Protective Materials for Maritime Vessels

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1.0 Introduction

As early as 1950 a new generation of composite materials were being developed to support the offshore oil & gas, aerospace, and defense industries. These materials included syntactic foams, glass and ceramic-based hollow micro and macrospheres, unique polymers, elastomers, and rubber. Today, these composites are in use world-wide. Driven by the maritime industry's need for lighter, more efficient and safer vessels, these lightweight composite materials serve as the foundation for multi-functional structures to satisfy complex material design requirements.

These materials are being introduced, as well as, for consideration in new maritime vessel design and construction as survivability, maritime security, and force protection solutions. More importantly, the benefits associated with these new high-performance composites are that they are now lighter and stronger than ever, provide climate and physical protection, are customizable, cost effective and easy to install, and are in most cases repairable.

2.0 Purpose

This Protective Materials for Maritime Vessels paper focuses on efforts to introduce and support next generation composite product and material solutions that sustain this critical technology area. The paper also addresses the relationship of these products and materials, their relevance to multiple market segments and technology sectors being presented at MAST 2009, and how they can be maximized through weight and cost savings without sacrificing capabilities.

3.0 Background

For centuries, protection of maritime vessels has been a concern of militaries, merchants, and governments alike. Over the past several decades, there have been significant advancements in composite material protection technology that have resulted in applications that are much more effective than traditional materials. These materials include those used for new ship, submarine and submersible design and construction; hull structures; piping and electrical systems; harbor and maritime security; and force protection. Applications include:

- Fire and thermal protection
- Blast/ballistic protection and containment
- Surface and subsea buoyancy
- Piping, fluid, and electrical systems
- Structural lightweight panels
- Munitions transport and storage
- Noise, anti-vibration, seals, and signature reduction

One example of the benefits of some of these materials is found in the U. S. Navy 688 Class Submarine syntactic foam eyebrow module with its structural, thermal, energy absorbing, and buoyancy capabilities. Notably, the survivability of the USS San Francisco, following the January 2005 undersea mountain crash incident, was attributed to the performance and capabilities of this material solution. The foam has a foot-seawater (FSW) rating of over 6,500 and a strength rating of 3,000 psi. Another example is the use of syntactic foams for blast mitigation and containment for land, air, and sea force protection. Grade A shock certified materials have been designed for use in protecting high value marine assets, from ship hulls (above, at, and below the waterline) and superstructures, to pressure and shock wave containment.

When these foams are combined with ballistic protection applications they are able to form hybrid-armor systems, providing the capability to protect better than any other alternative. It is estimated that these material solutions would have prevented or significantly lessened the effects of the bombing on USS Cole in 2000. Likewise, shipboard fire protection is considered the most critical concern for all marine vessels. Recent advancements in elastomer, rubber, and syntactic foam composite technology have introduced materials to protect against extreme jet and pool fires with temperatures as high as 3000°C.

The first commercial use of syntactic foam was introduced in 1957 and in 1958 by Emerson & Cuming, Inc., the first complete line of high performance glass microspheres or microballoons. This technology and the use of polymers, elastomers and rubber, were subsequently introduced to the offshore oil exploration market as early as 1969. Since then, these composite materials have been used in the development and manufacturing of over 80% of the world's drill riser buoyancy modules, distributed buoyancy for flexible and rigid production riser, and deepwater mooring buoys. Similarly, their introduction into the U.S. Defense and commercial subsea exploration market, for use in ship, submarine, deep-sea submersibles, and other buoyancy applications, has been instrumental in technology advancements in these areas. Today, the focus is on anti-blast and ballistic protection technology for which several unique composite systems have been developed that have proven to be successful in test. These systems are planned for initial introduction and deployment in surface, subsea and land theater applications later in 2009 and in 2010.

Advanced composite materials will continue to shape the foundation for future marine design and manufacturing. The flexibility and diversity of these materials, used in standalone or hybrid solutions, will ensure unlimited protective application support across multiple market segments and within all aspects of the world-wide defense industry.

