WHY ARE COMPOSITE MATERIALS NOT REPLACING METALLIC MATERIALS FOR ARMOURED VEHICLES?

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ABSTRACT

The need to increase the performance of armoured fighting vehicles (AFVs) led to a number of research programmes being undertaken in UK and the USA to identify the benefits and issues of using composite materials for the production of AFVs. Despite these programmes demonstrating the potential for lightweighting of AFVs through the use of composites, steel remains the material of choice for the production of new AFVs. This paper will explore why this might be the case and identify what needs to be done if composites are to compete with metallic materials for this application.

1 INTRODUCTION

The need to provide lighter weight AFVs while maintaining and or increasing the survivability of these vehicles has remained a key requirement from their inception during World War 1. For the purposes of this paper, AFV refers to any vehicle that requires armour and is likely to be subjected to a range of threats from bullets, mines, artillery fragments and chemical energy shaped charge weapons. Reducing a vehicle's weight can increase its deployability, mobility & manoeuvrability and or firepower or payload capacity. However, as seen in recent years in the deployment of land vehicles in Iraq and Afghanistan, the need to counter new threats by upgrading the armour has often compromised other performance capabilities, by increasing their weight, reducing their manoeuvrability and transportability and increasing their logistical support train (fuel, munitions, rations, maintenance spares) requirements. Reducing a vehicle's weight by composite structures should be a means of restoring or even improving a vehicle's capability. However, AFVs have a unique set of requirements compared to non-military vehicles due to the need to design for survivability, while limiting the unit cost of a vehicle. This is illustrated in the figure below, which shows the "Iron triangle" for AFV design supplemented with other characteristics such as cost. In addition, any new material or process can then introduce additional risk to the design.

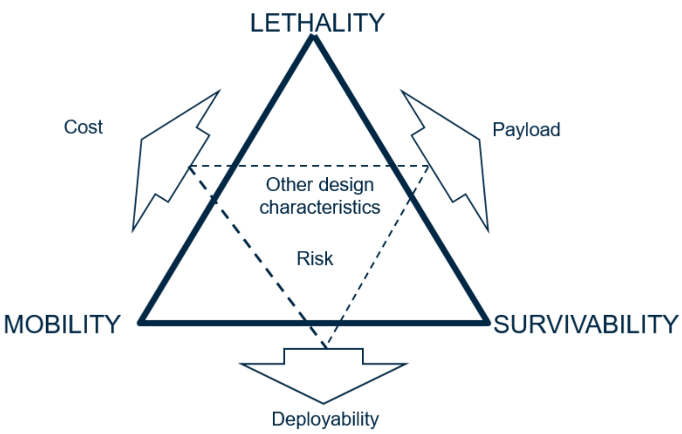

Figure 1: Iron triangle for AFV design characteristics

The requirement for lighter AFVs has led to many programmes exploring different materials to meet the diverse structural and survivability requirements. However, considerable time and cost is required to reach the requisite level of design maturity for a new material to allow it to be included in the initial design of a vehicle, without incurring a high degree of risk. As a result, the development and qualification cycle for materials is often “out of sync” with the procurement design cycle for vehicles, making it difficult to insert new materials early in the design cycle.

When comparing the requirement priorities for AFVs against aircraft which use composites extensively, it could be argued that the design priorities are different, with aircraft having a top priority for performance encompassing speed, agility, range and payload, whereas for AFVs survivability is the priority in order to undertake a mission. Unlike an aircraft in which every kilogram of weight saved can be compared against the cost of the fuel saved, the cost saving for increased survivability is not easily calculated.

2 COMPOSITE MATERIALS FOR AFV

It is important to remember that vehicle protection can never be guaranteed, and that all vehicles are potentially vulnerable to threats, which exceed those considered during their design. This is particularly relevant in the case of light AFVs, where the ability to carry the mass of applied armour is limited by the need to retain a high level of mobility and, in some cases, the strength and stiffness of the base vehicle chassis. Due to the risk of overmatching threats leading to hull penetration, a composite spall liner is generally required inside the metal hull of AFVs.

This is due to the very different behaviour of these materials when they are perforated/over matched by a shaped charge weapon such as a rocket propelled grenade (RPG). This weapon uses shaping of the explosive to focus the explosive energy to form a high velocity jet or to form an explosively formed projectile (EFP). Figure 2 illustrates the influence of liner shape on weapon effects.

