight loss results is due to loss of the plastisizer in the explosive charge. The investigated samples shrunk in the same time up to 2.35% in diameter and 2.1% in length at temperatures of +71°C. The effect was smaller at +63°C.

Because of the loss of weight and dimensions (diameter, length) of the samples showed an increase of the density from 1.66 g/cm³ to 1.71 g/cm³.

Without the possiblity of interaction from the sample with the environment, the effect was nearly in the range of the measurement accuracy. In the following table a comparison of the weight loss and the change of the dimension of unpacked and packed PBX samples is shown.

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Storage temperature	Storage time	Weight loss		Geometry change			
				Diameter		High	
		unpacked	packed	unpacked	packed	unpacked	packed
[°C]	[months]	[%]	[%]	[%]	[%]	[%]	[%]
+21°C	0	0	0	0	0	0	0
	12	-0,03	0,04	-0,05	0,16	0,04	0,12
+63°C	3	0,55	--	-0,49	--	0,18	--
	4	--	0,02	--	0,05	--	0,28
	6	0,79	--	0,53	--	0,38	--
	9	2,08	--	1,18	--	0,96	--
	12	2,5	--	1,14	--	1,17	--
+71°C	3	3,79	--	1,67	--	2,21	--
	4	--	0,02	--	-0,02	--	0,39
	6	3,88	--	2,35	--	2,13	--

Table 1: Comparison of the weight loss and the change of the dimension of unpacked and packed PBX

The TNT based explosive charges showed no effect concerning the changing of geometry and weight caused by the temperature storage.

Shore A Hardness

Based on the results of the weight loss it is expected that the Shore A hardness increase significantly provided the weight loss is based on the loss of plastisizer.

The results of the unpacked samples showed that the shore A hardness increased extremly at high temperatures. Already after 3 months at 71°C the shore A grew from 65° up to a level outside of the measuring range from maximum 100 Shore A.

In the same time the shore A of the packed PBX sample increased only 16 shore A and achieved the end level of polymerisation of the binder system. With longer storage time no change of the shore A values was detectable.

Because of the high value the measurement of shore A of the melt cast explosive was not possible.

Mechanical Properties

The change of the mechanical properties of the aged samples was tested by using a tensile test and compressive test at different temperatures (-40°C, +21°C, +63°C). The tensile tests were conducted only with the unpacked PBX samples; the compressive tests with packed and unpacked PBX samples as well as the melt cast samples.

The biggest change of the mechanical properties was detected in the unpacked PBX in the tensile and compressive tests. In Figure 2 results of the elongation tests are shown. At 21°C

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only small changes were detected. A bigger change was measured after 6 months at 63°. The test samples stored for 3 and 6 months at 71°C as well as the sample stored for 12 months at 63°C were very hard/brittle so that no failure up to the maximum force of 200N of the apparture was detected.