4.0 The Problem

4.1 Fire & Thermal Protection

Effective fire and thermal protection, and the management of it, continues to be an addressable problem for maritime vessels. Whether marine vessels are used for defense, oil and gas production and storage, or for cargo transport, fire onboard sea going platforms continues to be the number one threat. Today, most vessels maintain systems to prevent and protect against fire; however, they consist of materials that are heavy, costly to install, difficult to maintain, and are not repairable while at sea. Composite material alternatives eliminate many of these problems and are now available to protect against extreme fires to decking (above and below), piping and electrical systems, fuel and water storage, cargo containment, and munitions.

4.2 Blast & Ballistic Protection/Containment

The war in South West Asia and other conflicts around the world illustrate that asymmetric warfare is on the rise, and will continue for the foreseeable future. The weapon of choice for terrorists, insurgents, and more recently seagoing pirates, has been the use of improvised explosive devices (IEDs), suicide bombers, high speed watercraft utilizing rocket propelled grenades (RPGs), small arms fire, and snipers to inflict maximum terror and damage to U.S. and Coalition Forces and the commercial shipping industry. To protect against these serious threats, the Governments have embarked on a variety of programs, to up armor high mobility multipurpose and tactical vehicles and maritime platforms to protect personnel, material, and equipment. The maritime industry (defense and commercial) has and continues to search for solutions to protect against these threats.

The effectiveness of these efforts has been mixed at best. The current use of steel plate armor and other heavy composites as add-on armor is not only costly to purchase and install, but it also creates supportability problems for vehicles and marine vessels alike, such as excessive tire wear, transmission and engine failures, increased fuel costs, topside structural weight limitations, and

excessive corrosion. In some cases, the additional armor creates new hazards for personnel. When insurgents use RPGs or other high speed armor penetrating projectiles, the steel and/or composites can melt or splinter, creating additional high speed fragments that injure people inside the vessels.
As a result of these in-theater situations, the most costly affect to personnel to date has been Traumatic Brain Injury (TBI) due to the lack of non-metal, non-ceramic solutions for anti-blast and anti-ballistic protection. This has direct application for maritime vessels that steam in harm's way or work/support dangerous industry segments. This has been further exacerbated by the fact that the U.S. for instance, currently has no blast triage concepts for hospitals and first responders.

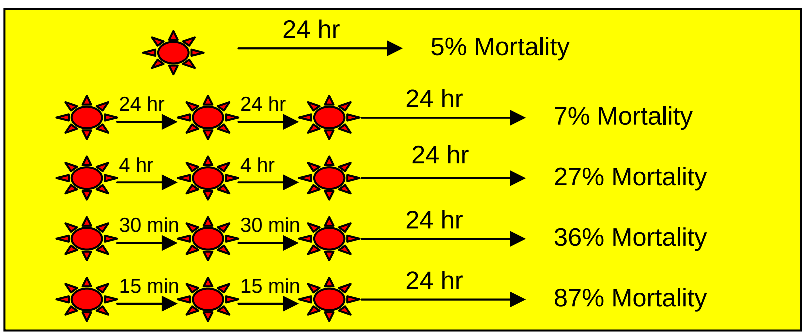
When exposed to multiple blast effects, injury is a function of:

- Wave duration
- Pressure
- Impulse (only for short duration)
- Number of exposures

When the threshold overpressure for injury/death from a single blast is exceeded, then injury (rate of) death increases with subsequent blasts.

Example I – Background:

- Experimentation on rats
- Long duration wave
- Overpressure = 26 psi

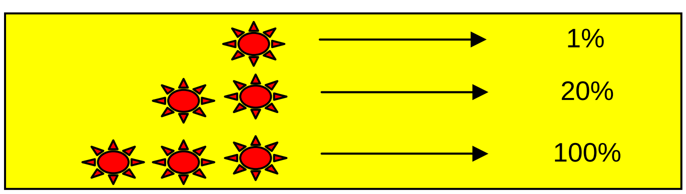


Example II – Background:

- Experimentation on sheep and swine
- 1 blast per minute

Results:

- Once threshold for pulmonary hemorrhage is reached – "remarkable increase" w/ repeated blasts



At supra-threshold levels, multiple low-dose blasts interact synergistically to enhance injury and mortality.

