Syntech

Synbiosys's Phase Change technology for high performance armour

Synbiosys Ltd
www.synbiosys.co.uk

Commercial POC:	Dr. José Videira	jose@synbiosys.co
Technical POC:	Dr. Gareth Tear	gareth@synbiosys.co

Executive Summary

Synbiosys has developed a patent pending technology for harnessing a thermodynamic process (phase change) in materials. This phase change mechanism can absorb and dissipate large amounts of energy in nanoseconds. Phase change happens regardless of threat hardness or shock lensing attempts. This material technology, we call Syntech. Generally to be used as the front impact layer, Syntech's key properties are:

- Stopping power of Tungsten Carbide, weight of Aluminium, cheaper than Steel (opaque), price point of Glass (transparent).
- Armour piercing effects are nullified.
- Resistant to km/s fast, blunt threats e.g. IED shrapnel
- Superior multi-hit performance through damage localisation
- Low-cost manufacturing using low-cost abundant key source materials.

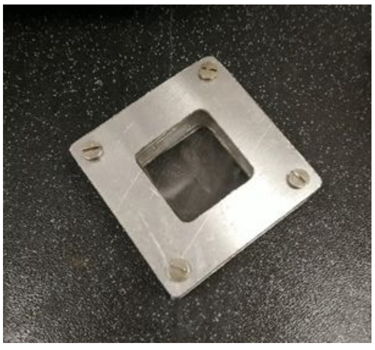
Applications :

- Platform opaque armour
  - Aircraft, rotorcraft, land vehicles
- Transparent armour - platforms and buildings
  - Aircraft, rotorcraft, land vehicles
- Body armour
  - Male and female, armour piercing plates
- Hardening buildings, critical infrastructure and fortifications
  - Retrofitting, bespoke, fragment resistance
- Munitions protection and Insensitive Munition compliance
  - Mitigation barriers, rocket motor casings

The vision of the future is that this phase change technology is harnessed in many different materials, and will lead to a new generation of thermodynamic armour.

Our knowledge in utilising this process in our initial transparent armour product will pave the way to drastically improve armour piercing and fast fragment resistance in all armours, opaque and transparent, in all applications ranging from building, vehicle and personnel.

Synbiosys is the only organisation in the world that understands how to harness phase change for armour applications.



Achievements and outcomes up to now

- Plate impact experimental data confirming the existence and possibility of harnessing phase transformation for ballistic resistance applications
- Plate impact experimental data confirming phase transformation upper and lower pressure boundaries for our initial armour material
- Peer reviewed conference proceedings in NDIA IMEMTS 2018 for fast fragment resistance.
- Ballistic experimental data using representative .44 magnum rounds indicating utility in transparent armours
- Numerical models for Syntech for future development
- Poster presentation at APS SCCM 2019 - 19/06/2019 for transparent armour
- Peer reviewed conference proceedings in APS SCCM 2019 for transparent armour

Key properties of Syntech

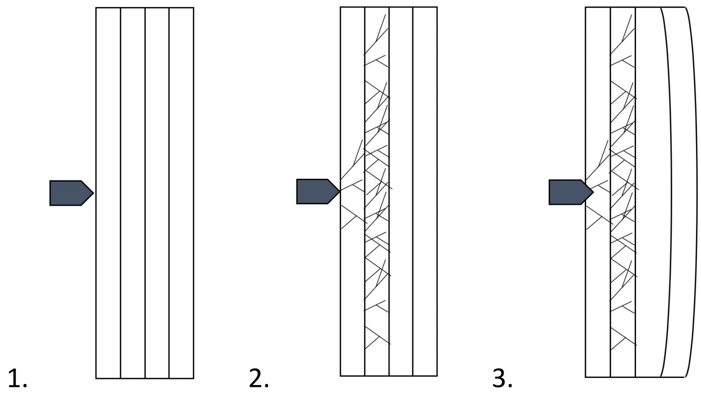
Syntech will act as a complementary feature to both conventional armour mechanisms of fracture and plastic deformation.

Syntech as an energy absorption mechanism is inherently non-destructive and reversible. The mechanism also reacts to, and travels through the armour material, at a speed of 7km/s. The phase change energy absorption rate in Synbiosys's initial armour material is estimated to be 100kJ/m^2/µs at <2% strain. This means we have the potential to cycle through this mechanism multiple times before material fracture.