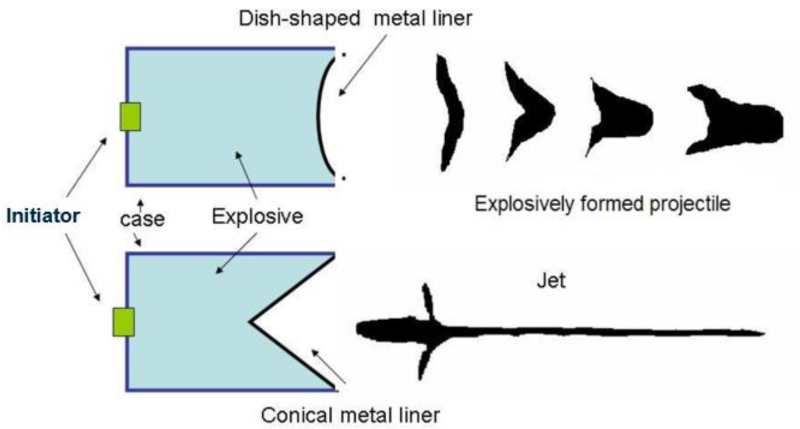

Figure 2: Effect of liner shape on weapon effects

With a conical metal liner, the liner collapses as a detonation wave within the explosive moves along the warhead from the apex of the cone to the base. The metal remains a solid, but possesses a sufficiently high velocity (7,000 – 8,000m/s at the tip) that it behaves as though it were a liquid and flows hydrodynamically. In this velocity regime both the target and projectile materials are treated as fluids, neglecting their strengths, as the pressure exerted by the projectile is orders of magnitude greater than the armour materials’ strength.

The purpose of the spall liner is to minimise the spread of primary and secondary metal projectiles within the vehicle in the event of the metallic hull/armour being completely penetrated (overmatch), and its effectiveness is measured by identifying the angle of spread of the fragments, which may be represented by a cone, as illustrated in Figure 3. The smaller the cone angle of fragments, the higher the probability that a particular occupant will survive the penetration of the hull, and the better the spall liner’s performance. The spall liner material is non-structural composite, and it is attached to the metallic hull purely to mitigate threat damage and protect the crew and internal components.

Consequently, in addition to higher specific structural properties for composites compared to metals on a weight for weight basis, a key advantage for the use of composites to replace metallic hull structures is the ability to increase occupant survivability. By eliminating some or all the metallic hull and armour by using composite materials as the structure, there is no need for a separate spall liner, since the debris produced during an overmatch event for a composite is much less damaging than the relatively large secondary fragments produced when a metallic target is overmatched. This then eliminates the mass associated with a separate spall liner.

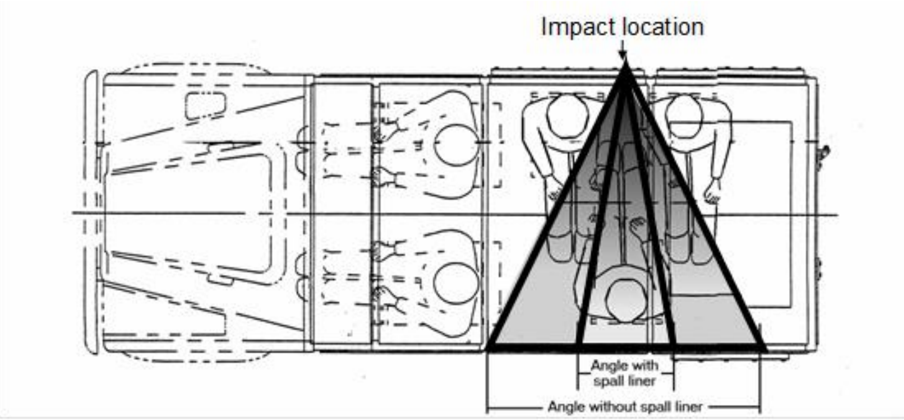

Figure 3: Illustration of debris cone within a vehicle resulting from penetration of hull/armour

3 PREVIOUS RESEARCH ON COMPOSITE MATERIALS FOR AFVs

To build confidence in the use of composite materials and provide an AFV design base, the UK MOD through QinetiQ and partners, undertook a considerable amount of research in the use of composites for AFVs, producing technology demonstrators and running international collaboration projects with European partners. The Advanced Composite Armoured Vehicle Platform (ACAVP), demonstrated that Glass Reinforced Plastic (GRP) materials could be used to form the load-bearing hull for an AFV [1] capable of carrying the loads imposed from the suspension / running gear and associated equipment, and to provide ballistic and spall protection, shown in figure 4.

Figure 4: ACAVP

The ACAVP hull was manufactured using a variation of resin transfer moulding (RTM), called vacuum infusion moulding (VIM) to produce a glass fibre reinforced plastic (GFRP) hull. Note this process was a variation on the now standard Resin Infusion under Flexible Tooling (RIFT) moulding process in which means to accelerate the flow and improve the saturation of the preform with a resin, such as highly permeable media are used. A non-prepreg (impregnated fabric) autoclave route was selected since the manufacturing of AFV hull structures was seen as having characteristics closer to composite shipbuilding than to composite aircraft structures, i.e. the production of GFRP mine counter measures vessels (MCMV) due to their non-magnetic nature, underwater shock resistance, buckling resistance and corrosion resistance. MCMV vessels such as the Royal Navy constructed HMS Wilton, a 450 tonne (t), 46.3 m long monolithic MCMV, was constructed by hand-layup in 1973 followed by further GRP ships; Hunt class MCMVs (13 in class) Sandown/class Single Role Mine Hunters (SRMH, 13 in class). A number of the ships are still in service, with vessel service life expected to exceed 50 years [18]. By using VIM for ACAVP, this produced a composite laminate with improved performance compared to that possible via a hand lay-up wet-out process.

