The Advantage of Composite Materials in the Design, Construction and Use of Hard-Wall Shelters and Container Systems

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The recognition of (carbon) composite materials as a technologically superior element compared to steel and other metal alloy shelter materials, in addition to their improved cost effectiveness, paves the way for acceptance as the new industry standard by the military and other government customers. This paper will demonstrate that the market is now prepared to embrace composites' strength, light-weight advantages and cost efficiencies.

United States Secretary of Defense Donald Rumsfeld has stated on numerous occasions that a high-tech, efficient and mobile military must define the future of our armed services. A key aspect of this "mobile" military is the notion of a smaller logistical footprint—meaning less impact to the surrounding environment, less maintenance, less cost, less weight, less fuel, less space used—that delivers higher productivity and achieves better safety, cost and mission outcomes. To that end, the creation and provision of composite tactical shelter and container systems that protect humans and equipment in military situations and other government applications has become a top priority as the world continues to adjust its priorities in a post 9/11, terror-prevention world.

Shelter and container systems that perform under extremes of temperature, environment, geography, combat and/or utility are more readily achieved with the use of (carbon) composite materials and technologically advanced engineering techniques.
And although carbon fiber is clearly the composite industry's best solution for high-strength and lightweight structural components, its expense has been borderline prohibitive for many applications until very recently. However, a drop in carbon fiber prices during the past several years has led to its more mainstream integration into products ranging from automobiles to golf-club shafts.

A Changing Industry: Shelter and Container Performance Essentials

The shelter industry faces tremendous overhaul in the coming years. Traditionally used, old-line technology and materials are increasingly viewed as too heavy, too costly to maintain, and not a suitable match with the new military vision of a lighter, stronger, corrosion and maintenance-free tactical mobile shelter. Primarily, we argue that four main factors are driving change in the industry. These include:

- innovative new designs and technologically advanced engineering are making their way to the marketplace;

- materials that have been cost prohibitive in the past are now significantly more economical, thereby dramatically improving the results that can be achieved by their use in fabrication;
- the market push for highly sophisticated and technical product features and "extras" is becoming an industry standard; and
- the military's mandate for a reduced logistical footprint has become a requirement that all shelter manufacturers must meet.

At the forefront of this market and product evolution, composite materials provide the fundamental foundation fro this change.

Composite Advantages, Functional Benefits

Composite shelter use has many advantages over traditional metal and alloy-based structures, not the least of which are composites' superior strength-to-weight ratio, lower maintenance requirements and greater corrosion resistance.

Composites exhibit a higher strength to weight ratio than steel or aluminum and can be engineered to provide a wide range of tensile, flexural and impact strength properties. For example, a composite's strength per unit density is roughly two times that of aluminum and four times that of steel.
A principal advantage held by composite shelter manufacturers is their use of carbon fibers and epoxy resin in an advanced "prepreg" composite construction for its MERWS and ISO container products. Carbon and glass reinforcement fibers have comparable densities, but the carbon is about four times stronger, with a strength of 100,000 psi compared to glass' 25,000 psi. Greater strength and less weight dramatically improve shelter performance outcomes.

Additionally, composites are corrosion resistant to most chemicals, do not suffer from electrolysis and incorporate long-term benefits such as weather ability and UV stability.

In summary, composites offer the following significant advantages.

- High Strength with Low Weight
- Corrosion Resistant
- Longevity

Designer Flexibilities

A designer has enormous scope to produce composite components of any size and shape and with fewer parts. In effect, the designer has the opportunity to design the material to meet the required performance. Because of the viscoelastic character of polymers, composites are inherently better damping materials for noise or vibration. In addition, composites can retain their shape under mechanical stress and temperature extremes. Within sandwich composites, thermal insulation can be improved

In summary, composites offer the following design features.

- Dampening of noise and vibration

- Dimensionally stable
- Improved thermal insulation

Composite Cost Advantages

The corrosion resistance and weather ability of composites substantially reduces maintenance costs and extends product lifetime. Their lightweight composition leads to savings in transportation and installation costs. Reducing the total number of shelter parts also leads to reduced costs.