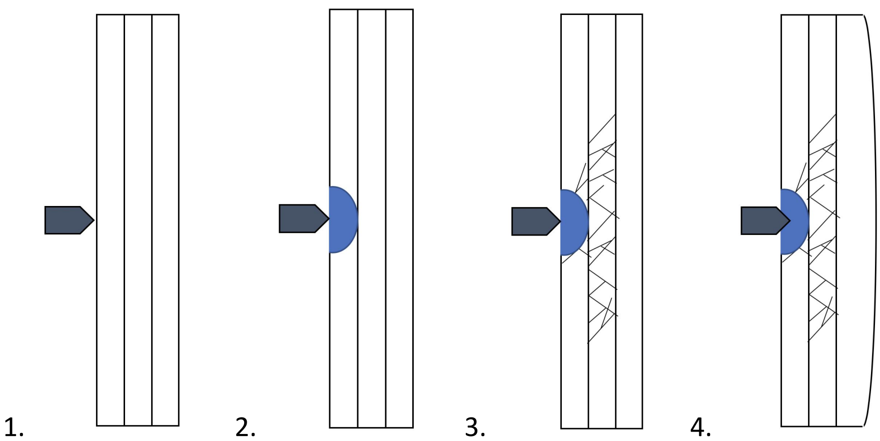
The hardness of the threat material is irrelevant to Syntech's functioning. We can consider it to be "hardness agnostic", and such conventional armour piercing materials such as Tungsten Carbide have their material advantage nulled.

Syntech also limits shock lensing effects, and as such prevents damage localisation caused by e.g. fast moving blunt threats. We envision that Syntech is more effective than other materials against fragments and shrapnel travelling faster than 1km/s. Against very fast threats, Syntech is key in providing protection in shock regimes where conventional materials like kevlar and steel can be considered incompressible fluids with zero protection capabilities. The physics suggests that the fast projectile superiority also applies to the current cutting edge transparent armour material, ALON.

The initial Syntech material used has a density of 2.7 g/cm^3, similar to that of aluminium. This is 3 times less dense than Maraging Steel and almost 6 times less dense than Tungsten Carbide. The large scale manufacturing process is projected to involve sintering at a temperature, pressure and duration an order of magnitude lower than ALON.



Conventional armour when impacted (1), fractures (2) and then plastically deforms (3) to stop a projectile.



Syntech adds a new mechanism to absorb energy. At impact (1) the armour undergoes a phase transition (2) which is much faster than fracture. This reduces the amount of fracture damage (3) and decreases the thickness of the plastic/anti-spall layer (4).

Figure 1 - ***Top****: Convention armour energy dissipation mechanism.* ***Bottom****: Syntech's additional mechanism and how it can be applied to reduce the thickness and damage on armour.*

Use cases for Syntech

Syntech is a technology platform, enhancing material properties and rapid energy absorption in high energy impact applications, from velocities of a handgun round (500m/s)all the way up to space debris (7km/s). In all cases, Synbiosys aims to control and engineer the phase change to provide the most effective energy absorption, and deliver the desired material properties at the right time.

Platform opaque armour (Syntech-V)

Lighter, armour-piercing (AP) resistance

Both land and aerial platforms require lightweight armour solutions. The issue of weight is even more pertinent for aerial vehicles. The greatest benefits would be seen in replacing, in-part or completely, steel or ceramic layers, thus enabling the reduction of all layers within the armour system. <u>This is all done with a material that would be cheaper than Steel to manufacture.</u>

Taking advantage of Syntech's hardness agnosticism and its effectiveness at dissipating energy, we can improve upon current conventional armour composites by:

a) Replacing denser metallic/ceramic AP resistant layers with less dense Syntech material layers, thus making current AP resistant armour systems lighter.
b) Elevating the performance of non-AP resistant armour systems by adding a thin, light Syntech material layer.
c) Reducing the weight of complex shaped steel structures such as hatches, grills and gun turrets for cost equivalence by replacing significant steel with a thin Syntech layer.