Not only was the composite structure (hull) comparable with small marine structures such as MCMVs, but production numbers for AFVs can be relatively small (low hundreds). Production quantities have a strong influence on the selection of processing method, since low volume or one off component quantities can be economically manufactured using out of autoclave (OOA) techniques, which require both a low investment in process machinery and tooling costs. Autoclave manufacture requires more robust tooling and investment in process machinery. In choosing a manufacturing process, the following parameters also have to be addressed:

- Component tolerance & quality control;
- Maximum component operating temperature;
- Thickness of component;
- Required fibre volume fraction.

The mechanical properties of a composite are dependent on void content, fibre matrix interface and state of matrix cure. For optimum mechanical performance, for a fibre volume in the region of 55 to 60% is required Thick-section composites also have a number of unique problems associated with their manufacture. These are:

- A very long processing window for the resin to allow complete resin infiltration;
- Excessive resin exothermic temperatures during cure;
- Poor resin/fibre consolidation leading to high levels of voids, especially for prepreg processing.

All the above must be controlled to ensure a low void content (<2%). This was achieved for the ACAVP demonstrator by using a development programme to identify the optimum processing conditions for the process selected to manufacture the hull. VIM offered a more consistent, higher quality product than that produced by hand laminating methods, while providing manufacturing costs below those associated with prepreg manufacture. For production of the thick (greater than 10 mm), composite VIM was selected due to the following advantages:

- Materials costs similar to compression and hand laminating lower than for prepreg materials;
- Superior dimensional & quality control than that possible by hand laminating manufacture;
- Thicker fabrics can be processed than that possible for hand laminating due to wet issues;
- VIM materials do not have the limited storage/shelf life problems associated with prepreg materials.

At the time, (1998) VIM was a novel production process, but variations on it have since been used for a range of marine craft and for composite windmill blade manufacture, but the advantages remain. The design of the ACAVP hull consisted of two mouldings, a top moulding that includes the front glacis and pannier sidewalls, and a bottom moulding incorporating the floor, toe plate and lower sidewalls. The hull was separated into three areas using composite bulkheads as shown below in figure 5.

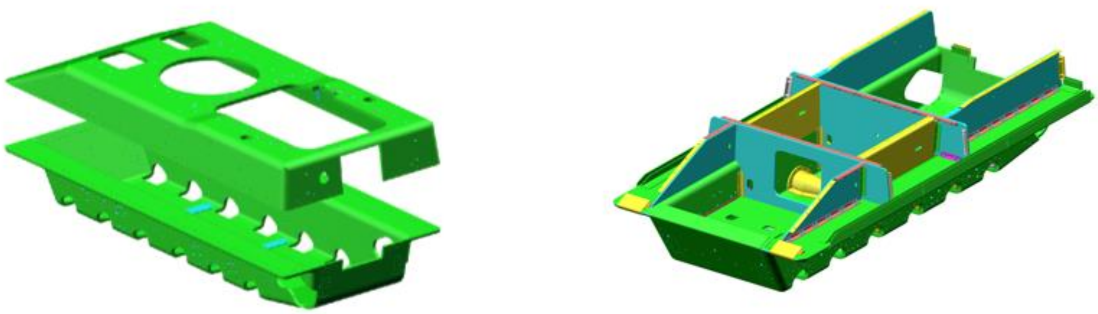

Figure 5: ACAVP GRP mouldings (left) vehicle layout (right)

The thickness of the hull walls (30 to 40 mm) was determined by the required structural performance and ballistic performance in combination with attached applique armour. Both stealth materials and materials to provide the required electro-magnetic shielding performance were introduced into the composite structure.

The two mouldings were joined using a bolted joint design along the main moulding edges. The ability to produce a hull from two components rather than combining a number of component parts together, can obviously lead to a reduction in the manufacturing cost of the assembly, by reducing associated manufacturing time and labour costs.

The approach of integrating a composite structure with external steel blast protection was investigated via the European Carbon Armoured Fighting Vehicle (CAFV) programme [Ref 2, 3 and 5], and the UK Lightweight Materials and Structures for Blast and Ballistic Survivability (LiMBS) programme. CAFV explored the use of carbon fibre reinforced plastic (CFRP) and hybrid composites for AFV structures. The LiMBS programme evaluated methods to attempt to optimise these material combinations to provide lightweight structures with blast and ballistic spall performance. The use of composites for subcomponents of an AFV such as the wheels and suspension arms has also been explored.

