Adhesion between Energetic Crystal and Polymer Bonded Explosive (PBX) Binder System

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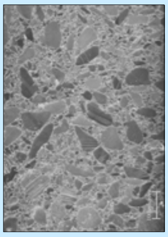
1. Abstract

In a Polymer Bonded eXplosive (PBX) the strength of the adhesion between the energetic crystals and the binder system on the micro-scale, is often reported as a key factor in determining the material strength on the macro-scale. Additionally, it is of obvious importance in terms of safety performance; damaged PBXs have been shown to be significantly more sensitive to impact ignition. Here, we present data collected from idealised experiments, designed to investigate the tensile strength of the adhesive bond between HMX surfaces, and that of a current binder system.

Experimental values of the thermodynamic work of adhesion, determined from surface energy measurements of both HMX and the binder system using liquids of known surface tension and polarity. These are compared against measured works of adhesion obtained from tensile experiments using laboratory grown HMX crystals. It is found that latter values are always greater than the former; the observed differences are due to viscoelastic loss mechanisms within the binder layers.

2. What is a PBX?

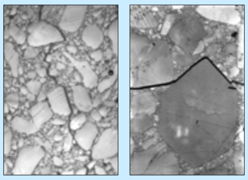


EDC37 microstructure

Polymer **B**onded e**X**plosive (PBX) EDC37:

- Crystalline cyclotetramethylene tetranitramine (HMX), 91 % w/w.
- HMX has bimodal particle size distribution with peaks at 20 μm and 100 μm.
- Gel-based binder (NC/K10), 9 % w/w.
- PBXs are chosen for explosive performance, safety and structural properties.

3. Background to adhesive failure



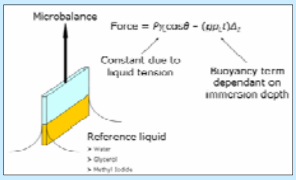
Brazilian test failure: clean debonding of binder from HMX crystals. EDC37 (left) and PBX 9501 (right). From Rae *et al.* (2002).

Optical instrumentation of Brazilian disk experiments performed on PBXs, including EDC37, has shown that tensile strain localises in the binder (Goldrein 1996).

Cracks follow the perimeter of large crystals, often this is accompanied by debonding between the two as illustrated (Rae 2000).

Two complimentary approaches to study adhesion: *Thermodynamic Work of Adhesion* (TWA) and *Measured Work of Adhesion* (MWA). The first is that intrinsic work which done against the bonds which adhere the HMX and binder. The second represents this as well, plus viscoelastic losses due to the binder that are present in any mechanical experiment.

4. Surface energy measurements

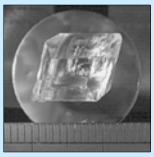


The Wilhelmy plate method was used, as described by Rosano *et al.* (1971). Binder coated microscope slides were immersed in reference liquids. The resultant pull due to surface tension was measured.

From these data the surface energy of the coating can be inferred (42.5 ± 2.8 mJ/m^2), and when combined with HMX data (Yee *et al.* 1980), the TWA calculated.

Crystal Face	HMX surface energy /mJ/m^2	HMX – NC/K10 TWA /mJ/m^2
{011}	45.0	81.5 ± 6.5
{010}	46.0	78.8 ± 7.9
{110}	48.0	79.7 ± 8.3

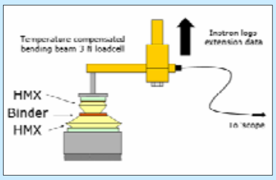
5. HMX-binder-HMX tensile experiments



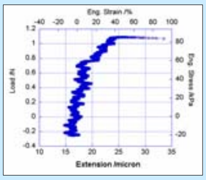
HMX single crystal, scale bar in mm.

HMX Single crystals were grown using a solvent (acetone) evaporation method. A photograph of a typical 'large' crystal is shown, the upper most face in figure is a {010} type face.

Thin layers of NC/K10 binder were spin-coated on to the HMX.

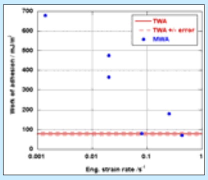


Load measurements were made using an amplified Novatech F301 3N loadcell. Tensile experiment performed as shown.



Load-displacement and engineering stress-strain data for an experiment where the upper crystal was pulled off at a cross-head extension speed of 1.0 mm/min are shown. A simple failure energy is calculated on the basis of work = force × displacement

6. Combined results



The MWA results may be directly compared to those of the TWA experiments.

Whilst the number of experiments is still few, and the data somewhat scattered, we may draw some immediate conclusions:

- As the loading rate increases the general trend is for the MWA to decrease. This could be due to viscoelastic losses at lower rates, and a loss-reduced glassy response at higher rates.
- At the highest strain rates the MWA is in excellent agreement with the TWA.

7. Conclusions

- Surface energy of the NC/K10 binder is 42.5 ± 2.8 mJ/m^2.
- TWA of 78.8 ± 7.9 mJ/m^2 for the {010} HMX face.
- MWA values compare favourably with TWA at highest applied stain rates. Differences at lowest rates (MWA > TWA) attributed to bulk viscoelastic loss within thin binder layer.
- Data essential for micromechanical model validation and useful for small-scale evaluation of new formulations.

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9. References

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