Applications:

Lightweighting air platform armour for equivalent performance

- Marshall's ADG current armour solution for the C-130 Hercules is simply ultra high molecular weight polyethylene (UHMWPE), with metallic or ceramic impact plates being too heavy to provide heightened protection. A Syntech front layer could further reduce the weight of this armour for performance parity, or increase it to AP resistance with minimal weight gain.

Increase protection for equal weight on attack air platforms

- Performance enhancement for minimal weight gain would be even more significant to the protective tub within attack platforms such as the Apache helicopter, which require resistance to AP or higher-calibre ammunition.

Equivalent performance with much reduced cost on land platform complex structures

- Complement steel complex molded structures such as hatches, grills, vision blocks and gun turrets. Adding a few millimetres of Syntech can reduce thickness by inches, reducing cost and manufacturing complexity and cost, as well as weight.

- Lightweight composite armour systems - replacing significant thicknesses of ceramic/steel and polymer backing by adding a thin layer of Syntech into the system.

Transparent armour (Syntech-T)

The most recent results for Syntech in a transparent armour used case is presented in an APS SCCM 2019 conference proceedings. A draft of this is attached to this white paper.

Synbiosys envisions a 50% reduction in thickness and 50% in weight for conventional transparent armour for equivalent ballistic protection standards. This has clear benefit for vehicles which need to offer protection with a low visual signature.

The aim is to manufacture Syntech-T at the same price point as conventional Glass. This is possible as all steps of the manufacturing process are low-pressure, low-temperature, compared to all other ceramics.

Transparent armour is Synbiosys's first application of phase change armour as:

- Weight is a first and second order problem in vehicles:
  - It massively degrades vehicle handling performance, it increases wear and tear on components and fuel consumption.
  - The logistical costs of fuel are also up to 100x the cost of the fuel itself.
- Current ballistics standards are rated to three strikes within 120mm of each other. Syntech's mechanism of energy dissipation would enable smaller areas of catastrophic damage on a window material, thus paving the way for a window that can tolerate smaller strike groupings as well as more strikes in total.

Applications:

Lightweighting platform windows

- Synbiosys envisions a 50% reduction in thickness and 50% in weight for conventional transparent armour for equivalent ballistic protection standards. This is done by removing layers of glass, or reducing the thickness of the glass layers, by adding a thin Syntech front layer. This can be applied to both land vehicles and air platforms.

Increase protection on attack air platforms

- Significant performance for transparent armour in air platforms such as helicopters are unviable due to the weight or cost of current transparent armour technologies. Performance enhancement for minimal weight gain would be even more significant for attack platforms such as the Apache helicopter, which require resistance to AP or higher-calibre ammunition.

Transparent Reactive Armour

- Syntech has the ability to absorb a significant amount of impulse generated from the activation of reactive armour. The level of absorption would open the possibility of windows that can truly achieve STANAG 4569 levels 5 and 6, without prohibitive thickness or loss of optical clarity.

Body armour (Syntech-P)

Synbiosys envisions a 50% reduction in thickness and 50% in weight for conventional AP-resistant body armour. Like platform opaque armour, this is all done with a material that would be cheaper than Steel to manufacture.

Taking advantage of Syntech's hardness agnosticism, its effectiveness at dissipating energy, and its cost-effective and flexible manufacturing techniques, we can improve upon current conventional body armour composites by:

a) Enabling more complex body armour geometries whilst maintaining protection standards.
b) Replacing denser metallic/ceramic AP resistant layers with less dense Syntech material layers, thus making current AP resistant armour systems lighter.
c) Elevating the performance of non-AP resistant armour systems by adding a thin, light Syntech material layer.

Applications:

Complex geometry body armour e.g. female armour plates

- Syntech-P's polymer matrix construction can be easily cast into complex body shapes. Further, due to the nature of phase change, the shape of the Syntech layer will not affect its protective performance. By adding Syntech-P as the front layer, Synbiosys envisions the possibility of enabling composite armour plates to take on more complex geometries without impacting performance.

Lightweighting body armour for equivalent performance

- By replacing a significant amount of a ceramic or steel front plate with a Syntech-P layer that is the same density as aluminium, Synbiosys envisions performance parity with a 50% decrease in weight.

