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STRUCTURAL AND CHEMICAL CHANGES IN PBX INDUCED BY RAPID SHEAR FOLLOWED BY COMPRESSION

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Combined shock and shear phenomena occur in most explosive hazards or accidents situations, and in many general weapons applications. Explosive's material properties at high deformation rate are important to understand and model the initiation process. Microstructural characteristics of plastic-bonded explosives samples recovered after low amplitude and long duration loads are presented in this paper. The investigation was performed on RDX based plastic bonded explosives. These materials are exposed to mechanical loads that combine rapid shear deformation followed by compression. The shear and compression test used, is designed to allow levels of shear and compression to be varied independently. Experimental test generates strain rates in the range of 10^3 s^{-1} and limited pressure amplitude (<10kbars) with finite rise time of the order of 1-3 Mpa/µs. Microstructural characteristics of samples recovered after variety of insults are determined by used different analytical tools. Impurities and defects, relevant to chemical and structural changes of the explosive sample, are observed. ATR microscopy is used to obtain the chemical profiling on microsections of the recovered samples. Scanning Electron Microscopy (SEM) and Micro-tomography are used to observe damages (intra and inter granular cracks, debonding, local fusion area, …) in surface and in bulk. Discussion is made about the appearance of impurities and defects in function of the theoretical particle size distribution for pristine and damaged explosive samples.

INTRODUCTION

The need to understand the dynamic behavior of plastic bonded explosives (PBXs) at low and high strain rates is of critical importance in a range of applications including mortars, shells and penetrating munitions subject to high acceleration or penetration loading [1,2].

Under such dynamic conditions, the strain-rate dependence of the energetic material cause the material behavior to be significantly different from what is observed under quasi-static conditions.

The stress loading produce large deformation of the composite material and

induce its structural change [3,4]. Solid particles move from each others with some debonding from the polymeric matrix and possible solid interaction [5].

The presence of shear bands in pressed high explosives has been investigated experimentally and numerically by many authors. Skidmore et al. characterized shear bands in PBX9501 damaged by shear impact using microstructural observation techniques [3] and so did Peterson et al. in sugar mock of PBX9501 during punch penetration [6].

This process can result in the undesirable ignition of the energetic material.

The stress loading experienced by explosives in the acceleration or deceleration scenarios is substantially different from shock loading induced by impacts. Loads encountered exhibit low amplitude (< 10 kbar) with finite rise time associated with long duration (~1 ms).

Compression and shear inside the energetic material appear in an independently or fully coupled manner.

Novel test techniques are recently design to investigate the chemical change for PBXs under the dynamic loading describe previously.

Compression tests [7][8] are frequently used to identify the parameters equation of state of the explosive at lower stain rate. Explosive ignition event is never reported.

A number investigators have studied explosive sensitivity to combined pressure and friction or rapid shear loading. Initiation of reaction has been reported with Friction [1,8] and combined shear and compression test techniques [8,9].

APPROACH

This part of the research focuses on the dynamic stress-carrying capacity behavior of cast cured plastic bonded explosives.

The study is performed on RDX based plastic bonded explosives.

Explosive sample is subjected to strain magnitude between 15 % and 100 % (punching condition) at strain rates in the range of 10^3 s^{-1}. The shear and Compression test, developed by SNPE, is used to subject explosive samples to various combinations of shear and shock.

Mechanical loading is then parameterized in strain, strain rate and pressure levels by used the SNPE experimental/numerical-based procedure [10].

Different RDX based cast cured plastic bonded explosives are studied (Table 1).

TABLE 1. EXPLOSIVES STUDIED

Ref.	Solid % Vol.	RDX % Vol.	AP % Vol.	Al % Vol.	HTPB % Vol.
B2211D	76	20	40	16	24
B2238	74	74	-	-	26
PBXN 109	71	59	-	12	29

High strain rate stress-strain behavior is also studied, using a split-Hopkinson pressure bar (SHPB) apparatus [11].