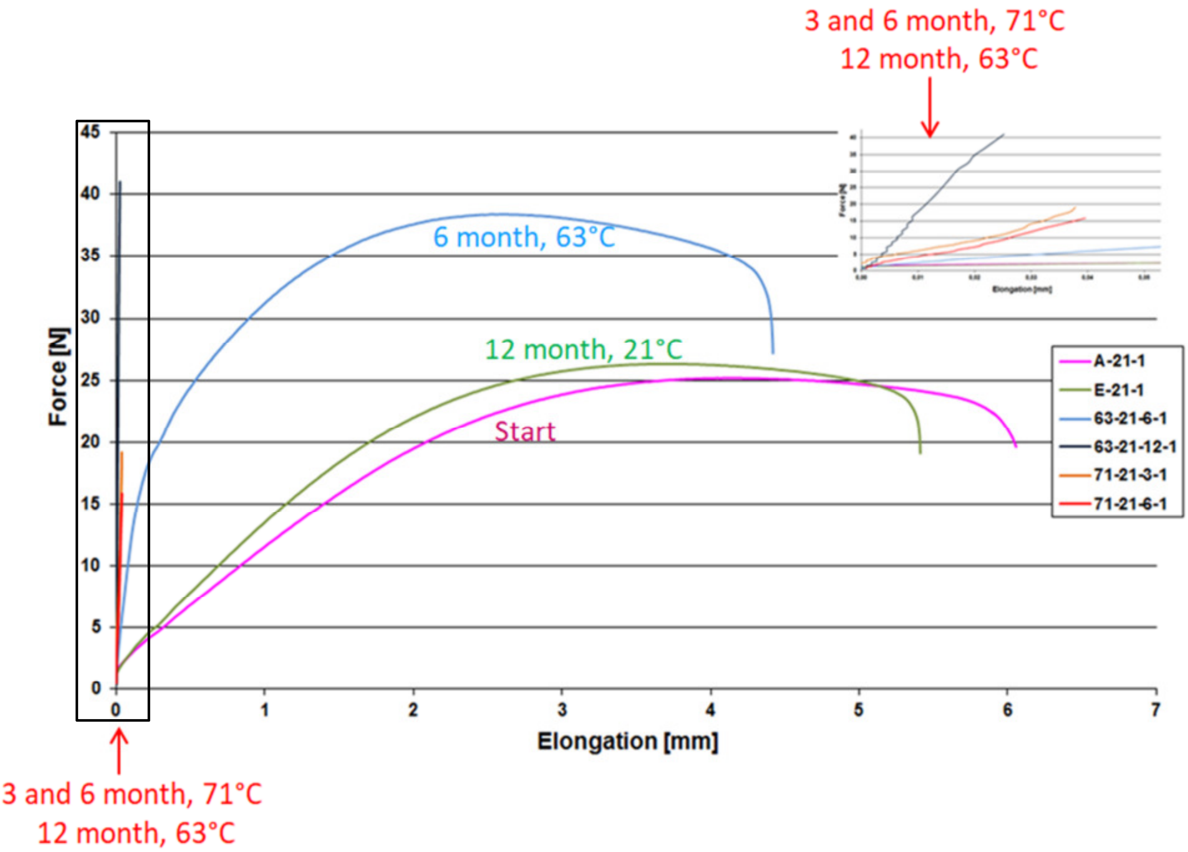

Figure 2: Elongation tests of aged PBX samples (unpacked)

A comparison of compressive tests of packed and unpacked samples is shown in Figure 3. The storage temperature of the samples was 71°C. It was shown that the compression curve of the packed sample at 71°C after 4 months is nearly the curve of the unaged sample. The unpacked sample showed a signifant shift to higher forces at failure after 3 months at +71°C. The elastic deformation change is signifant, as well. This results showed a drastic change of the mechanical properties when the samples were in contact to the environment.

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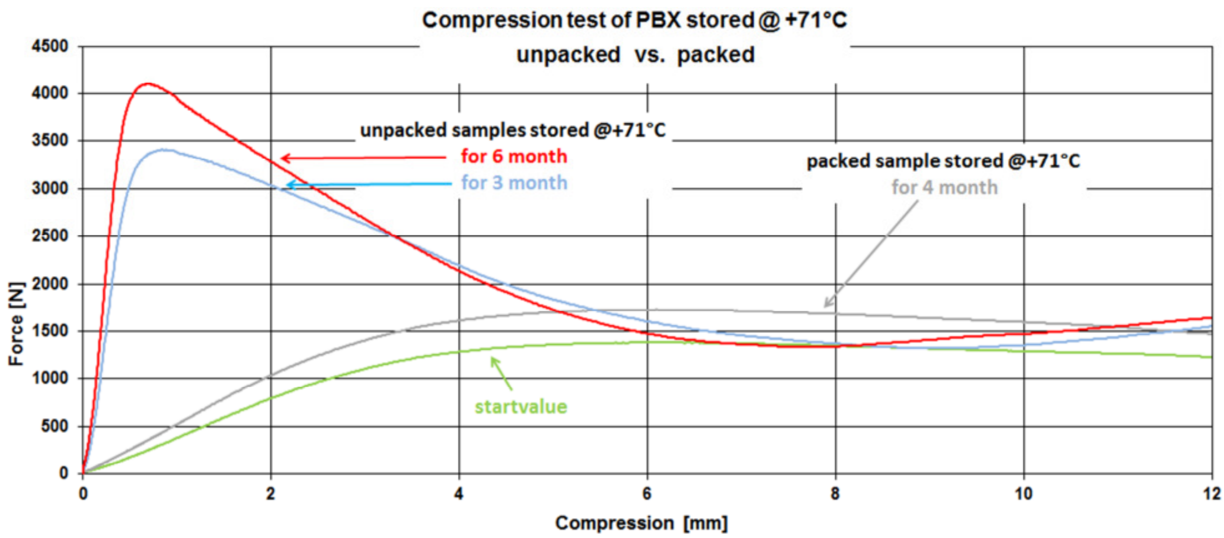

