Stopping km/s Blunt Fragments and Limiting Shock Lensing with a New Advanced Energy Absorbing Composite

Gareth R Tear[1], Gianmaria Bullegas[1], Jose Videira[1]
[1]*Synbiosys Ltd., UK*
gareth@synbiosys.co

Abstract We are developing a lightweight ceramic/polymer composite for km/s fragment resistance. It uses a fundamentally new physical process for energy absorption that complements the conventional forms of energy dissipation of fracture and plastic deformation. This composite comes into its own against very high impact velocities, being able to provide protection in shock regimes where conventional materials like kevlar and steel can be considered incompressible fluids with zero protection capabilities.

This material can be used in rocket motor casings for increased IM compliance. It can absorb and dissipate energy extremely quickly (of the order of 100kJ/m2/µs). Crucially it limits shock lensing effects, augmenting current capabilities against blast and shaped fragments. The energy dissipation mechanism propagates at 7km/s inside the material and activates with minimal (<2%) overall strain of the structure. The design of the composite is flexible enough to be optimised for a range of projectile threats and velocities.

In practical terms, the composite has the same density as aluminium and is made from cheap raw materials. It can also be made transparent, enabling applications beyond rocket motor casings into protective blast windows.

We present here experimental verification of our fundamental energy absorbing process through plate impact experiments, taking measurements by interferometry (PDV) and high-speed videography. We demonstrate that this process does provide a significant (20m/s) decrease in rear surface velocity in plate impact experiments.

Introduction

Shock to Detonation Transition (SDT) is one of the phenomena limiting effective energetic materials for use in dangerous environments. Explosive efficiency, whether measured by weight, impulse or another metric, is sacrificed to achieve the low sensitivity demanded by Insensitive Munition (IM) requirements. Traditionally IM technology has focused on chemically developing explosives and compositions which have low intrinsic sensitivity. In this paper we present a mechanical mechanism for dissipating hot spot formation and attenuating shock fronts directly, allowing more efficient explosive compounds to be used, whilst maintaining the munitions overall IM compliance.

The mechanism has been implemented into a composite form of protection, offering the ability to absorb energy at the shock front, reducing the strain rate on the material behind the composite. It achieves this with less than 2% strain, making it a viable composite for protecting energetic material. The mechanism attenuates energy at the shock front, and can prevent the large transient impulses characteristic of shock waves and particularly dangerous to energetic material.

Vision for the composite technology

The composite has a density of around 2.5g/cm^3. The raw materials can be considered abundant and will cost around $2000 - $5000 per ton to purchase, and the manufacturing involves traditional composite construction techniques with temperatures not exceeding 200°C.

This rocket motor casing composite will be the first of a family of composites developed by Synbiosys Ltd for impact protection. A transparent version can be made for window applications. High temperature performance of the composite is yet to be tested. Given the upper impact velocity is 7km/s, this composite family could be useful in certain space applications.

Experimental Method

One dimensional plate impact experiments are used to demonstrate the shock front attenuation and to characterise the material. Fragment impact experiments are used to validate the one dimensional behaviour into a more general and realistic loading scenario.

Sample Preparation and Geometry

The sample is manufactured from industrially sourced raw materials. The sample is polished on a lapping wheel to get flat and parallel sides (typically 2 sodium light bands) resulting in samples of around 20 mm to 30 mm in diameter and 5 mm to 15 mm thick. Low viscosity Hysol 9483 epoxy is used to bind the target material with any window or driver layers used on a per experiment basis.

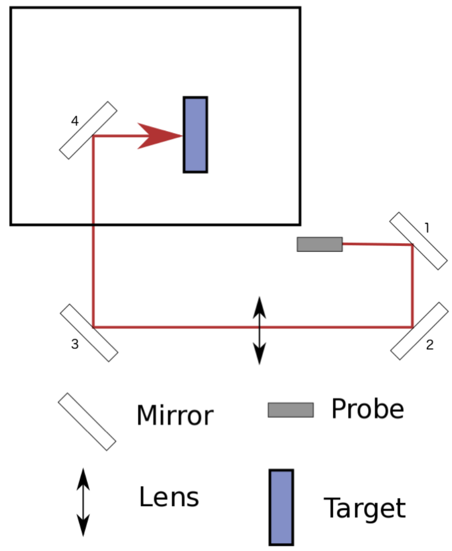
Plate Impact Facility

Plate impact experiments are conducted on the Imperial College London 32 mm bore light gas gun. Using helium, velocities of up to 800 m/s have been achieved. The sample is mounted in a ThorLabs 3 inch optical mount, and aligned normal to the barrel. The alignment procedure is:

1. Align a laser diode coaxial to the barrel using an iris.
2. Align the target mount to be concentric with the barrel using a 3 inch iris mounted in the target holder.
3. Align the target mount to be normal to the barrel using a 3 inch planer mirror.

