ELACO PTY. LTD. - ACN 110 104 571
Innovative Advanced Materials
and Design Solutions

ELACO Pty Ltd

Ballistic potential of ELACO composite solutions

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ELACO Pty Ltd

Part 1 - Introduction

1. Background

The global political situation with the threat of direct conflicts and terrorist attacks is increasing the interest in protection and armour for personnel, vehicles, ships, special equipment, buildings and other structures.

The desirability of a composite solution for armour protection arises from the parallel needs for mobility and transportability.

The market for composites in military vehicles is large and growing. The potential for applications in non-military use is also enormous.

2. Composites in ballistic applications

Mobility and speed of the armoured vehicle is a key component in its survival in a combat situation and hence the lower the weight, the faster and more manoeuvrable the vehicle can be for a given powerplant.

For example, the standard weight of a main battle tank, typically over 60 tonnes and smaller vehicles could be conceived at or around the 23 tonne if the armour protection was reduced in weight.

In the USA and UK the composite armored vehicle has been already produced with a full glass fibre composite hull, the ACAVP – Advanced Composite.

3. Principles of Armour work

The role of armour is to protect a person structure or device. This is done by absorbing the kinetic energy of the projectile. The energy may be absorbed by plastic deformation or fracture processes.

An armour plate may have to fulfil two functions – a protective role and a structural role. If the material used for the armour is fulfilling both roles then it usually provides protection by having sufficient strength not to be ruptured during the impact. The tensile strength under high strain conditions will be the key factor in determining the thickness of material that must be used.

Currently, protective panels are designed to allow entry of a bullet (non-ricochet), and then defeat the energy of the bullet through a controlled process of ply-delamination. The kinetic energy of the bullet is released or dissipated through this ply-release or delamination.

The different projectile may concentrate the point of attack at certain places, and then it may be desirable for the armour to act to spread the area over which the projectile is damaging the material. For these reasons it is often desirable for armour to be based on a multimaterials, multilayer arrangement, with different layers providing specific functionality in the armour.

Typical modern lightweight armour comprise a ceramic face plate with a more flexible backing layer. The role of the ceramic outer layer is to blunt the projectile and dissipate the load over a wide area. The ceramic layer will fracture during impact and the extent of fracture or rubblization.

Armours may be designed to meet specific threat levels, usually defined as a combination of projectile mass and velocity. It is important in some situations, where the threat is small arms fire up to heavy machine guns, to provide for a multi-hit capability as well as resistance to a single shot. This introduces a need for the damage process that results from each ballistic impact to be contained within the minimum area possible.

4. Ballistic performance of composite materials

The ability of a material to provide a useful contribution to an impact event depends on the hardness of the materials, which is critical for blunting a projectile, and the strain to failure which determines the ability of that material to absorb energy via a global deformation process involving either brittle cracking in the case of ceramics and composites, or plastic deformation in the case of some metals.

Currently, composite materials rely primarily on brittle microfracture events to absorb energy. This means that the ultimate energy absorption is largely controlled by the strain to failure of the fibres. Once the fibres have ruptured, the armour collapses and no further energy is absorbed. Composites based on high strength, high elongation to failure thermoplastic fibres might be expected to absorb energy via plastic deformation and drawing of the fibres.

For fibre composites where the fibres are bound with a matrix system, the fracture processes can be considered to operate in two separate phases:

- The initial entry phase of the projectile results in a combination of compression and shear failure in the materials,
- This is superseded by tensile deformation and delaminations during the exit phase.

In general terms glass fibre composites outperform carbon fibre due to their greater strain to failure, while S-2 glass fibre composites have outperformed E-glass for similar reasons.

Traditionally, composites are considered to be ‘soft’ armour materials. This means that, to date, their ability to withstand penetration from a shaped or pointed charge has been limited.

5. Multi component armours

The most effective armours are not single component systems based on steel, composite or other systems, but multicomponent armours that combine layers of dissimilar materials. The components usually include an outer ceramic layer which acts to blunt and wear down the projectile, where the ceramic layers are supported by a more flexible strong backing layer whose function includes catching the slowed remnants of the projectile.