Therefore, the high initial cost of a carbon composite is somewhat deceiving, because it exhibits significantly higher strength and stiffness per unit density, especially compared with metals. This translates into a carbon-fiber composite with less weight but similar or improved strength relative to a glass composite or metal, compensating for its higher material cost.

In summary, major savings in assembly costs can be achieved by designing a single composite part to replace a multiple part assembly of alternative materials.

- Installation
- Transportation
- Maintenance

About Composites: In Detail

A composite is simply a material composed of at least two dissimilar elements acting together to produce a set of properties different from those of each individual element. Generally, composites are comprised of a bulk matrix and reinforcement, usually a fiber, which strengthens the matrix.

The most common synthetic composites are:

- *Polymer Matrix Composites (PMCs) or Fiber Reinforced Polymers or Plastics (FRPs), which use a polymer-based resin for the matrix and reinforcement fibers such as glass, carbon, and/or aramid;*
- *Metal Matrix Composites (MMCs), which use a metal-based matrix, such as aluminum, and reinforcement fibers such as silicon carbide*
- *Ceramic Matrix Composites (CMCs), which rely on a ceramic matrix reinforced with short fibers made from silicon carbide or boron nitride, for example.*

Polymer Matrix Composites are the most common, and the most applicable to the shelter industry. With PMCs, an applied load is spread between each fiber across the composite by the resin matrix, so the properties of each element contribute to the properties of the resulting composite.

The properties of any PMC, therefore, depend on:

- *The fiber's properties*
- *The resin's properties*
- *The fiber-to-resin ratio (Fiber Volume Fraction)*
    - *Mechanical properties of fibers are generally much higher than the mechanical properties of resins, so a higher fiber volume fraction will lead to a composite's increased mechanical properties.*
- *The orientation and geometry of the fibers in the composite*
    - *Fibers have their highest mechanical properties along their lengths, so their position in the composite creates direction-specific loading properties. This ”anistropic“ feature helps determine where along main load paths the highest fiber concentration should go, and reduces the amount of extra material where the loading requirements are low.*

The composite properties of particular interest are high strength and stiffness combined with low densities, which create the high strength-to-weight ratios that give composites an advantage over metals for shelter construction.

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The most common fibers in a FRP are glass, aramid (Kevlar), and carbon. The most common resins are polyester, vinylester and epoxy. The most widely used and least expensive composite is a glass-reinforced polyester. And most composite shelter manufacturers use a glass fiber with vinylester sandwich composite.

Carbon fiber is created when a carbon-rich organic element already in fiber form is oxidized, carbonized, and graphitized in a controlled environment. The resulting fibers are grouped according to their strength and stiffness per unit density, or modulus.

The categories are:
- High Strength (HS)
- Intermediate Modulus (IM)
- High Modulus (HM)
- Ultra High Modulus (UHM) – generally aerospace grade

All grades of carbon fiber range in diameter between 5mm and 7mm, a relatively small diameter that allows for higher fiber surface areas in the composite. This spreads the fiber/matrix interface load and contributes to the greater stiffness and strength of a carbon-fiber composite.

But carbon fiber alone has marked advantages over other commercially available fibers, including the highest specific stiffness and very high tensile and compression strength. Carbon fiber also is highly resistant to corrosion and fatigue.

Some of the main advantages of carbon fiber are its:
- High tensile strength
- High tensile modulus
- High compression strength
- High compression modulus
- High flexural strength
- High flexural modulus
- High interlaminar shear strength
- High in-plane shear strength
- High fatigue resistance
- Very low coefficient of thermal expansion (CTE) which allow structures to function in very high thermal extremes

Compared to other commercially available fibers, carbon fiber's weakness include:

- *Low impact strength*
- *Lower than glass or aramid fiber composites. HM and UHM fibers are particularly brittle.*
    - *When impact strength is critical, carbon can be combined with another fiber in a hybrid fabric that draws on the complementary strengths of both fiber types.*
- *Middle density*
    - *Less dense than glass, more dense than aramid*
- *Low fire resistance*
- *Low thermal insulation*
    - *There is still greater thermo-insulation inherent in a sandwich composite than in a metallic material*
    - *A thick foam core, like that used in Alkan shelters significantly increases the insulation value of a carbon-fiber composite without adding much weight.*
- *Low electrical insulation*
    - *An epoxy-resin matrix, which Alkan uses, has high electrical insulation properties that help offset this carbon-fiber disadvantage.*
    - *Currently, an Electro-Magnetic Interference (EMI) coating can be applied to the composite material. Alkan is working on incorporating greater EMI properties in its products.*
- *High cost*

Aerospace-grade UHM carbon fiber has decreased dramatically since it appeared on the market in the late 1960s. This price drop has accelerated as the worldwide capacity and application opportunities have increased, with carbon fiber recently dropping to about 25 percent of what its cost was ten years ago. And, as previously discussed, the high mechanical properties, low density, and resistance to corrosion and fatigue compensate for carbon fiber's high material cost.