The sample is mounted to a three inch cast PMMA disk. This PMMA sample holder is verified to be flat over 75 mm to within 2 light bands using a sodium lamp. It is assumed that the sample holder is flat, so that the aligned target mount places the sample in the correct orientation.

The plate impact facility has a four channel fibre based generation one Photonic Doppler Velocimetry (PDV) system operating at 1550 nm (Strand 2006). Each channel has a dedicated laser diode. A 250 mm working distance probe with a 5 mm aperture and an achromatic doublet lens with -60dB back reflectance is used to launch the laser light into free space. The free space portion shown in figure 1 uses a projecting lens to focus the PDV onto the target and alignment mirrors to align the laser.



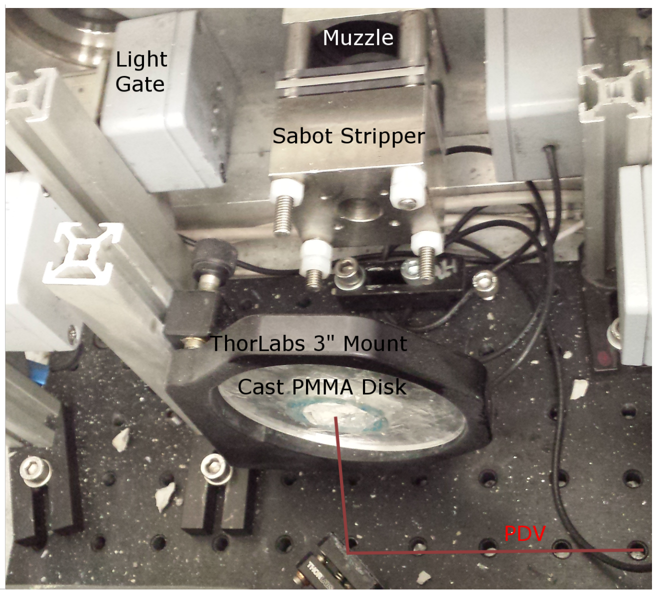


Figure 1 (Left): The PDV relay allows mirrors 1 and 2 to be used to align the beam along the axis of the lens. The lens is on a linear translation stage, allowing the lens to be moved along the beam path, changing the focal plane of the system for each new target. The mirrors 3 and 4 align the PDV onto the target. The barrel alignment laser is used to align the PDV with the centre of the target. Mirror 4 is sacrificial and must be replaced each experiment.
Figure 2 (Right): Target chamber of 32mm gas gun set up for fragment launch. To conduct plate impact experiments, the sabot stripper is removed from the muzzle.

Fragment Simulating Projectile (FSP) Impacts

FSPs conforming in geometry to STANAG 4496 are launched using the same 32 mm facility, however the sabot is stopped by a stripper plate attached to the muzzle. This stops the sabot whilst allowing the smaller fragment to pass. Velocity losses from the sabot speed to the fragment speed are minimal (typical less than 5 m/s). The stripper plate uses a sandwiched polycarbonate and aluminium structure to absorb energy, with a steel momentum trap as the last block. M6 studding is used to mount the blocks, and nylon nuts are used to hold the structure in place. Multiple sets of nuts are used, with clear space in-between, to ensure safe energy deposition into the target tank. A full description of the fragment launch capability is described in (Nguyen 2017, 2018). Figure 2 shows the target tank setup for fragment impact.

Results

Several impact experiments have been performed on plate impact and fragment impact scenarios. The results are separated into plate impact results, demonstrating the transient release phenomena, and fragment impact results demonstrating the capability.

Plate Impact

PDV data from the plate impact experiments shows a marked reduction in rear surface velocity when the transient release phenomena occurs. The plate impact experiments are used to determine the wave speed of this phenomena, and the optimal parameters of operation. The PDV spectrograms from two plate impact experiments demonstrating the reduction in velocity are shown in figure 3. A three point parabolic fit is used to determine the spectrogram peak, and the extracted velocity is shown in figure 4.