Scanning Electron Microscopy (SEM) is the main apparatus used to observe damages intra and inter granular cracks, debonding, local fusion area, in surface and in bulk. These microstructural characterization techniques have been developed at CEG for pressed explosives, based on TATB and HMX compositions [4], [13][14]. The feasibility and first examinations for RDX based plastic bonded explosives has been obtained recently [12].

Micro-tomography and ATR microscopy are also used as additional examinations to obtain the chemical profiling on micro-sections of the recovered samples.

SHEAR AND COMPRESSION INITIATION EXPERIMENTS

Figure 1 presents a schematic description of the Shear and Compression test.

The piston head is impacted by a heavy projectile launched by a light-gas gun. The piston movement produces the deformation of the specimen following by a pressure rising.

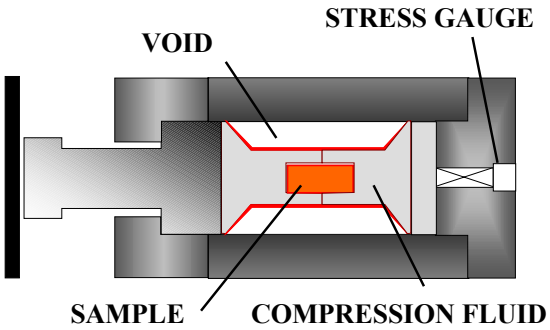

FIGURE 1. CONFIGURATION USED IN SHEAR AND COMPRESSION TESTS

Shear is obtained by radial deformation (stage 1), fitted by the geometry of the compression fluid. When the void is completely closed, confined compaction is realized (stage 2). A low vacuum level, 5 10^{-1} mbar, is applied inside the void.

Depending on the void thickness, deformation of the specimen lead to the matrix closure (polymeric binder) during the stage 1, and solid particles movement with possible interactions during the stage 2. Mechanical and reactive responses of the specimen during this process are investigated.

When the void is being closed, the information delivered by the gauge corresponds to the axial stress component only. At the closing void time, the others stress components are different from zero. Typical stress history recorded is done in the figure 2.

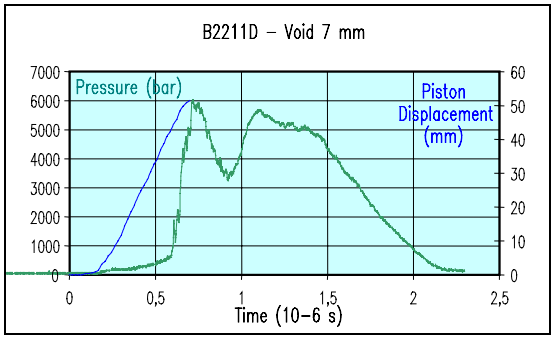

FIGURE 2. STRESS AND PISTON DISPLACEMENT HISTORIES - No-Go DIAGNOSTIC

Initiation diagnostic is assigned to the specimen scale. The No-Go specimen is associated with no weight loss and typical No-Go trace depict on figure 2. When the explosive initiates (a Go), the typical No-

Go trace is modified by a sudden rise in pressure before the peak is reached (figure 3).

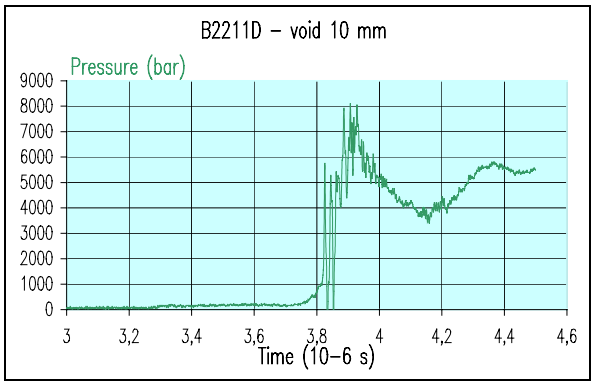

FIGURE 3. STRESS HISTORY - Go DIAGNOSTIC

The Go diagnostic is always connected with completed combustion of the specimen.

In table 2, specimen macroscopic responses associated with the mechanical loading parameters, strain, strain rate and pressure [10], are summarized.