Figure 3: Compressive test of aged PBX samples (storage temperature +71°C packed and unpacked)

The following picture (Figure 4) shows the effect of the ageing process on the PBX samples. The fracture pattern shows a significant disparity between the unpacked and the packed samples.

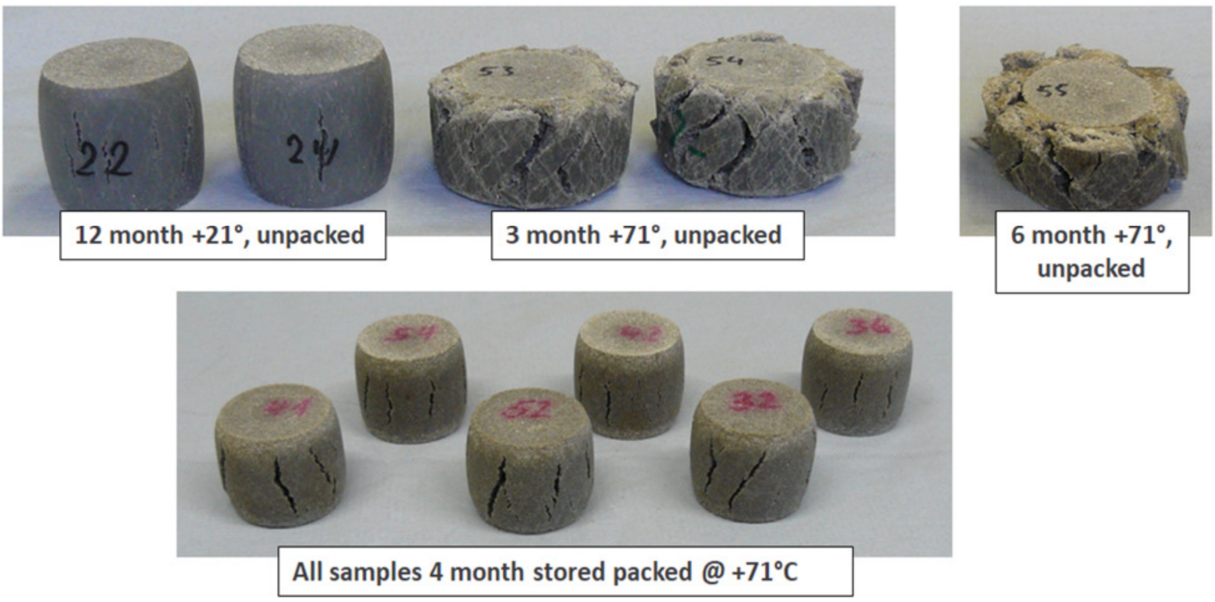

Figure 4: PBX samples after compression tests

The measurement of the melt cast explosive samples shows no influence of storage time and temperature.

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Thermal Analysis

The decomposition point of the aged PBX explosive charges were measured. The results showed that the ageing process at different temperatures has no influence on the decomposition point of the samples.

The melt cast explosives were measured using two different methods. The first method was the determination of the melting and decomposition point of the explosives. In this case the results showed no influence of the ageing process on the decomposition point.

In the past, ammunition filled with TNT based explosives were qualified for storage and use up to 51°C. New ammunition shall be safe for storage and use up to 71°C. Under certain circumstances this can lead to problems based on sublimation of the TNT. Long term isothermic mesaurements with DSC were done under different temperatures (67°C, 71°C, 78°C).

For the measurements a defined surface is needed. Therefore the MC-1 was temporarily melted in a cup with a diameter of 6.2mm ≈ 0.3cm² to get a nearly flat surface (see Figure 5).

Figure 5: MC-1 in a DSC cup, left side before melting, right side after melting

In the DSC Plot (Figure 6) a weight loss with temperature is measurable. With higher temperatures the weight loss grew. Based on this results the sublimation rates were calculated. The results are shown in Table 2.