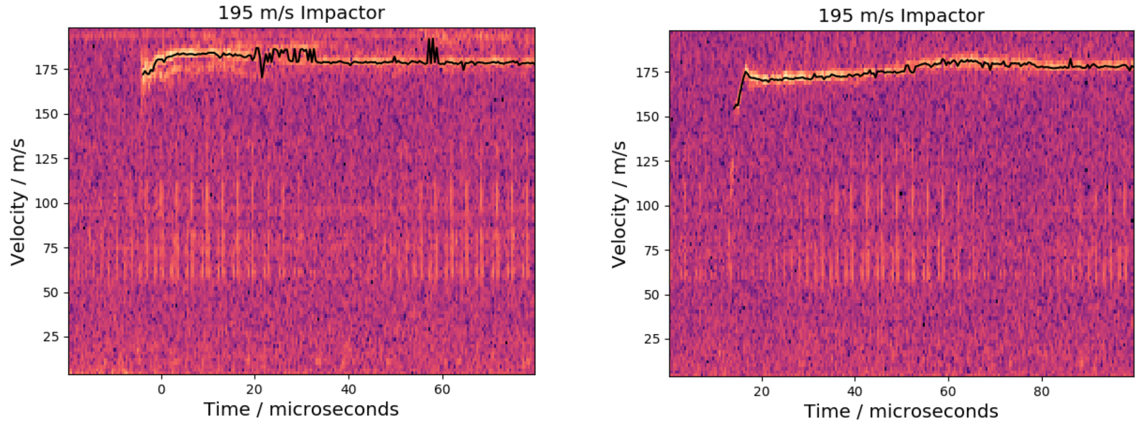


Figure 3: *Left* flyer impact at 195 m/s, demonstrating limited energy absorbing behaviour. The resulting shock peak is 185 m/s. *Right* improved energy absorption activated using a flyer impact at 195 m/s, showing an attenuation and ramping of the initial shock to 175 m/s peak, and the average absorbed impulse is 20kJ/m^2/microsecond.

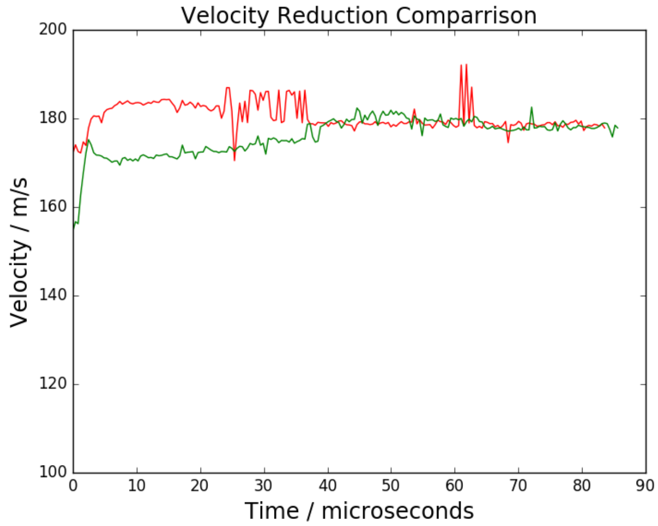


Figure 4: Extracted velocity curve from PDV, making the velocity reduction explicit. Note that the final velocity is the same, as these experiments are momentum equivalent. This ensures that, for an identical impulse, less energy is transferred (energy is dissipated by the release phenomena).

Using the reduction in velocity, an estimate of the energy absorbed, or effective toughness of the material, can be found. Using the pressure calculated from the Rankine-Hugoniot conditions, approximately 700 +/- 100 kJ/m^2 has been absorbed in this 20 mm thick plate. Taking into account the timeframe of energy absorption over 35 microseconds, the energy absorption rate (or power) is 20kJ/m^2/microsecond, or 20% of theoretical maximum.

Fragment Impact

A 430 m/s FSP was stopped using a 16mm thick non-optimised composite structure in figure 5, and an equivalent comparison carried out on toughened glass in figure 6. The FSP residual ricochet velocity was 20 m/s compared to toughened glass's 45 m/s. Glass was used in this instance as the composite can be made transparent, and comparison with transparent materials was desired.

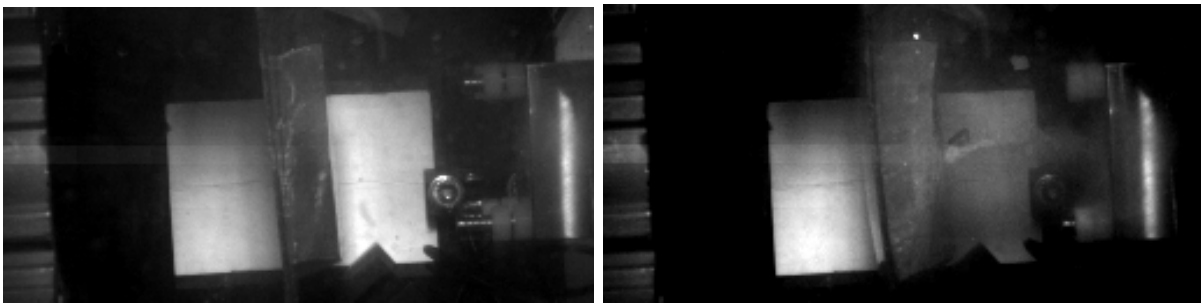


Figure 5: *Left* Energy absorbing composite target before impact. *Right* Target immediately after impact, with projectile bouncing off the surface at 20 m/s.