Hardening buildings and fortifications (Syntech-B)

We can harness Syntech material's resistance to shock lensing effects, and its plasterboard-like cheapness of manufacturing, to increase the hardness of critical building structures in a discreet manner for very little extra cost. Syntech materials can be incorporated into these buildings, either integrated directly into a building as part of its construction or as an add-on layer to walls or barriers.

The material will have the same manufacturing cost and integration simplicity as plywood or plasterboard.

Applications

Discreet critical infrastructure for hardening against rounds and IEDs

- Compatible with conventional, simple construction methods to integrate into a structure, much like plywood, Syntech-B will provide an exceptionally cost-effective and integratable building hardening solution. As either a cladding or mid-insulation layer, Syntech-B cladding and barriers can be added to critical infrastructure.
- With the ability to provide protection at much reduced thickness and weight, this opens the possibility of truly discreet protection against national security threats.

Munitions storage - permanent and rapidly deployable

- As described in the section below, there is a risk of sympathetic detonation of munitions if one is made to detonate. Syntech-B is geared towards fast fragment resistance, thus shrapnel will be slowed sufficiently to provide the unwanted detonation of any other munitions.
- Being the weight of aluminium, Syntech-B can be easily transported and deployed to forward bases for enhanced base safety.

Inter-vehicle barriers

- Syntech barriers can be placed between e.g. fully loaded jet fighters on the tarmac, to prevent sympathetic destruction, in the risk of an attack.

Insensitive munitions (IM) and preventing sympathetic detonation

Compliance with Insensitive Munition (IM) requirements often limits the choice of energetic material in munitions. Syntech allows more energetic material to be used whilst not increasing the overall sensitivity of the munition. In technical terms, we aim to reduce the sensitivity of munitions to Shock to Detonation Transition (SDT) and Unknown Detonation Transition (XDT) phenomena. We take advantage of two of Syntech's properties:

a) That it limits shock lensing effects, and as such prevents damage localisation caused by >1km/s fast blunt objects.
b) That the energy is absorbed and dissipated at very small (2%) strain.

By using Syntech, either munitions can be made more safe, or higher performance and more effective explosives and propellant compositions can be utilised with equivalent IM compliance.

Like platform opaque armour, this is all done with a material that would be cheaper than Steel to manufacture.

Applications

Syntech composite rocket motor casing

- A Syntech composite rocket motor casing which attenuates shock waves. By preventing the initial shock being transmitted to the rocket propellant, the IM threshold of the overall munition can be increased.

Syntech-doped rocket propellant

- Incorporate Syntech into rocket propellant compositions that are resistant to SDT events.

Cheaper mitigation barriers on naval platforms

- The hardening of naval platforms with Syntech composite mitigation barriers can provide effective protection in weapons and munitions bays, reducing the risk of total destruction of a ship if there were an attack or accident.

Cavitation Protection for Ships - Light hull and propellers

Syntech can provide additional protection to below water line armour on ships. By exploiting the phase change of Syntech to optimise shock coupling between the water and the ship's hull, cavitation damage can be reduced. This means the reduction of the effects of a) close proximity underwater detonation and b) cavitation from a moving propellor. As Syntech is a non-corrosive environmentally safe material, this can be made into a drop-in option for protection of existing assets.

Other uses

Other potential uses of Syntech can be explored in conversation with Synbiosys.

Current research progress

The current Synbiosys research effort has demonstrated the phase change behaviour, and attempted to develop a sample for ballistic protection. In order to aid the development process a numerical model for the material has been implemented. Current research is focussed on transparent armour.

Experimental development

The 32 mm Light Gas Gun in the Centre for Blast Injuries Studies (CBIS) was used for a number of recent experiments. Syntech samples were manufactured in house using our novel phase change layer and typical armour materials such as polycarbonate. For comparison, Romag's 24.7mm BR4/SG1 NS Bullet Resistant Glass/Poly CE BS EN 1063 were investigated. Samples were mounted in the 32 mm light gas gun using an aluminium extrusion stand and angled brackets were attached to the rexroth to prevent the frame moving too much during impact. Some samples were framed using aluminium and one sample was constructed from a piece of BR4 glass and fitted with a thin (2mm) layer of Syntech to study the damage reduction.