In the USA, there were a number of composite research programmes. In the 1970s and 1980s, the US Army Research Laboratory Materials Directorate in conjunction with a number of industrial companies looked at composite components for the AAV7 family of amphibian assault vehicles and the M113 armoured personnel carrier. A number of M113 composite hulls were constructed from both sandwich structures with skins produced from E-glass with a polyurethane foam core and monolithic structures. The Composite Infantry Fighting Vehicle (CIFV) (completed at the same time as ACAVP) programme looked to manufacture a composite vehicle based on the Bradley M2A1 AFV. This programme concentrated on the use of S-2 woven roving polyester prepreg to produce the composite hull with integrated ceramic armour. It was reported to demonstrate a 25% weight saving over an aluminium and steel construction, while utilising 65% composite materials by weight. The hull was produced in three pieces. The upper hull structure consisted of two halves with the joint line running along the centre of the hull. The hull also included an aluminium box beam subframe and an aluminium turret cage. The subframe was used to diffuse the running gear loads into the composite hull. The hull floor consisted of a single composite moulding, bolted to the subframe.

A major design problem preventing composite materials from significantly reducing hull weight is the opposing needs to provide the vehicle with both ballistic protection and mechanical structural performance. The level of ballistic protection provided normally correlates to the weight of the vehicle's hull and armour. Consequently, reducing hull weight can lead to a reduction in ballistic protection, unless the weight reduction is converted in additional armour mass, or the materials used have a higher ballistic weight efficiency. The potential weight saving for a composite vehicle compared to a metallic vehicle is very dependent on the threat level imposed on the vehicle. Studies based on the ACAVP concept with varying degrees of protection against medium calibre ballistic threats identified that the weight saving for a composite hull and armour system of equal ballistic performance as an aluminium hull and comparable armour system can vary between 6 and 15%. This is due to the higher threats requiring greater levels of armour mass which reduces the relative contribution of the weight saved from hull by the elimination of the spall liner and the use of the more structurally weight efficient composite materials.

3 INSERVICE APPLICATIONS OF COMPOSITES FOR AFVs

An outcome from the UK's composite research programmes detailed above was the development and procurement of the Foxhound armoured patrol vehicle, which is in service with the UK MOD, shown in Figure 6. This vehicle uses a GRP pod attached to V-shaped steel spine to provide a vehicle with unparalleled survivability at a weight of only 8 tonnes. As far as is known this the largest military vehicle in service in the world that uses composites for both the structure and the armour. Only by the use of composites could the level of survivability for the vehicle be achieved at the required weight for deployability by helicopter. It is not dissimilar to the CAV 100 vehicle from NP Aerospace that used a composite rear pod on a metal Landrover chassis. However, for Foxhound the composite pod forms the load bearing structure/spall liner of the complete vehicle as well as providing protection against ballistic, blast and fragmentation threats.

Figure 6: Foxhound vehicle

Despite the successful research programmes and the Foxhound vehicle going into service, the use of composite materials for military vehicles has not been realised in any other commercial AFVs, though limited use as been proposed in a number of projects as listed below.

- 2015 The Russian Armata main battle tank will reportedly feature a remotely controlled gun and fully automated loading, as well as a separate crew compartment made from composite materials and protected by multi-layered armour [7].
- 2014 Thales Australia for Hawkei light 4x4 protected vehicles. Quickstep will supply the vehicle's bonnet, side skirts and mud guards [8].
- 2014 Textron Systems Commando Select multimission armoured vehicle incorporates a monocoque V-shaped hull of welded armoured steel with exterior mounted modular expandable ceramic armour appliqué and a bonded composite inner spall liner for maximum survivability and exceptional crew protection [9].
- The Indian 4x4 LAMV integrates a monocoque composite material pod to protect the crew, with a full length high hardness steel bottom V Hull for blast protection [10].
- The SandCat is a composite armoured vehicle designed by Plasan of Israel. The SandCat is based on a commercial Ford F-Series chassis it uses steel base layer with a mix of internal/external aluminium, composite/ceramic and aramid components rather than a composite structure. The advantages of a bolted/bonded construction are stated to be ease of repair following damage, the option to upgrade parts or all of the protection as new technologies emerge, plus the ability to swap out specific panels to reconfigure a vehicle [19].

4 ISSUES LIMITING THE USE OF COMPOSITES

One of the reasons for the apparent reluctance to use composite materials is that current AFV manufacturers are not well versed in the design and production methods needed to produce a composite hull. The incompatibilities of composite materials with existing metals processes includes different design requirements (e.g. isotropy and homogeneity), manufacture (processability, dimensional control, cycle times, temperature tolerance, and assembly methods), and performance (coefficients of thermal expansion, electrical conductivity and ballistic efficiency). While substituting individual metal components with composite replacements can lead to both weight and cost reductions alongside improved durability, the dimensions of the composite components must conform to those of existing component designs in order to allow interchangeability between units. This design approach may lead to a less than optimum design for the composite component, and the potential weight savings and performance improvements for the composite component may not be fully realised. In order to achieve the maximum advantage from composite materials, the complete vehicle design strategy must be re-evaluated to effectively demonstrate the advantages offered by composite materials. Moving from incremental, part-by-part substitutions to whole platforms, shifts the emphasis from making composites compatible with metals to exploiting composites' unique benefits for solving system issues such as hull weight, hull stiffness and the financial cost per hull.