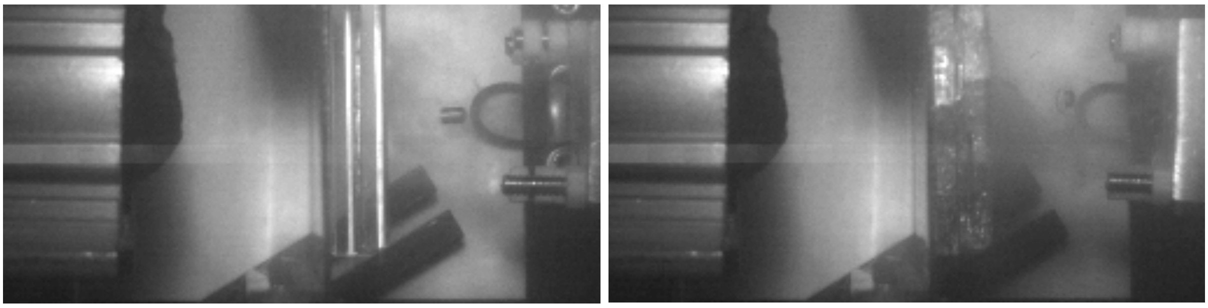


Figure 6: *Left* Typical toughened glass laminate target before impact, projectile approaching from right hand side. *Right* Target after impact, fracture to glass evident and fragment has ricocheted at 45 m/s.

Discussion

The present results demonstrate an ability to absorb energy at the shock front in one dimensional loading. This attenuation occurs from a transient release of the composite, preventing the high amplitude shock loading of the rear surface. Materials (e.g. energetic materials) bonded to the rear surface experience lower strain rates and so the impact velocity required to initiate an SDT event is increased. This allows more energetic materials to be used whilst maintaining IM compliance.

Three dimensional effects have yet to be fully characterised. In order to achieve this, multiple PDV channels are being deployed on future experiments, combined with rear surface imaging, to measure the effectiveness of this technique against converging shock geometries. As the attenuation of the shock front reduces its velocity as well as its pressure, regions of a converging shock front can be selectively slowed, to prevent the shockwaves reaching a focus.

There are two directions in which this technology can be developed.

Protective casings

As eluded to already, the development of a composite casing which attenuates shock waves is the primary focus. By preventing the initial shock being transmitted to the propellant, the IM threshold of the overall munition can be increased. This does not intrinsically lower the IM compliance of the energetic material, but as evidenced in the XDT phenomena, geometric and casing effects are an integral part of a munitions IM compliance testing.

Binder Additive

As the propellant is a composite, it is plausible to form an energetic composite that is resistant to SDT events. As the material is compressed, local hot spots are prevented by the rapid transient release phenomena, dissipating the build up of pressure in the hot spot. As the location of transient release can be engineered, an energetic structure can be designed with reduced sensitivity to anything except the designated detonator.

Conclusions

- One dimensional plate impact experiments demonstrate ability to directly absorb energy at the shock front.
- Initial low velocity fragment testing comparable to equivalent industry standard materials.
- Further development for high velocity fragments and three dimensional geometries is underway.

Synbiosys

Synbiosys is a materials innovation startup formed of alumni from Imperial College London. The company's expertise revolves around composites engineering, optical and solid state physics and shock physics. The advisors have a long history in working in academia, industry and government.
Organisations in which company members have been previously involved with are QinetiQ, Thales, AWE, the UK MoD (Department for Transport), the US DoD (DARPA and DTRA) and Imperial College's Institute for Shock Physics and Institute for Security Science and Technology.
Synbiosys as an entity has already a track record, having successfully delivered a project on time and on budget for DSTL for a different technology stream.

References

Strand, O. T., Goosman, D. R., Martinez, C., Whitworth, T. L., & Kuhlow, W. W. (2006). Compact system for high-speed velocimetry using heterodyne techniques. *Review of Scientific Instruments*, *77*(8), 83108. http://doi.org/10.1063/1.2336749

Nguyen, T-T, Carpanen, D., Tear, G., Stinner, D., Clasper, J., Proud, W. & Masouros, S. (2018). Fragment Penetrating Injury to the Tibia. *Accepted*

Nguyen, T-T, Masouros, S., Tear, G. & Proud, W. (2017). Investigation of Ballistic Penetration through Tibia Soft Tissue Simulant. *20th Annual Conference on The Shock Compression of Condensed Matter (Accepted)*