Permanent macroscopic deformation is obtained for the recovered samples. For low impact velocities and void thickness, the recovered samples keep their cylindrical shape, and the maximum permanent deformation is obtained in the middle of the sample.

With increasing impact velocities and void thickness, macroscopic radial fractures appear and the permanent deformation is like a wheel shape.

TABLE 2. RESULTS OF SHEAR AND COMPRESSION TESTS

	B2211D			***PBXN109***			***B2238***	
Void thickness (mm)	5	7	10	5	7	10	5	10
Impact velocity (m/s)	87.8	89.6	92	83	91	85	84	64.8
Closing void (µs)	255	411	590	285	400	517	315	646
Sustained pressure time (µs)	1800	2010	-	1100	1800	1500	1900	930
Peak pressure (MPa)	500	580	-	548	484	600	560	338
ε_{cal} (%)	47	61	>100	33	66	>100	40	60
Specimen shape			-					
Initiation diagnostic	No-Go	No-Go	Go Completed combustion	No-Go	No-Go	No-Go	No-Go	No-Go

MICRO AND MESOSTRUCTURAL ANALYSIS

The micro and mesostructural analysis are important to assess the mechanical and reactive behavior of tested explosives and to correlate the damage to the loading conditions of shear and compression.

The characterization of recovered samples, B2211D, PBXN109 and B2238, after shear and compression tests are presented. Scanning Electron Microscopy (SEM) has been used for the purpose. Several complementary techniques were also employed, like micro-tomography and ATR microscopy.

1. Sample preparation – SEM investigations

The samples are prepared by specific metallographic means. The samples are first potted in epoxy resin under modest vacuum and then cut with a diamond wire saw at determined locations (radial and axial sections). Thin cut sections are reimpregnated in epoxy resin and polished with automated equipment.

Observations are made with a scanning electron microscope by surveying the sample at various magnifications. The resolution is better than 1 µm. Images are taken to provide an overview of the damage. The microstructural observations have been performed at the Centre d'études de Gramat high explosives laboratory by P. Lambert, Sciences et Applications Society, Bordeaux.

2. Microstructural characterization

Cut sections are operated first in the main deformation area, and then perpendicular to this section, so that the damages are characterized in the volume.

A microstructural reaction threshold is characterized in the main deformation section for both B2211D and PBXN109 recovered samples above the impact velocity of 88 m/s and a gap of 5 mm.

Below the impact velocity of 88 m/s and a gap of 5 mm for both B2211D and PBXN109 samples, the main damage induced by the strain localization is the mechanical debonding (figure 4), obtained by local translations and slight rotations of the grains, restrained by the presence of the HTPB binder.

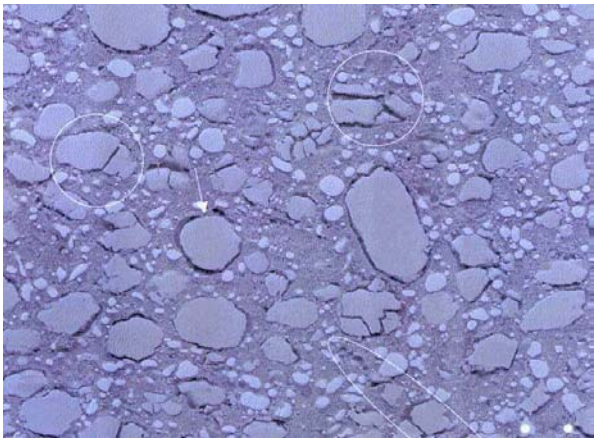

FIGURE 4. SEM MICROGRAPH OF B2211D – VOID 5 mm SOLID DEBONDING FROM THE POLYMERIC MATRIX

Debonding is particularly observed for coarse grades of AP for B2211D, and RDX for PBXN109. Prevalence of coarse particle is also viewed for B2238 from micro-tomography analysis (figure 5).