4.3 Surface & Subsea Buoyancy

At a mile (1.6 km) submersed, pressure is more than one ton per square inch (16,200 kPa). Subsea vessels need to maintain protection over extended periods at operating depths exceeding 20,000 ft (6,096 m). Similarly, surface vessels require the same high degree of hull and structural integrity to protect military and commercial operations, such as refueling, aircraft operations, weapons firings, cargo transport, and rough seas to name a few. Today, composite materials like syntactic foam continue to be engineered to high performance specifications to provide deep sea and surface ocean protection. Challenges stemming from this protection include advancement in materials to survive one mile pressures for 30 years with negligible buoyancy loss, to double-hull protection for surface vessels.

4.4 Piping, Fluid & Electrical Systems

The protection of a maritime vessel's infrastructure is critical at sea. Maintaining fire main piping, electrical, communications, and fuel/water systems is paramount to safe operation of crew and equipment. High valued assets, like control panels within command and control centers, ships power stations, refueling platforms and transfer stations, and weapons systems require 100% availability and cannot afford to be interrupted. The threat of fire, blast and ballistic damage, flooding, or even sabotage are all real concerns being encountered today. Advancements in elastomer, rubber, syntactic foam, and thermoplastic composite technology are all proven materials to provide protection in these areas.

4.5 Structural Lightweight Panels

Maritime vessels are being designed to incorporate the most advanced systems available on the market, and as a result, continue to have weight problems. This is especially true with topside structures of surface vessels. Limiting the weight results in the ability to make the overall ship lighter, provides for new buoyancy options, allows for larger cargo volumes to be stored and transported, and provides important survivability protection against rollover or listing during high sea states. Replacement or modification of these structures with lighter weight composites over metallic (mainly steel and aluminum) is an important engineering option and should be given serious consideration.

4.6 Munitions Transport & Storage

Military combatant and transport vessels operate daily in harm's way resulting in the requirement to maintain weapons systems and weapons/munitions of war. The protection of those weapons and the magazines that store them is paramount for the survivability of the vessel and for the readiness and protection of the other assets under their responsibility. Most vessels maintain some form of safe weapons loading, off-loading, and storage but many of those protective systems are made of metal, wood, or other composite materials with minimal protective qualities. These protective systems, however, are normally very heavy, possess the capability of sparking, and do not protect against critical fire, blast and ballistic threats to the weapon or magazine.

4.7 Noise, Anti-vibration, Seals, & Signature Reduction

Ship-builders, engine builders and manufacturers of special ship-borne equipment are continually looking to provide new levels of protection to maritime vessels against noise, vibration, intrusion, and detection. By reducing vibration and structure-borne noise, mountings make an important contribution to the standard of comfort and safety now expected by passengers and crew. Applications include main propulsion engines, generator sets, auxiliary machinery, exhaust systems and deck/super-structure isolation. Likewise, sealing solutions are currently in use as compartment seals on the UK's Astute Class submarines, surface and maritime vessel escape tunnels and door seals, on 90% of North Sea oil & gas platforms, and Floating Platforms for Storage & Oil (FPSO) - ship barges that pump and store oil and gas from the seabed - as compartment door seals, and drain gullies. These seals are also used in gasket designs within the aerospace and automotive industries and within the defense market for maritime and land applications. Reducing vessel signature (surface and subsea) from detection by radar or sonar is another important concern. This problem has potential disastrous effects, both militarily and commercially. Military vessels strive to maintain stealth characteristics and reduction to radar and sonar cross-section to avoid enemy detection but also need the ability to safely navigate in shallow and deep water environments. Commercially, protection is needed for harbor and port navigation to ensure that the ship signature is visible to other nearby vessels.

5.0 Material & Product Solutions

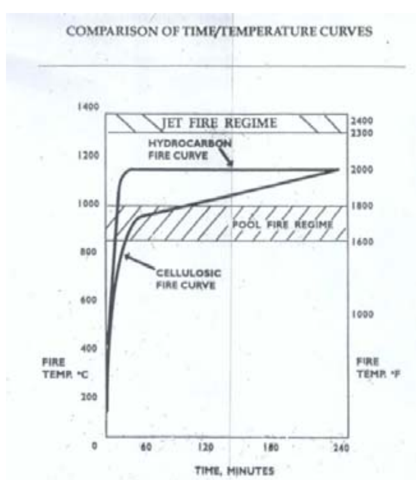
5.1 Fire & Thermal Protection

As early as 1900, rubber has been used in a wide range of applications that seal, dampen and protect. Since then, much advancement has been made in new composite rubbers now in use in some of the most demanding industrial environments. Although rubber composites are an integral technology in use offshore today, they are being widely introduced for alternative applications into new commercial and defense markets. These composites are being designed to be lightweight, fire, blast and impact resistant, and may be used in seals, thermal insulation for decking and bulkheads, ammunition protection, and fire suppression systems.