The initial multicomponent composite armours were based on ceramic outer layers supported by steel or more usually aluminium layers. Fibre composites have become recognised as the materials that provide the best combination of high (impact) performance and (lowered) weight.

Multicomponent composite armour systems are designed to provide protection by a controlled disintegration. Consequently most of these systems are not used to provide the basic structure of a vehicle - such as the hull or a battle tank - but are applied as secondary appliqué armour. These systems can be removed, repaired and replaced as necessary.

A range of standard requirements have been identified based on a set spectrum of standardised threats, for example NATO standards known as STANAG 4569. There are five identified threat levels and when tests are performed by subjecting panels to these threats, the success is based on the damage sustained by a thin metal witness foil positioned behind the armour itself.

The design of a composite, multi component armour is tailored to meet the threat level appropriate to the required end-use. The thickness of ceramic tiles is typically 8 mm for level 2 threats and up to 25 mm for level 4. The backing fibre composite layers could be 12 mm and 60 mm respectively.

Most armours would also posses an external fibre composite layer covering the ceramic tiles to provide general protection from minor damage.

Fiber reinforced plastic (FRP) composite materials, especially the glass fiber reinforced plastic (GRP) composites, are potential materials for many applications.

In addition to delamination, impact causes fiber failure, matrix cracking, and fiber-matrix debonding.

Meeting the performance needs of future military systems will require synthesis of new materials, modification of existing materials, design of property specific microstructures and composite architectures, and development of advanced modeling and characterization techniques for specific microstructures, properties, and both quasi–static and dynamic degradation and damage modes.

The materials processing subarea includes those technologies by which raw or precursor materials are transformed into affordable monolithic or engineered materials and/or components with the requisite properties and reliability for military utilization.

Recent advances in converting highly ordered polymers into textile fibers with outstanding strength–to–weight ratios will lead to lighter weight body armor, helmets, and shelters without reducing level of ballistic protection.

Part 2 - ELACO^{TM} Introduction

Under the current global economic situation, where the prices of composite materials and structures are high, with tendency to rise, it is desirable to develop cost effective composite structures, in terms of both materials and manufacturing.

Currently, limited applicability of some low–cost composite components in composite structures is a result of their specific mechanical properties.

It is known that mechanical properties of fibre reinforcements are an order of magnitude higher in longitudinal than in transversal direction of fibres. In case where a composite structure is loaded perpendicularly / transverse to the fibers, the matrix properties dominate because of a fact that the load is transferred mostly by the matrix. Unlike metals, majority of fibre reinforced composite materials do not undergo plastic deformation under impact as majority of them are very brittle.

1. ELACO^{TM}

ELACO® represents, in worldwide proportions, a new concept and technology for creating low-cost laminate structures, which exhibit an exceptionally high level of impact resistance and damage tolerance. ELACO^{TM} represents new, highly desirable composite architectures.

2. ELACO^{TM} specific abilities

ELACO^{TM} composites are created with an ability to extensively use properties of reinforcements in longitudinal direction of the fibre, even in the case of perpendicular / transversal outer loading with specific abilities to:

- disperse any perpendicular / transversal outer loading on the laminate surface to component forces that act in directions of the fibrous reinforcement; and
- disperse / spread any perpendicular / transversal outer loading over the large area of laminate to reduce specific loading per area, and to allow controlled dissipation and delamination cracking.

3. ELACO^{TM} structures

ELACO^{TM} structures are based on the use of cost-effective, standard materials (dominantly glass fibre and Aluminium), thus enabling enhanced performance while preserving costs.