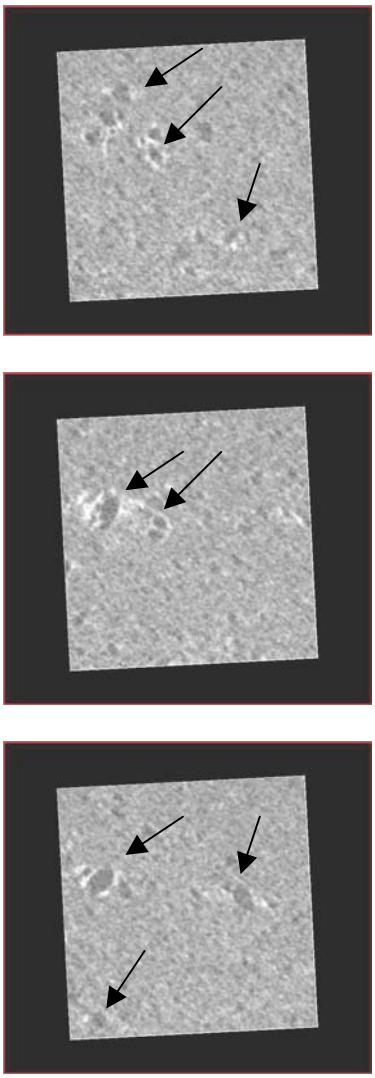

FIGURE 5. MICRO-TOMOGRAPHY PICTURES – B2238 – VOID 5 mm – PREVALENCE OF COARSE PARTICLES IN THE DEBONDING

Chains of microstructural radial fractures start propagating mainly in the matrix and around the crystals. Very little grains are broken and no slip is observed between the remaining parts of broken crystals. Grains show no plasticity effects, generally characterized by twin bands.

The development of such shear bands along slip planes is not observed in our recovered samples. The shear strains do not seem to lead to shear banding in this case of cast HE, because of more than 10 % HTPB binder.

Above the impact velocity of 88 m/s and a gap of 5 mm for both B2211D and PBXN109 recovered samples, particular zones have been observed in the middle of the cylindrical shape recovered samples and in periphery of wheel shape recovered samples. The opened debonding are different in character from the previously observed mechanical debonding.

The voids are wider and parts of grains seem to miss. It was previously demonstrated by local FTIR analysis, that the voids in this case are impregnated only in the maximum deformation zone of the recovered samples by the epoxy resin [4]. The connection of the opened debonding with the surface of the prepared sample explain the resin impregnation. This connection is caused by a higher mechanical deformation and is also related to partial reactions of grains, which burn the vanished parts of grains.

Indented and rounded edges of grains are observed, dealing with indications of melt or decompositions (figures 7 through 11).

The figures of reactions mainly affect parts of the crystals, and do not propagate between grains for example through reactive cracks, suggesting a freeze of the reaction.

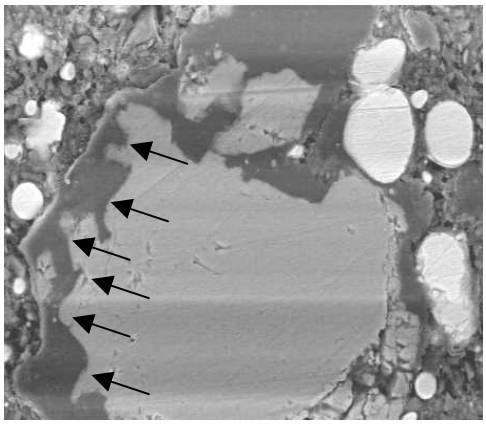

FIGURE 6. MICROGRAPH OF PBXN109 - VOID 5 mm – ***grain is highly modified resulting in a skeletal structure***

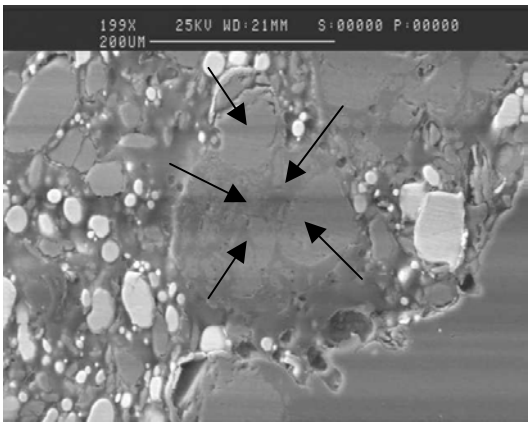

FIGURE 7. MICROGRAPH OF PBXN109 - VOID 7 mm – ***no propagation between grains suggesting a freeze of the reaction***