Weight loss	Temperature	Sub Rate
[mg]	[°C]	[ng/cm²*sec]
0,16	67	8,8
0,6	71	33,1
0,9	78	49,7

Table 2: Sublimation rate at different temperatures

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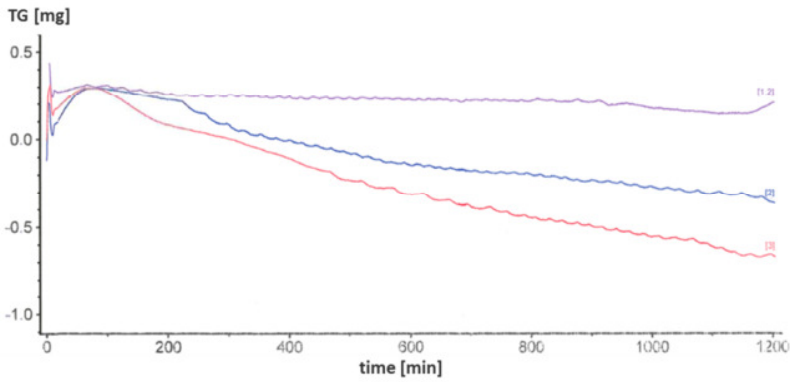

Figure 6: DSC Plot of MC-1 at constant temperature; red 78°C, blue 71°C, violet 67°C

Impact and Friction Sensitivity

Until now only the aged and unpacked samples of the PBX were measured using the BAM drop hammer and the BAM friction sensitivity tester.

The PBX samples which were aged at 63°C up to 12 months showed no influence on the impact sensitivity. But after 6 months at 71°C the impact sensitvity of the aged PBX decrease from 18J to 8J.

Concerning the friction senstivity, the ageing process has no influence. All results of the impact and friction sensitivity are shown in Table 3.

Storage		Tests	
Temperature	Storage Time	Impact Sensitivity	Friction Sensitivity
[°C]	[month]	[J]	[N]
Start RT	0	18	240
+21°C	12	18	240
+63°C	12	22	240
+71°C	6	8	240

Table 3: Overview of results of friction and impact sensitivity

GAP Test

To test the shock wave sensitivity, various GAP tests were undertaken. For these tests only one PBX type was used. The samples were aged in the PMMA tubes, so that the samples were packed.

The tests were carried out before and after ageing. Freshly produced PBX showed the lowest sensitivity (GAP 8mm). After storage for 4 months at room temperature and under high

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temperatures the GAP for no detonation grew to 11mm. No difference in GAP due to storage temperature was measureable. All data are shown Table 4.

Storage		GAP Test	
Temperature	Storage Time	Go	NoGo
[°C]	[month]	[mm PMMA]	[mm PMMA]
Start RT	0	7	8
+21°C	4	9	11
+63°C	4	10	11
+71°C	4	10	11

Table 4: Results of 21mm PMMA GAP test

Up to now, no test with the aged melt cast explosives were done.

Conclusions

Investigations with three different main charges concerning the ageing process were done. Two different RDX based PBX samples and one TNT based melt cast explosive were tested. The samples were stored under different temperatures (21°C (reference), 63°C, 71°C) for up to 12 months. All samples were stored packed, and one PBX sample was stored unpacked.

The results of the PBX samples showed, that the storage conditions (unpacked or packed) have a significant effect on the mechanical properties. The properties of the unpacked samples change extremly (density, weight loss, Shore A, tensile and compressive tests) compared to the packed samples. A difference between the two different PBX types were negligible. The TNT based explosive charge showed no influence on the mechanical properties due to the ageing process.

Measurements using the DSC showed no change of the decomposition point of all samples due to the ageing process. More relevant were the isothermic long term tests with the TNT based explosive. The samples were measured via DSC at constant temperatures of 67°C, 71°C and 78°C for period of 20h. A weight loss due to sublimation of the TNT material was detected. The effect grew with higher temperatures.

The investigated safety tests (friction and impact sensitivity) showed effects of ageing at 71°C of the unpacked PBX samples. At 63°C no effect was measurable. The packed samples were have not been measured yet. The GAP tests were done only with packed PBX samples. Here no negative influence caused by the ageing process was detectible.

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