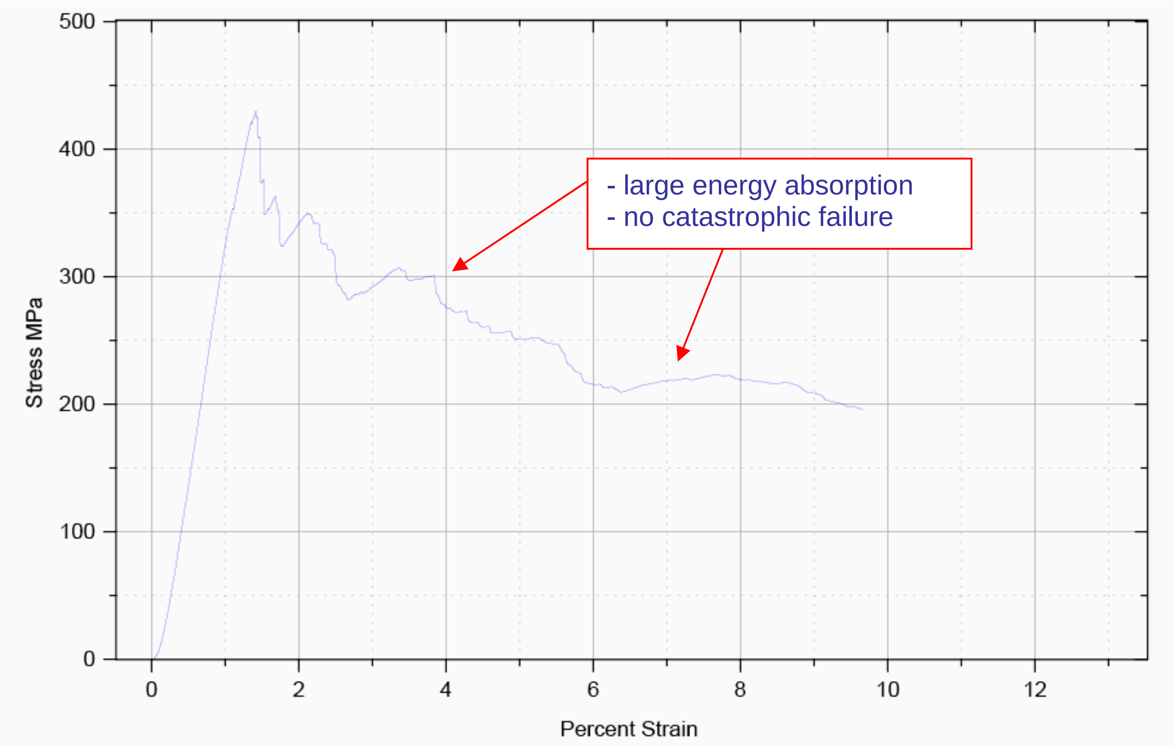
Yet, for superior and some specific performances, specialised materials such as Carbon, Aramid and others could be incorporated into appropriate ELACO^{TM} structures.

To illustrate how significant cost savings may be made, we will use one simple example:

- To manufacture a 2.5 mm thick flat panel from Carbon fibre, 10 -12 plies of Carbon fibre in needed;
- To make a similar panel based on the ELACO^{TM} concept, only 2 plies of Glass fibre and one ply of “other” materials may be used, which could cost only as much as a single ply of the Carbon fibre, with overall reduction in manufacturing time.

If it is assumed that an ELACO^{TM} structure will be loaded predominantly in bending, statically and/or dynamically, it is evident that the ELACO^{TM} core will take most of the shear stresses. Skin layers of the laminate will be loaded in tension and compression and provide most of the bending stiffness. In this case, the core will act as a core in sandwich composites by displacing stiff skins away from the neutral line and therefore maximising the laminate’s stiffness and strength.

A 3D structure of the core will force formation of delamination cracks with paths much longer than in the case of flat metallic sheets. This will maximise energy absorption during the laminate shear failure, increase its compliance even more during loading (Figure 1), slow down the damage event and prevent penetration or catastrophic failure of the laminate.



- large energy absorption
- no catastrophic failure

Figure 1.

Figure 1. shows bending characteristics of one of the generic ELACO® structures.

Creation of multilayered structures is possible, especially having in mind that, for example, thicknesses of steel meshes start from 0.2 mm. As shown in Figure 2., there have been ELACO™ generic structures created in a range of thicknesses, including as thin as 0.5 and 0.8 mm (note their bending abilities).

Figure 2.

To create ELACO™ structures with highly tailored properties, it is possible to use materials with different basic properties, such as mild steel, high tensile steel, aluminium, brass, etc.