Impacts against spherical ball bearings as well as bullet simulating impacts were conducted. For the bullet simulants a copper projectile machined to the shape of the flat nosed .44 calibre magnum round was produced (shown in Figure 2). Both were launched by attaching the projectile to the end of a sabot, and separating the projectile and the sabot at the muzzle using a series of impedance matched plates and momentum traps.

Figure 2 - *.44 magnum rounds mounted on sabots, ready for firing*

Diagnostic tools and results

One of the key pieces of instrumentation is Photonic Doppler Velocimetry (PDV) which records the velocity of a surface. This provides vital information regarding the amount of energy and momentum transferred to the armour. If the phase change occurs as expected, there should be a noticeable drop in the rear surface velocity, as kinetic energy is converted to thermal energy. This is shown in

Figure 3. Additionally fractography in Figure 4 is used to study the damage evolution in transparent armour, and understand how the phase change hinders and reduces fracture formation.

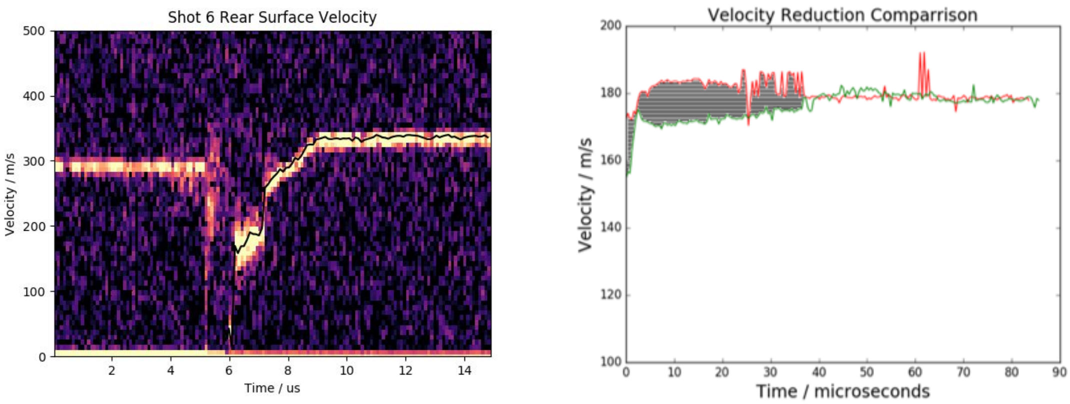


Figure 3 - *PDV data.* ***Left****: Raw spectrogram data from a recent experiment.* ***Right****: Comparison data from two shots showing phase change (green) and without phase change (red). The area in gray represents the energy absorbed by the phase change.*

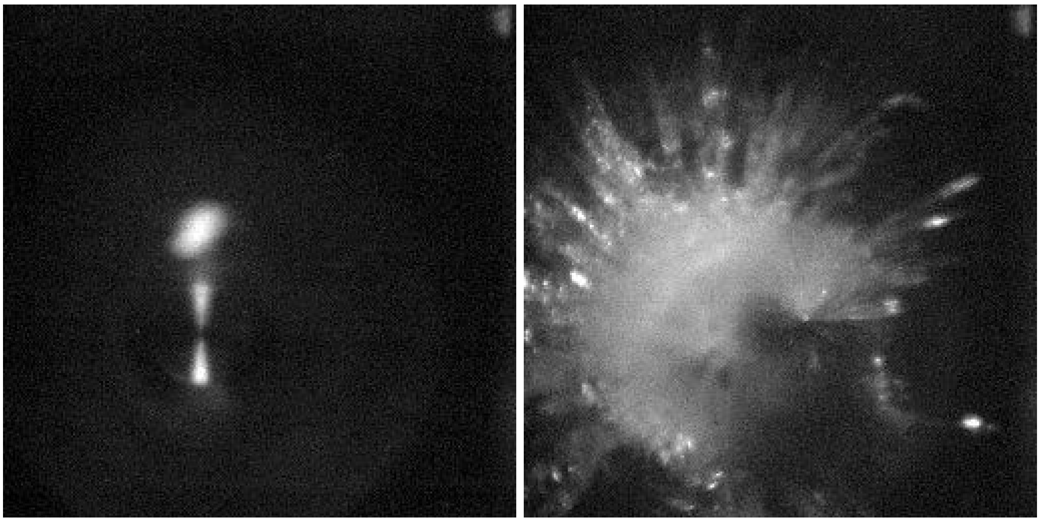


Figure 4 - *Fractography photographs on impact.* ***Left****: Pre-impact frame showing flat nose of bullet approaching target.* ***Right****: Impact frame showing fracture spread and shape.*

Simulations and predictive optimisation of armour

Synbiosys has begun developing in-house cutting edge phase change simulation software to understand phase change energy absorption phenomena, and to design the next iterations of Syntech samples. Further work will be needed to grow this into a fully functional software package that can be applied to all armour scenarios.