Most carbon fibers used in the composite industry are pre-impregnated, or coated with a heat-curing resin, before they are combined with the resin matrix. Fiber properties are very important in the overall strength of a composite, and carbon fiber contributes the greatest available strength and stiffness to Alkan composites.

The properties of the composite are also dependent on the type of resin matrix the system uses, the properties of the resin itself, and the interaction between fiber and resin. Already addressed is the amount of fiber in the composite; this can be quite high in carbon-fiber composites given the small diameter of carbon fiber filaments.

True to their name, PMC matrices use polymer-based resins, which can be categorized according to their reaction to heat.

- *Thermosets undergo a non-reversible chemical reaction resulting in a hard, infusible product with final mechanical and physical properties*
    - *Thermosets include epoxies, bismaleimides, polyimides, vinylesters, and phonemics.*
    - *While some thermosets produce volatile by-products, polyester and epoxy do not.*
- *Thermoplastics, like metals, melt or soften with heat and then harden when cooled.*
    - *Thermoplastics include nylons, polypropylene, polyethylene, polystyrene, and polytheretherketone (PEEK).*
    - *Thermoplastics can usually only be reinforced with short, chopped fibers.*

To produce a viable structural composite, all resin systems must have strong mechanical, adhesive, and toughness properties and good resistance to environmental degradation. The vast majority of structural composites use polyester, vinylester and epoxy resin matrices.

Polyesters are the lowest-cost resins and easy to use. However, they have only moderate mechanical properties, can shrink significantly when cured, have high styrene emissions and can only be worked in a limited time range.

Vinylesters, which cost more, have higher mechanical properties than polyesters and are very resistant to chemical and environmental factors. Like polyester, however, they can have a high cure shrinkage and high styrene content.

Epoxy resins are the highest performance resins currently available, with higher mechanical properties and environmental resistance than most other resin types, as well as high electrical insulation and good chemical resistance.

"Epoxy" refers to an oxygen-carbon chemical group with one oxygen atom bonded to two already-bonded carbon atoms. This chemical construction is what makes epoxy stiff, tough, and heat-resistant; it contributes to the high water resistance of epoxy, and makes it particularly good at absorbing mechanical and thermal stresses. Epoxy's high thermal properties, for instance, mean it can be temperature resistant up to 140°C wet and 220°C dry.

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One central advantage epoxies have over other thermoset resins is their low shrinkage during cure. Shrinkage occurs when resin molecules rearrange and reorient in the liquid and semi-gelled state, contributing to built-in stresses and the overall weakness of the final product. Polyesters and vinylesters have shown shrinkage up to 8%, where the epoxy chemical reaction shows only about 2% shrinkage. This minimizes internal stresses and increases the epoxy composite's mechanical properties, such as tensile strength and stiffness, as well as its resistance to fatigue and degradation.

Obviously, how well a resin matrix adheres to fiber reinforcements and/or to a core material in a sandwich construction is an important factor in composite construction. Epoxy resin systems have better adhesion properties than polyester and vinylester resins, which makes epoxy laminates more resistant to micro-cracking and ultimate failure.

The disadvantages of epoxies are few, but they are more expensive than other resin systems, and can be corrosive to handle. Also, the mixing of epoxy resins is critical to their success in application.

Given the overall superiority of the mechanical properties of both carbon fiber and an epoxy resin matrix, carbon-fiber-epoxy composite is one of the highest-performance and most efficient structural composite materials available today. The Alkan structure, for example, is designed to carry up to a 191,000-lb force on any given corner – quite an achievement for a shelter that only weighs in at 3,000-4,000 pounds.

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