In combination with variety of reinforcement materials and resins, ELACO^{TM} generic laminate structures may be created as more or less stiff, more or less elastic or partly stiff and partly elastic.

4. ELACO^{TM} in ballistic protection

By applying the unique ELACO^{TM} architecture, it is possible to create complex structures with various properties in different sections. That may significantly contribute to creating structures with ballistic / blast protective features, which would have both stiff and elastic segments as a part of the same structure, to absorb high level of impact energy.

As already stated, currently the ability of a material to provide a useful contribution to an impact event depends on the hardness of the material (which is critical for blunting a projectile), and the ‘strain to failure’ (which determines the ability of that material to absorb energy via a global deformation process involving either brittle cracking in the case of ceramics and composites, or plastic deformation in the case of some metals).

Currently, composite materials primarily rely on brittle microfracture events to absorb energy. This means that the ultimate energy absorption is largely controlled by the strain to failure of the fibres. Once the fibres have ruptured, the armour/structure collapses and no further energy is absorbed. Composites based on high strength, high elongation to failure thermoplastic fibres could be expected to absorb energy via plastic deformation and drawing of the fibres.

However, through the application of the unique ELACO^{TM} architecture, the above statements are dramatically changed based on unique ability of ELACO^{TM} structures to:

1. create the internal mechanism for outer loading / force dissipation from perpendicular to longitudinal components of that loading that act in longitudinal direction of main fibre reinforcement axis,
2. create internal mechanism to disperse / spread outer point loading over the large area significantly reducing specific loading per area,

3. more efficiently use advantageous properties of fibre reinforcements (their tensile properties); and
4. control the delamination in a highly predictive way.

The ELACO™ generic laminate structures have mechanical properties in range of those of mild steel and higher than aluminium, with a specific density starting from around 1280 kg/m3 - see Figure 3 immediately below:

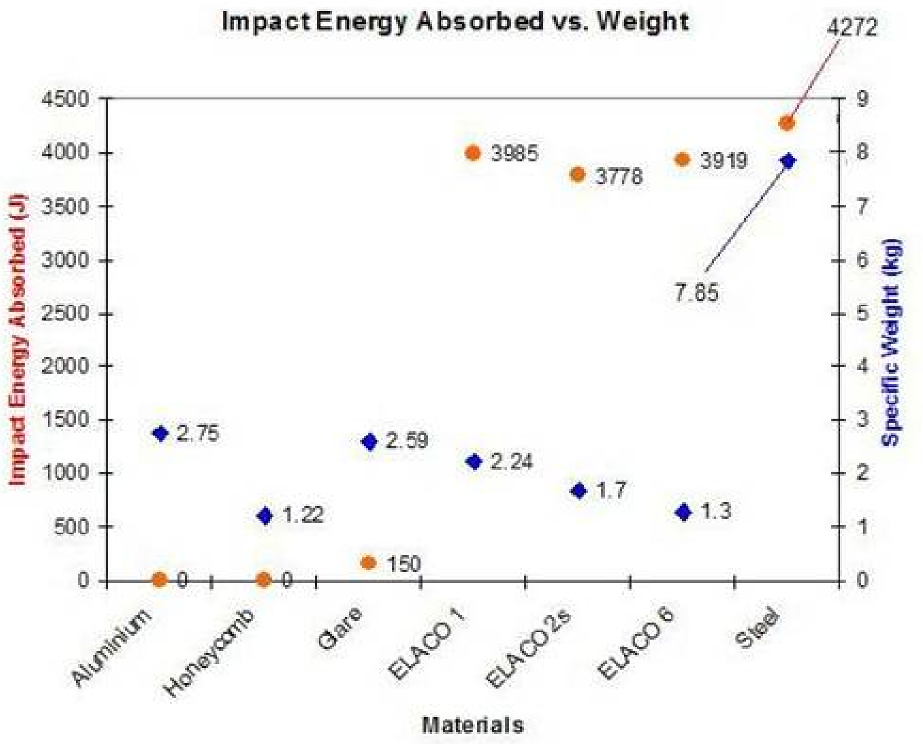


Figure 3.

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