Using the PDV data, direct comparisons to the simulations can be made. This is due to the simulation calculating particle velocity directly, and PDV directly measuring particle velocity in the experiment. Using our data set, a model for Syntech is being developed, allowing us to make predictive optimisation of armour, as shown in Figure 5.

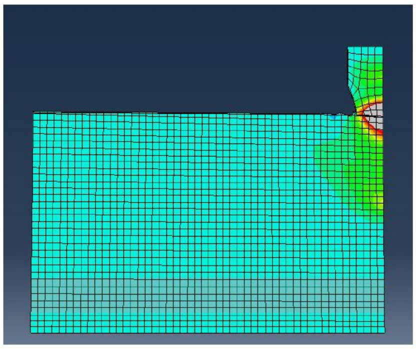


Figure 5 - *Simulation results on phase transformation. The grey area indicates phase transformation.*

Practical proof of phase change for armour

As discussed at the start of this paper, Synbiosys envisions several uses of Syntech, with new areas of design space opened up by the phase change mechanism.

Improved multi-hit performance of existing armour

A 2mm layer of Syntech can be added to commercially available BR4 glass, and drastically reduce the damage sustained by the sample. In Figure 6, a comparison of the same glass, shot with the same projectile at the same speed, one with Syntech and one without, shows visually the reduction in damage.

(A) (B)

Figure 6 - ***(A)*** *Commercial BR4 sample impacted with .44 simulated magnum round and* ***(B)*** *a BR4 sample impacted under the same conditions as* ***(A)*** *except having 2mm of Syntech on the front*. *The vast reduction in damage to the Syntech-layered sample is seen clearly in* ***(B)****.*

Thinner transparent ballistic armour

In Figure 7, freeze frames from the same shots show the difference in rear surface deformation of the two samples, giving another perspective on how damage to the glass is significantly reduced using Syntech. The control BR4 glass sample, when hit a .44 projectile, deforms significantly as mechanism to absorb and dissipate energy. The glass sample with a 2mm layer of Syntech shows no deformation, indicating that the energy absorbed and dissipated in a much more efficient and less physically demanding manner.

This shows that it is possible to reduce the thickness of current armour and achieve the same level of protection. The video from which the freeze frames are taken from can be found on our webpage: https://www.synbiosys.co/whatwedo/