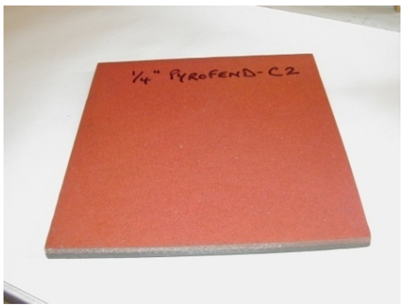
All of the material and product solutions discussed below either meet or exceed the requirements of MIL-PRF-32161 and MIL-STD 3020, as well as, shock testing. All products can or could be manufactured to the areal weight requirement of approximately 1.0 lbs/sq ft or less. These products are designed to pass surface flammability, physical and shipboard durability tests IAW MIL-PRF-32161 and as required by the NTA.

Safety is a key priority in many industries and especially within the military, commercial shipping and oil & gas industries. To meet this demand, a rubber and laminate based passive fire protection system called FIRESTOP™ is in use today. This material has been engineered into products that provide maximum levels of fire and thermal protection for decks, structures, piping and electrical systems and weapons/munitions. This technology utilizes a combination of flexible rubber, laminate and steel layers to seal and protect structures and equipment against all types of fire penetration, including the extreme conditions of a jet fire with temperatures up to 1300° C.

Fire Protection Ratings			
Jet-Fire		HC-Fire	
Heat Flux	250-350 kW/m²	Heat Flux	150 kW/m²
Temp	1100-1300°C	Temp	1100 °C
Speed	40 - 110 m/sec	Speed	20 – 40 m/sec
Duration	15-120 minutes	Duration	15-120 minutes



Because syntactic foams are inherently lightweight and strong, they can also be designed for use in custom applications, such as for fire or thermal protection. When further combined with other protective materials such as metal, plastics, hard coatings or even rubber composites, the foam will support the production of even thinner and lighter weight products; however, further research, development and testing are normally needed to determine the optimal combination of materials to withstand a broad range of these types of threats. This material is also currently being engineered for spray-on applications that are capable of protecting personnel and equipment in severe fire or thermal environments.



Fire Resistant Syntactic Foam

Fire resistant foams are used to provide a range of structural compositions with improved fire resistance characteristics. By structural, this means the ability to bear either static or cyclic loads consistent with the intended application. Conventional phenolic foams are considered not suitable for such applications due to their brittle, friable nature. The composition of fire resistant foams derives its mechanical properties from the inclusion of microsphere fillers that do not compromise the excellent fire and thermal properties. However, other non-cellular components can be utilized with this base solution to greatly enhance the mechanical and structural capabilities of this material without compromising thermal protection properties.

- UL 1709 - standard hydrocarbon test for the Oil & Gas Industry Test sample is subjected to a 2300F flame for 60 minutes

- MIL-STD-2031 - standard test for fire protection in a submarine. No smoke or toxic emissions are allowed for this test. Very few U.S. companies meet this standard and it is more expensive.

- ASTM E119 - standard fire wall test for the Building & Construction industry. Fire resistant phenolic foams have passed a 3 hour fire wall test at 3M.

5.2 Blast & Ballistic Protection/Containment

In early 2008 several new material solutions were introduced to address the subject of TBI (as previously discussed) using alternative lightweight composite armor protection for the U.S. warfighter. These materials provide protective qualities deemed necessary for the capability of a hybrid-armor system solution, exploiting two existing technologies with fundamentally different properties that in combination, promise protection against blast/shock wave effects and ballistic threats respectively.