The main issues that have limited the use of composites compared to metallic vehicles are:

- The cost of production including the need for non-destructive testing to confirm both the quality of the mouldings and the joining techniques;
- The durability/impact resistance of composites against both low and high velocity impacts and associated repair techniques;
- End of life recycling/disposal.

These issues are discussed below.

4.1 Material and production costs

Looking at the materials that could be used for AFVs, if we just consider steel as the current "go to" material for AFV production, we can compare the options available as shown in figure 7. Taking the fibre types available, for optimum structural performance S2-glass fibre composites are superior to E-glass reinforcement and also offer better ballistic performance. Aramid fibre composites have some limitations as structural materials due to their relatively poor compression properties, which can be mitigated by hybridization. The optimum ballistic materials against small arms and fragments are those utilizing Ultra High Molecular Weight Polyethylene (UHMWPE) fibres but to achieve this the associated matrix must be relatively soft/compliant thereby limiting their use as structural materials. CFRP remains a material that while providing the ultimate material where stiffness is the design driver, suffers from significant damage tolerance concerns. However, as demonstrated in the CAFV and LiMBS projects, hybridization of carbon fibre with S2 glass can achieve an optimized structural and ballistic material. As detailed above, all the composite solutions have the advantage of not generating dangerous spall fragments when they are overmatched by threats and fail.

High-strength steels, generally contain 0.25–0.4% carbon and alloying elements such chromium (which increases hardness) and nickel (which increases toughness). The tensile strength of such steels has varied from 850MPa to1700 MPa [20]. The various grades related to hardness and strength changes the ability of steel to be welded and formed. Rolled Homogeneous Armour (RHA) with a Brinell hardness (BH) of around 300 provides significantly improved ballistic performance compared to mild steel materials. The tempering process used after the heat treatment gives the armour a uniform microstructure, hence the 'homogeneous' designation and was the main steel used on AFVs until the advent of a range of new harder steels.

Higher hardness steels have increased ballistic performance but at the expense of increased brittleness and reduced formability (bend radii and welding issues) such that at 600+ BH the material may only be used as an applique armour, rather than a hull structure [20].

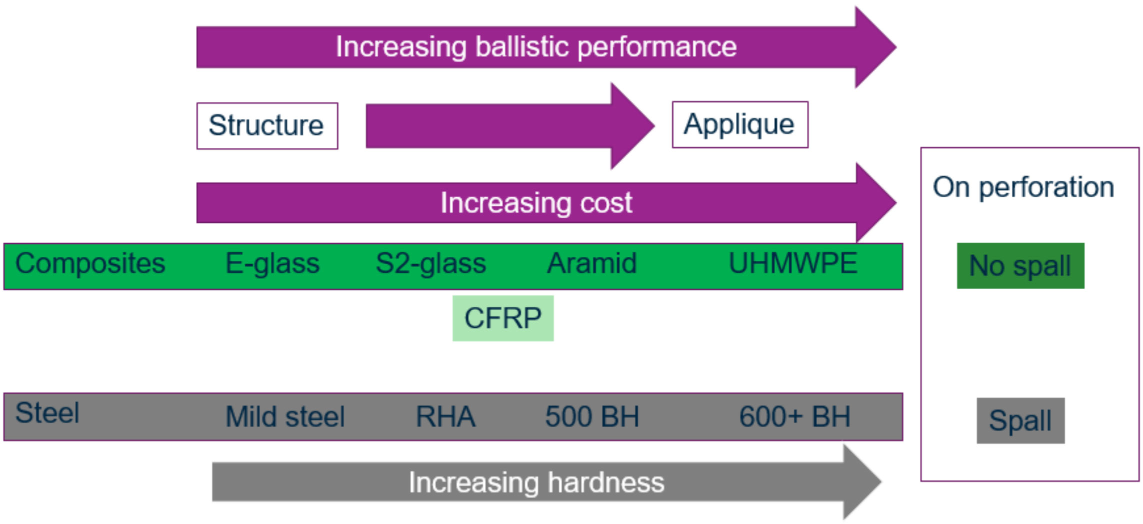

Figure 7: materials for vehicle manufacture

As highlighted above, fibre composites can be hybridised leading to many different materials with different matrix materials and fibre orientations and volume fractions. However, this vast array of potential materials makes it difficult to have comprehensive material property databases for all but the most common types of laminates based on defined manufacturing methods. This can lead to a reluctance of designers transitioning from metallic to composite materials due to costs and time to generate the required property data.