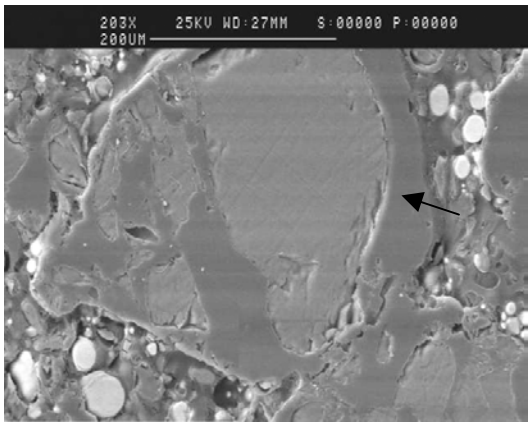

FIGURE 8. MICROGRAPH OF PBXN109 - VOID 10 mm – ***rounded edges***

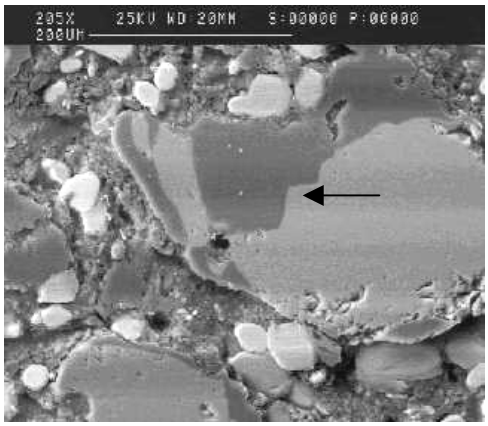

FIGURE 9. MICROGRAPH OF B2211D - VOID 7 mm – ***indented edges***

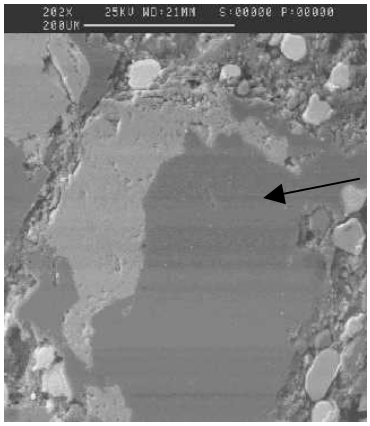

FIGURE 10. MICROGRAPH OF B2211D - VOID 10 mm – ***resin impregnation dealing with indications of melt or decompositions***

DISCUSSION

The involved mechanisms of reaction, related to the localization of shear strain and delayed compression and release, could be viscous heating to open and close the debonding, and associated compression of the air capture in the debonding.

Some tests were performed to support the air capture mechanism involved previously.

FTIR analysis performed on B2238 with one bubble of 6 mm in diameter, located at the middle of the sample, shows a partial RDX consumption and the decreasing or vanishing binder aliphatic CH with oxygen functions appearance, relevant of binder oxidation.

Others shots have been performed on PBXN109 with same experimental conditions than the second shot (see table 2). Atmospheric pressure inside the fitted void tend to increase the occurrence for the complete combustion of the sample.

Further work is needed to confirm the mechanism proposed.

CONCLUSION

This kind of meso-scale analysis is performed on RDX based plastic bonded explosives submitted to shear and compression experiments. Recovered samples are prepared by specific metallographic means. The strain localization induces mainly the mechanical debonding, without leading to shear banding.

The microstructural characterizations show also evidence of local reaction threshold affecting the grains in their periphery, no propagation through reactive cracks is noticed suggesting a freeze of the reaction.

The involved mechanisms of reaction, related to the localization of shear strain and delayed compression and release, could be due to the air trapped in the opened debonding, with a preferential coarse particle appearance. The thermal ignition could then occur by air viscous heating.

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