Lightweight syntactic foams have been reengineered and improved for a broad range of military and marine composite applications in this area. Today, researchers are focused on tailoring the properties of microspheres and syntactic foams to the production of armored systems using blast-mitigating materials. Research is demonstrating that, when combined with other high-strength materials, syntactic foams are ideal for producing moldable, protective panels that absorb and dissipate blast energy rather than just transmit and reflect the effects. Among the key applications envisioned for the anti-blast products are:

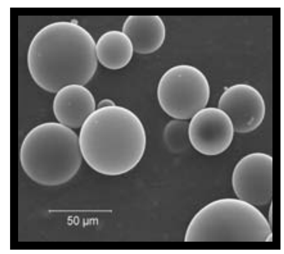
- Lightweight armor systems for military vehicles and marine vessels
- Lightweight panels for doors, walls and structures for the protection of high-value assets
- Munitions transport and storage
- Thermal protection
- Noise and signature reduction

The benefits associated with these new high-performance composite products are all similar in that they are lightweight, strong, provide climate and physical protection, are customizable, easy to install, and in most cases repairable alternatives to other less adequate materials. Examples of current and potential customers include the governments and militaries world-wide, the offshore oil & gas industry, merchant marine industry, commercial shipbuilding, and maritime exploration.

For these products, composite foam microstructures have been tailored to achieve a desired functionality on the macro-scale level. Some of these macro-scale properties are controlled elastic, thermal, and electrical; for example, composites consisting of engineered semi-rigid reinforcements embedded in compliant matrix material. One example is Energy Absorbing Material (EAM) syntactic foam. This foam consists of a flexible epoxy system using composite macrospheres and lightweight glass microspheres which form the foundation for hybrid-armor systems.

Glass microspheres are microscopic hollow thin-walled glass spheres composed of borosilicate or sodium borosilicate glass. To the naked eye they resemble a fine, white, free-flowing powder. However, magnification reveals them to be near perfect spheres. Due to their exclusive glass chemistry and method of manufacture, glass microspheres exhibit the following properties:

- High temperature resistance
- High specific strength (strength to density ratio)
- Clean surface chemistry
- Narrow particle size distribution
- Low thermal conductivity
- Low dielectric constant
- Low dissipation factor



Glass microspheres help reduce costs, enhance properties and improve process ability, such as in syntactic foams or in extrusion insulation tape. There are five distinct product series. All five series are produced from a high silica glass, with some series possessing material integrity up to 800°C / 1,472°F. Glass microspheres exhibit excellent specific properties- due to the removal of sinkers (broken spheres) - and high packing factors. However, additional steps during manufacturing have resulted in unique properties for each series.

Macrospheres are hollow composite spheres and ellipsoids that may be added to syntactic foams to achieve higher performance characteristics for unique applications. Manufactured using a sacrificial core, they range from 0.125 to 5.5” in diameter and provide increased specific strengths by dramatically reducing syntactic foam density. Macrospheres are available in a wide range of densities and strengths with carbon fiber, glass fiber, and Wollastonite reinforcements; ongoing development may soon yield aramid and ultra-high molecular weight polyethylene fiber reinforced macrospheres. Particulate reinforced composite macrospheres using hard shell materials like silicate carbon, tungsten, and tungsten carbide are also being developed for abrasive applications.

As mentioned above, EAM is an epoxy syntactic foam. This foam uses a room temperature curing system, although elevated temperature post-curing is recommended. The densities (26 to 40 pcf) currently contain glass or carbon macrospheres and can be engineered to meet changing threat requirements. EAM panel design also utilizes an outer layer composite compression skin, such as fiber glass Kevlar, steel, thermoplastic, Dyneema, or aramid which provides matrix stability, and in armor system designs, initial fragmentation/ballistic protection. EAM can also be combined with other materials to form layered hybrid system solutions for the mitigation of specific known threats.

This foam is the only Grade A shock qualified castable syntactic foam on the market today. Grade A means that the foam will not crack from the detonation of 60 pounds of high energy explosive 20 feet away. This is a 901C shock test.

EAM Panel

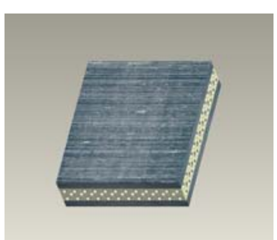
Why should syntactic foam be considered for blast mitigation?