It is interesting to note that aluminium was seen as the material to replace RHA for AFVs with various grades used for the British Warrior and USA M113 vehicles, the reason being the improved weight specific mechanical properties of the less dense aluminium particularly out of plane stiffness compared to steel. To provide the same level of protection as RHA, the aluminium plates need to be thicker resulting in greater resistance to bending, which means that aluminium-hulled AFVs can often dispense with the stiffening elements common in steel-hulled AFVs. However, various issues were found using aluminium, notably stress corrosion cracking that required in-service repairs. Whilst new grades of aluminium were subsequently developed, the use of aluminium highlighted the issues and risks associated with new materials. With the advent of a range of steels in the 1990s with different performance characteristics which were easy to weld and cheaper, steel has regained its place as the primary material for AFV hulls. However, for the car industry aluminium being a lightweight material, which is durable, flexible and can easily be bonded, has become the material of choice for the industry, in its efforts to reduce the weight of future cars.

4.2 Ballistics

For all the above materials the shape, material and speed of the projectile influences the ballistic response of the material. For composites, the thickness of the laminate will change the mechanism of energy absorption, with thin laminates experiencing in plane membrane tension, which maximises the energy absorbed. As the thickness of the laminate increase, the ballistic performance will increase but the energy absorption will be via fibre crushing and shear, rather than tension, which reduces the ballistic efficiency of the material. For metallic materials, this drop in efficiency is not observed.

The other difference between composite and metallic ballistic performance is how the edges of the materials react to ballistic impact. For a bullet hitting an edge of a metal plate, the plate will produce nearly the same ballistic performance as for hitting the middle of the plate, but for composites, especially for those produced from UHMWPE; the low stiffness of the laminate can allow the projectile to push the laminate out of the way. Consequently, the design of the integration of the laminate into the structure is more complex for composite materials.

4.3 Hull Production cost

As highlighted above there is a need to reduce the cost of the composite hulled vehicles. Figure 8 below provides a simple overview of the manufacturing requirements. Unlike marine vessels and aircraft which required curved structures, flat plates can be used to build the essentially box like AFV structures.

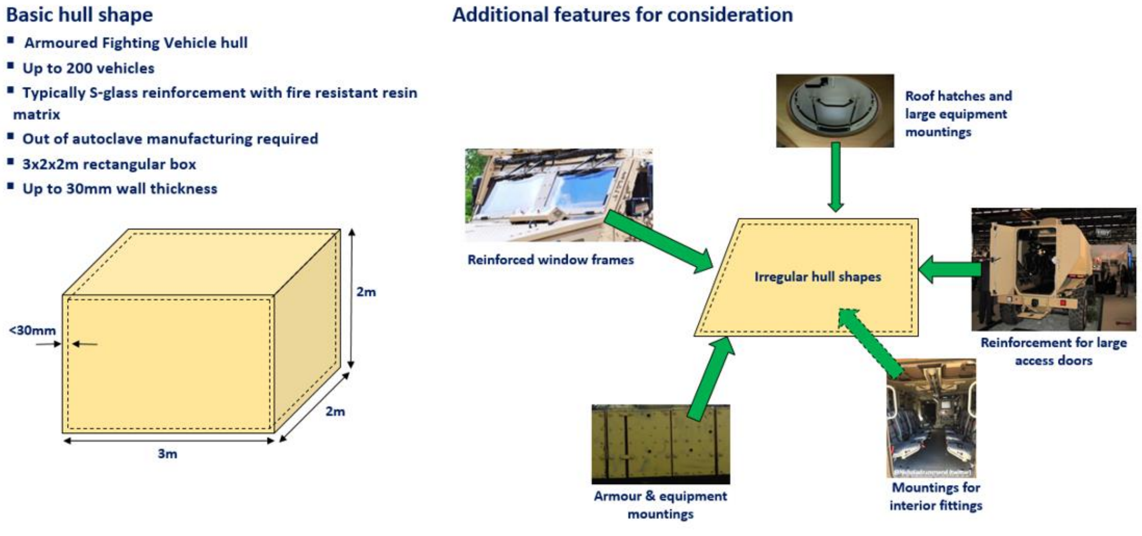

Figure 8: Basic manufacturing requirements for a composite AFV hull

The processes of choice for composite marine vessels has become RIFT via oven curing which would appear the optimum route for AFV hulls. Correct infusion and consolidation across the entirety of the laminate still requires significant time, labour and cost, and failure can lead to both financial and environmental ramifications through the wasted time, material, energy and resources. In the author's opinion, it was unfortunate for the Foxhound project, that the senior design team had a background in Formula 1 motor racing which led to the selection of prepreg materials processed via autoclave moulding, which resulted in expensive composite hulls, compared to those possible by RIFT. The reasons given for this manufacturing route were concerns about achieving consistent fibre volume fraction laminates and controlling the thickness of the hull moulding to ensure the integration of components within the hull. This was despite the success of the ACAVP programme demonstrating that thick composite sections can be manufactured with consistent performance characteristics. Industry surveys indicate that for parts sized from $8m^2$ to $130m^2$, ovens can be installed for one-seventh to one-tenth the cost of a comparably sized autoclave, and the cost of dry fibre and liquid resin to make oven-curable versions of the parts can be as much as 70% less than the same materials converted to prepreg [21].

