

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



DM Williamson, SJP Palmer, WG Proud and JE Field

Physics and Chemistry of Solids, Cavendish Laboratory, Madingley Road, Cambridge CB3 0HE, U.K.

## 1. Abstract

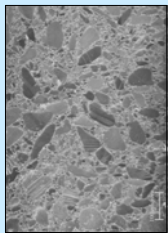
In a Polymer Bonded explosive (PBX) the strength of the adhesion between the energetic crystals and the binder system on the micro-scale, is often reported as a key factor in determining the material strength on the macro-scale. Additionally, it is of obvious importance in terms of safety performance; 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?

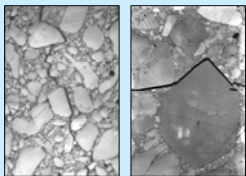
Polymer Bonded explosive (PBX) EDC37:

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



EDC37 microstructure

## 3. Background to adhesive failure



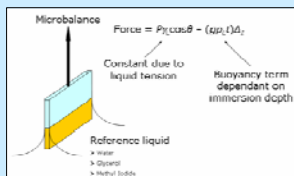
Optical instrumentation of Brazilian disk experiments performed on PBXs, including EDC37, has shown that tensile strain localises in the binder (Goldrein 1996).

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

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

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

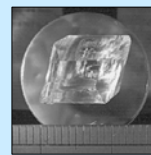


The Wilhelmy plate method was used, as described by Rosano *et al.* (1971). Binder coated microscope slides were immersed in reference liquids. The resultant pull due to surface tension was measured.

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

Crystal Face	HMX surface energy /mJ/m <sup>2</sup>	HMX - NC/K10 TWA /mJ/m <sup>2</sup>
{011}	45.0	81.5 $\pm$ 6.5
{010}	46.0	78.8 $\pm$ 7.9
{110}	48.0	79.7 $\pm$ 8.3

## 5. HMX-binder-HMX tensile experiments

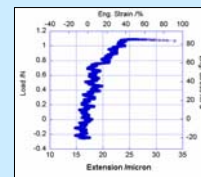
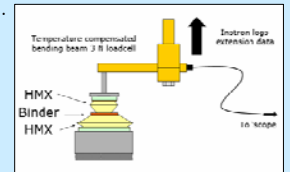


HMX single crystal, scale bar in mm.

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  $\times$  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  $42.5 \pm 2.8 \text{ mJ/m}^2$ .
- TWA of  $78.8 \pm 7.9 \text{ mJ/m}^2$  for the {010} HMX face.
- MWA values compare favourably with TWA at highest applied strain 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.

## 8. Acknowledgements

The authors would like to thank EPSRC for a studentship for D.M. Williamson and grants for the high-speed cameras. They would also like to thank AWE Aldermaston for materials, discussion and funding. WG Proud is OinetIQ Senior Research Fellow at the Cavendish Laboratory. Prof. JE Field is thanked for his valuable advice and comments. R. Flaxman and D. Johnson of the Cavendish Laboratory's workshop are thanked for technical assistance.

## 9. References

- Goldrein H.T. 1996 Applications of optical strain measurement techniques to composite materials. PhD thesis, University of Cambridge.
- Rae P.J. 2000 Quasi static studies of the deformation, strength and failure of polymer bonded explosives. PhD thesis, University of Cambridge.
- Rae P.J., Palmer S.J.P., Goldrein H.T., Field, J.E. and Lewis, A.L. 2002a Quasi-static studies of the deformation and failure of PBX 9501. *Proc. R. Soc. Lond. A* **458** 2227-2242.
- Rosano H.L., Gerbacia W., Feinstein M.E., and Swaine J.W. 1971 Determination of the critical surface tension using an automated wetting balance. *J. Coll. Int. Sci.* **36** 298-307.
- Yee R.Y., Adicoff A., and Dibble, E.J. 1980 Surface properties of HMX crystal. *In 17th Combustion meetings: papers JANNAF.*