Syntactic foams are inherently energy absorbing. One cubic inch of syntactic foam can contain up to 125 x 10^6 hollow glass microspheres which, upon collapse, provide an extraordinary reduction in blast shock waves. In fact, independent blast testing results demonstrated that syntactic foam-based solutions can mitigate 99+ percent of a 750 psi shock wave (The syntactic foams were placed between one pound of C-4 and pressure transducers located 44 inches from the C-4 when detonated. The 750 psi blast effect at the transducers was reduced to less than 5 psi). Subsequent testing of one pound of C-4 using the same EAM panel with a frontal blast wave of 3500 PSI from 18 inches resulted in a backside attenuation of 4 PSI at approximately 22 inches. Glass microspheres maintain their material integrity at temperatures up to 800°C/1,472°F and have a 10:1 weight advantage over steel (38 lbs/ft^3 vs 490 lbs/ft^3).

Recently developed is a novel composite armor system that exploits the ability of reinforced thermoplastic laminates to deform on impact and stop projectiles. The low production cost for these polymers makes it cost effective to mold materials into a variety of net-shapes and impact strengths that can act as effective shields against severe threats. This composite armor is the product of integrating molded thermoplastics, innovative new bonding chemistry, ballistic cloths, and ultra-hard strike face fillers, fibers and aggregates. In comparison, monolithic metal, ceramic, or thermoset-based composite materials (widely used today) frequently shatter when struck by blast fragments or projectiles; while thermoplastic composites do not shatter or experience brittle failure. These composites accomplish this by distributing impact loads over greater area due to their characteristically high ductility. In terms of ballistic performance, these composites are comparable to RHA (rolled homogenous armor) steel for rifle threats, and provide FSP (fragment simulation projectile) threat protection at a lower weight than steel. Recent testing of the newest vehicle armor demonstrated the ability of the armor to stop high level FSP and multi-hit threats with reductions in the combined weights of assembled materials, welding, and brackets.

<u>Hybrid-Armor Composite Systems</u>

Combine thermoplastic armor for shrapnel- free ballistics protection and syntactic foams to reduce the effects of blast and acoustic waves



Ductile thermoplastic resins and over-molded foam blast cores

Compression / injection processes provide panels and net shape parts

Protection of high value assets: Maritime vessels, people, equipment, information, ammunition, etc.

These solutions should be given serious consideration for various tactical military and civilian applications requiring rapid, cost effective, and superior protection to people and equipment in various environments. Hybrid-armor can also be used in all types of watercraft to enhance crew and vital component protection as illustrated below. The material has adequate structural strength to be used in place of other materials, or can be applied as a retrofit with minimal weight accretion. For example, the material can be applied directly to the inside of the bulkhead to protect sensitive equipment, as well as, crew members.

Practical considerations for designing and manufacturing a hybrid-armor solution include:

- Perceived threat(s) & actual threat requirements
- Hybrid armor design to include ballistic and blast protection
- Design possibilities include: removable panels, uni-system (single mold shape) or multi-molded shapes
- Testing of solution concept – potentially multiple designs for single or multiple threats
- Choice of materials
- Weight-to-strength/strain ratios
- Cost to develop and future initial and full production costs
- Ease of replacement or repair
- Supply chain management

Current and future maritime vessels applications include blast protection panels, enclosures, frames, radomes, and hulls and superstructures for surface and subsea (manned and unmanned). The hybrid-armor system provides significant advantages in a wide-range of activities that include:

- RF transparency providing both stealth and communications shielding capability
- Potential integration with embedded sensors, electrically activated polymers and related nano-technology
- Low heat absorption
- High torsional and flex strengths for excellent structural integrity
- Moldability for complex geometries (net shape)
- Multiple-hit survivability with small-diameter, localized damage sites and low to zero fragmentation upon impact
- Ductile polymer structure eliminates crack propagation and facilitates on-site repair
- Low manufacturing costs thanks to readily available high-speed molding processes and commercial off the shelf resins, binder and filler production

EAM Ultra-light

Syntactic foams have also been designed for blast containment. These foams are ultra-light three-phase structures composed of macrospheres in a rigid resin binder, carefully engineered to optimize energy absorption. This foam offers a well-defined crush stress and has a long constant stress plateau, key advantages for the design of lightweight crushable structures. The foam contains large amounts of void space to maximize the compaction stage of crushing and delay the onset of foam densification.