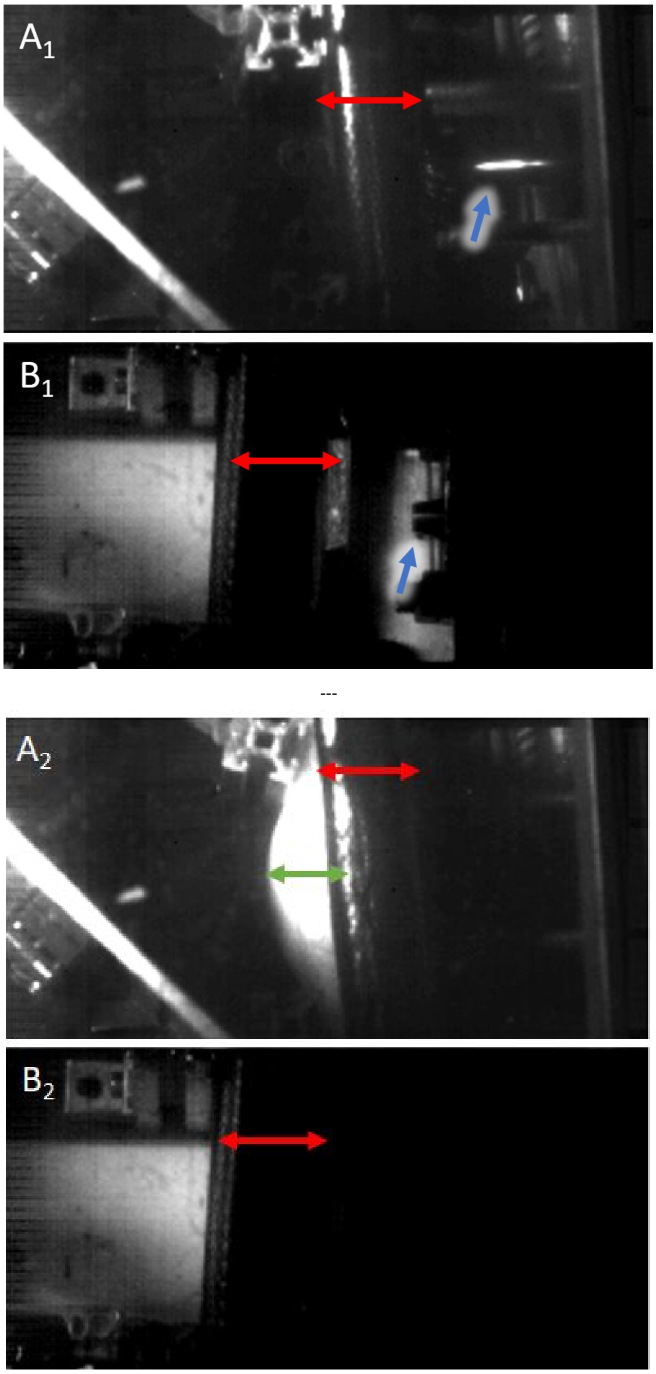


Figure 7: *Freeze frames from high speed camera footage.* ***Top****: Samples before being hit,* ***A_1*** *being the conventional BR4 glass with no front layer, and* ***B_1*** *being the same spec BR4 glass with 2mm of Syntech. You can see the thickness of the samples (red double arrow) and the incoming .44 projectile (pointed out by the blue arrow).* ***Bottom****: Samples having been hit with the .44 projectile.* ***A_2*** *shows The conventional glass shows large deformation (shown by the green double arrow) to absorb and dissipate the energy.* ***B_2*** *shows the Syntech layered sample with no deformation.*

Technology readiness level

Phase change as an armour technology

Utilising phase change as a mechanism for protection is at TRL 4. We understand what it takes to engage the phase change within our chosen material.

Manufacturing

The manufacturing process, and thus the projected cost, of Syntech products is highly variable depending on the application. Manufacturing of Syntech is at TRL 2, and the timelines and cost of development is significantly less for opaque applications. Pathways for manufacturing, including their development requirements, have been set out by Synbiosys for each application and can be discussed further in conversation.

Synbiosys background

Synbiosys is a startup specialising in ballistics and blasts, with the founding team comprising of PhDs and postdocs from the Shock Physics, Solid State Physics and Aerospace structures groups in Imperial College London. All personnel maintain a wide breadth of experimental expertise, developed in careers blending cutting edge academic and industry practice. Deep interdisciplinarity within Synbiosys personnel enables it to provide a holistic overview of a complex problem, with a wide range of experience including, but not limited to: solid state physics, adaptive structure design, numerical modelling, fluid dynamics, shock physics and composite materials engineering.

Synbiosys’ board of advisors include Prof Deeph Chana, co-Director of the Institute for Security Science & Technology at Imperial College London and Dr Brad Pietras, Technology Strategy Director for Rolls Royce and ex-Vice President (Technology) for Lockheed Martin.

Synbiosys can perform fundamental materials R&D, mechanical design and structural testing, composite materials design and manufacturing as well as ballistic impact and blast modelling and testing.

Synbiosys has an established track record of producing outstanding work in a rapid time frame across a range of defence and security fields, working with defence primes and government, both UK and its allies, on providing solutions to key capability gaps. Previous projects and contract work performed by Synbiosys personnel include that for U.S. organisations such as the TSA, DARPA, TSWG, DTRA, and U.K. organisations such as TfL, CPNI, DSTL and DASA. Commercial work includes working with Thales, Shell, CrowdVision, BP, Petrobras and Reliance Industries.