In terms of the choice of resin to be used, while Vinylester and polyesters can be half the cost of epoxy systems, due to the mechanical and environmental requirements fire, smoke and toxicity retarded (FST) rated toughened epoxy systems would be the resin of choice due to availability and performance.

S2 glass fabric provides both the mechanical and ballistic performance required for the hull. By using a dry fabric with a resin, it will cost significantly less than the cost of a glass fibre prepreg. Carbon fibre could be utilised in a hybrid with the S2 fibre but this will increase the cost of the hull due to the higher carbon fibre cost.

Dry fabric hand layup has the potential to be faster than prepreg through the use of heavy fabrics such as tri-axial and quad-axial non-crimp fabrics (NCFs) and mechanical assistance to help deposit and tension the fabric. This method is also adaptable, being able to employ a range of material formats including 3D weaves, and braids. By using heavyweight fabrics the labour hours required to form the hull laminate can be significantly reduced compared to using a prepreg fabric. However, debulking will still be required to enable the fabric to be compacted to achieve a composite with a fibre volume of around 55% as demonstrated on the ACAVP programme. There is the potential to combine hand layup with preforming and automated lay-up such as automated tape laying and automated fibre placement technologies (ATL/AFP) where the laminate shape makes this viable [17].

While it is difficult to get exact numbers to make the calculations, the CAFV project estimated that a metallic hulled vehicle of comparable size but higher weight and lower overall survivability is estimated to cost 1/2 that of a composite hull due to higher:

- Material costs: e.g. fibres, fabric and resin compared to steel;
- Manufacturing costs: labour time, integration complexity, machining requirements, NDE to ensure quality control.

This was based on using existing techniques from other sectors such as aerospace and F1 that are not cost effective in for the AFV requirement. Out of autoclave, marine manufacturing techniques would offer manufacturing routes closer to those currently used for metallic AFV structures. Any improvements in the cost ratio will increase the chances of the composite technology being used.

4.3 Damage tolerance and repair

Unlike aircraft and marine vessels, AFVs are required to deliberately impact into structures/trees etc, in order to move to their required locations. In addition, military vehicles have a large incidence of low velocity impacts between vehicles, which can lead to damage. Steel has the advantage of being able to deform without necessarily generating damage to the structure, whereas composites being inhomogeneous laminar structures, upon impact can lead to structural damage requiring repair.

Metallic structures can fail at welds and may be visually apparent. In contrast, composite structures have failure modes that are not often apparent upon visual inspection leading to damage not being immediately identified. Delamination can occur within the laminate, which requires ultrasonic inspection techniques, which add to expense of maintenance tasks.

Repair techniques for large composite structures are well developed but are more time consuming than those used for metallic structures, due to the need to remove the damaged material which due to delamination can be extensive, before relaminating. For metallics, the use of welding repairs can be more cost effective as they require moderate technician skills and equipment capability.

Improved toughness thermosetting resins continue to be evolved but offer in reality-limited improvements sufficient to mitigate low velocity high-energy impacts as seen in AFVs. Thermoplastic composites should improve the toughness of the composite, but these require more costly processing routes than those currently used due to the higher processing temperatures and are unlikely to be cost effective. QinetiQ has undertaken a limited exploration of the use of a thermoplastic that can be processed like a thermoset (i.e. low viscosity 2-part precursor that can be used in for infusion), produced by Arkema. This is a PolyMethlyMethAcrylate (PMMA) brand name 'Elium' [12]. The potential advantage of this system is that out of autoclave techniques can be used unlike standard thermoplastic processing, and Arkema state the resin has been used for large structures such as wind turbine blades. However, the resin forms a relatively weak bond with glass fibres, with the best bonding being achieved using a vinylester size on the glass. Laminates plates have been ballistically tested by QinetiQ using the system, but the results were disappointing. Further investigation into this type of resin including polydicyclopentadiene (pDCPD)-based thermosetting polymers would be of value.

The ability to use self-repairing composite structures remains elusive despite the many years of research devoted to this topic. The company CompPair Technologies claims that their HealTech^{TM}, materials when used to build composite structures, enables the repair of damaged composite products in 1 minute, in place and without any additional material and processing step, this being for structures up to 3 mm in thickness. All that is required is to heat the damaged area of the part at moderate temperature (100-150°C), which can be done using a heat gun, a heat blanket, or an oven [13]. Unfortunately, currently the technology is for use with their prepreg materials rather than for OOA processing, and it is unclear how practical the approach is for thick section composites.

3D fabrics and techniques such as through stitching and tufting can reduce the size of the damage associated with impacts but at the penalty of increased material cost, manufacturing complexity and difficulty of repair to achieve comparable performance to the baseline material, when looking at laminate thicknesses of around 30 mm.