The primary use of crushable foam is for energy absorption, e.g., protective barriers, infrastructure panels, void fill, pressure vessel testing, and flyer plate backing material. This foam is also an excellent lightweight, high specific property core material.

5.3 Surface & Subsea Buoyancy

As previously presented, syntactic foams are the primary material solution for surface and subsea buoyancy. These foams are manufactured by grade depending on their intended use and specific requirements.

Machinable Foams

EL Grade – Is one of the first deep water syntactic foams. Used in the manufacturing of ROV's, HOV's and AUV's. This foam possesses excellent chemical resistance, especially to hydraulic fluid, diesel fuel and jet fuel.

TG Grade – Mostly comprised of styrene monomer with some acrylic monomer and glass microspheres. Also used in the manufacturing of ROV's, HOV's and AUV's and in mine neutralization systems because of their zero magnetic and acoustic signatures.

DS Grade – High performance multi-functional epoxy combined with lightweight glass microspheres to produce an ultra-high strength-to-weight syntactic foam material for deep-sea applications.

Pourable Foams

VF Grade – Epoxy syntactic foams in varying densities use a room temperature curing system. Used to fill control surfaces in 688 Class U.S. nuclear submarines, Swedish and Australian diesel boats, and French Triumphant nuclear submarines.

5.4 Piping, Fluid & Electrical Systems

FIRESTOP™ technology is one of the newest and most advanced composite material solutions available today for the protection of piping, fluid, and electrical systems from fire, blast, impact, corrosion, and flooding. One product on the market today utilizing this technology is ELASTOPIPE™. ELASTOPIPE™ is an explosion, impact, and fire-proof fire-water system which is an alternative to traditional metallic and fiberglass-based piping systems. It is specially designed to substitute rigid pipes in sprinkler, deluge and firewater supply systems, and is a perfect alternative solution for traditional shipboard or submarine fire main and countermeasure washdown systems.

ELASTOPIPE™

Unique Piping System - ELASTOPIPE™ is made of synthetic rubber and it replaces today's rigid steel, titanium, copper nickel, cast iron, and fiber glass piping. The unique features of the product make it ideal in deluge and sprinkler systems on offshore oil and gas installations and ships and in industrial plants, mines and other hazardous environments. It can be used to partially or fully replace old systems and is also ideal for use in temporary deluge systems when high safety levels need to be maintained during modifications. Its flexibility enables it to be moved and reused.

Non-Corrosive - Metal corrosion can cause blocking of pipes and nozzles, leading to production shut downs or reduction in capacity. ELASTOPIPE™ is completely non-corrosive, maintenance free with a lifecycle of over 30 years.

Less Engineering Work - The design of optimal routing when using flexible ELASTOPIPE™ differs from that used for traditional rigid pipes. It is possible to achieve a substantial reduction in the number of construction drawings and accurate measurements needed, as well as the amount of engineering work required. No on-site prefabrication is necessary and installations may be modified spontaneously on site.

Fire and Impact Resistant - The functional abilities of fire water systems can also be threatened by fire, fragments from explosions and other types of impact. ELASTOPIPE™ is fire resistant, and can even withstand jet fires with a heat flux of 390kW/m^2, temperatures above 1250°C and flame speeds which exceed the speed of sound for one hour, with no water in the pipe for the first five minutes. ELASTOPIPE™ has a resistance to explosions that is unrivalled and is only limited by the choice of the support system in use. Its impact resistance is demonstrated by there being no reduction in burst pressure following an impact of 800 Joules. It's durability ensures safe transportation and installation.

ELASTOPIPE™ Fire Protection

Minimized Water Hammer - ELASTOPIPE™'s smooth inner surface (Hazen Williams factor of c=155) ensures that it will last throughout the product's life and allows for flexible bends, ensuring high water flow speeds. The flexible material of ELASTOPIPE™ serves to dramatically reduce dynamic pressure effects, i.e. water hammer. Based on real measurements, the reported reduction in water hammer is up to 60%, clearly demonstrated during the commissioning tests of deluge systems.