An alternative approach to the composite monocoque is the use of space frame structures that allow for the removal of the damaged hull skins. To overcome the issues with the bolting of the skins to the space frame, the use of disbondable adhesives would increase the viability of the design. Work on dismountable adhesives has been undertaken by Broughton at Oxford Brookes university, exploring the use of thermally expandable microspheres (TEMs) embedded in an adhesive system [15]. This indicated that incorporating TEMS reduced the mechanical strength of the adhesive by around 25%, but on the application of heat stimulus, the strength dropped to less than 10% of the original bond strength allowing the bond to be more easily broken for disassembly.

A paper by the Royal Society of Chemistry (RSC) [14] has reviewed the use of debondable adhesives to aid recycling components such as wind turbine blades and provides a list of some commercial examples of debondable adhesives and their application fields. It also lists the debonding stimuli required. Unfortunately, the only appropriate method for thick composites is heat, but as demonstrated by Broughton, issues remain on how to apply the heat locally to panel to be removed from the structure. Additionally there is the issue of the resistance to a fire on board an AFV either due to issues with the vehicle's propulsion or electrical systems, or from attack from external sources (e.g. Molotov cocktail). In the event of such a fire, it would not be acceptable for the composite structure to start to fall apart! A potentially safer approach would be the use of electrically debondable acrylic adhesives based on imidazolium ionic liquids [16]. Solvated salts or ionic liquids are incorporated into the adhesive matrix. The additives provide ionic conductivity to the adhesive, making it susceptible to electrical stimuli and leading to electrical debonding. Voltage induced debonding can avoid the risk of mechanical, thermal and/or chemical damage of the components, but it requires the use of conductive substrates such as metals or materials that can be covered with a conductive layer. Debonding occurs upon application of a voltage between the two bonded substrates. Various debondable adhesive solutions have been developed and a few are even commercialized, but with varying success and inconsistent performance. Further work is required to achieve a reliable solution appropriate for a structure that could be in service for 30 years.

4.4 End of Life Recycling/Disposal

When looking at the whole life cost of an AFV platform end of use recycling must be considered. For metallic hulls, recycling is a proven process but for composites, there is more of a challenge. Currently grinding of composites to form a low performance low cost filler remains the main recycling option. Work to produce resins that can be removed to release fibres for reuse is on going, which appear to be based on epoxy resins that can be chemically broken down [11]. While this approach is appropriate for the majority of epoxy based composites, there would be concerns if used for military vehicles, in which a range of hostile chemicals can come in contact with the laminate including acids, fuels, biological agents and bodily fluids. Therefore, caution is needed when considering a chemical that could be easily used by opposing forces to weaken the hull structure. Outer and inner coatings impervious to the chemical could be applied to a laminate but this introduces further costs and raise issues where through holes in the composite hull could be prone to chemical attack.

5 CONCLUSIONS

The future design of armoured fighting vehicles is difficult to predict but there remains a strong desire to reverse the ever-increasing weight of AFVs. The ongoing need to reduce vehicle weight cannot be addressed currently by composites due the issues highlighted in this paper. Composites must be combined with both synergistic materials/production processes, and vehicle designs if the stated benefits are to be met. It must also be realised that benefits do not come without costs both financial and operational. Affordability in terms of unit product cost (UPC) is often a key selection criteria and is weighted more prominently than performance advantages over conventional materials.

The AFV industry prefers to maintain designs built on previous successful vehicles which is a safer and risk averse approach. Key issues to overcome the reluctance to use composites include:

i. Due to the wide variety of candidate composite reinforcements, fibre orientations, resins and manufacturing processes, the design data to design composite structures is not available in the same format as that for structural metallic materials, which increases the complexity and risk of designing with composites;
ii. New manufacturing routes to produce defect-free large structures, with minimised labour;
iii. Damage detection and improved damage tolerance designs with associated repair procedures and technician skills are required;
iv. Effective end-of-life technologies to improve life cycle costing assessments.

The use of new manufacturing techniques to reduce production costs in combination with automated quality inspection is required. However, the issue of durability of composites still needs to be addressed in order to make composite AFVs as durable as the existing metallic vehicles.

Due to the relatively low AFV production numbers, it is doubtful that the manufacturing costs for composite vehicles will ever be as low as for metallic hulls. Similarly, the cost of composite materials will not be as cheap as for metallic materials, if only due to the huge difference in raw material production volumes. It is however, important to put these cost increases in context with the overall cost of an AFV, where the price for a hull can be less than 10 % of the overall cost of the vehicle. An increase of even of 20% in the hull cost is still only an increase of 2% for the AFV, but with the potential increase in performance being much greater than 2%.

Finally, where can the use of composites best be demonstrated for AFVs? As discussed above, the benefit of using composite materials is dependent on the ballistic protection defined for the vehicle and the design of the vehicle in terms of “traditional” monocoque or possibly a composite crew capsule design. It is my opinion that a vehicle designed for protection against 14.5mm armour piecing threat or less using the combination of a composite hull and ceramic armour, made from carbon fibre and S2 glass fibre and UHMWPE is the ideal vehicle to display the capabilities of composite materials. For higher ballistic threat levels and vehicles limited to only a small number of crew, such as main batlle tanks, even the use of a composite crew capsule maybe not be viable solution.

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