No Hot Work – Full ELASTOPIPE™ installation can be completed without the use of adhesives, welding or hot work. It can be cut with a hand-held pipe cutter without the risk of sparks occurring, and the pipes are joined mechanically using air operated hand tools. Since ELASTOPIPE™ is flexible, it can easily be bent to a radius equal to five times its own diameter. Installation is therefore simpler, faster and less expensive than with rigid pipes such as HDPE, and installation time can be reduced by up to 50% compared with other systems.

Another FIRESTOP™ product is ELASTOSHIELD™. ELASTOSHIELD™ provides the same protection qualities and characteristics found in ELASTOPIPE™ but is designed for the protection of cables, electrical wires, fiber optics, hydraulic and fluid lines, communication lines, and other critical support assets. It maintains the same protection ratings as ELASTOPIPE™, as well as, low smoke and toxicity.

ELASTOSHIELD™ JF-CP provides electric cable protection to extend service life of cables in a fire. It resists both jet-fire and pool-fire and is tailor-made to suit any required function time in a fire. The concept was developed for protection of electric cables for firewater pumps, and is designed for ultimate performance in critical areas where a fire can occur. ELASTOSHIELD™ JF-CP's rugged design gives additional protection against mechanical damage. The product size range is up to 300mm^2 in diameter with a standard length up to 60 meters, longer lengths can be produced on request. JF-CP is resistant to jet-fire with 500 volts, temperatures up to 1300°C, seawater, UV, ozone and most solvents. It is also maintenance free.

ELASTOSHIELD™ JF-HP provides the same protection as ELASTOSHIELD™ JF-CP and protects the environment from damage and reduced oil spill in case of a hydraulic hose burst. It is tailor-made to suit any application and is available in sizes from 3/8” to 2”. Most common threads and styles of couplings will be applicable. Standard lengths are up to 15 meters, with longer lengths available upon request. JF-HP is resistant to working pressures up to 420 bars, temperatures up to 1300°C, and seawater, UV, ozone and most solvents. It is also maintenance free.

5.4 Structural Lightweight Panels

Syntactic foams, mainly EAM or VF Grade are perfect for the design of lightweight strong material for structural barriers, bulkhead and deck integrity or even complete replacement of shaped or linear surfaces. Additionally, rubber composites, as previously discussed in this paper, are perfect lighter-weight alternatives for decking, bulkhead, and piping designs.

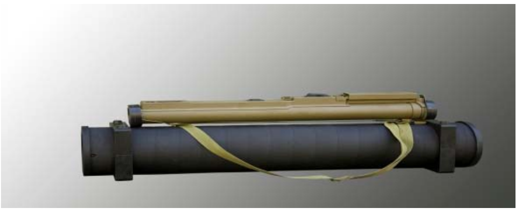
One product available today and installed on oil and gas platforms world-wide, as well as on several classes of military warships, is another FIRESTOP™ technology product called Vikodeck™. Interest in this product significantly increased after the Piper Alfa oil platform accident in the North Sea in 1988. Without any protection of the steel structure, the platform melted and personnel were not able to gain access to escape routes or life boats. Today, most of the oil companies coat their risers and critical equipment with Vikodeck™. Vikodeck™ prevents the fire from escalation, protects against blast and impact, insulates, and increases the overall lifecycle of critical equipment and structures.

Vikodeck™

- Approved for Smoke and Toxicity by MoD - Defense Standard 02–711 Issue 2. Publication Date 13 April 2006.
- Spread of Flame; Rated Class 1- BS 476 part 7
- IMO Res. A 754 (18) and NPD’s time/temperature curve in a simulated H-curve.
- Dampens, reduces noise, and protects impact, high loads, explosions, erosions and extreme fire
- Maintains stability and integrity in extreme conditions from -200°C to + 3000°C Material properties for Vikodeck™ (tensile strength, compression set, tear strength, aging, chemical properties, nose reduction etc.) are expected to meet U.S. Navy requirements
- Meets current ONR 1” material thickness requirement for U.S. flight deck thermal management.
- FMV, Norwegian and Swedish Frigates- protection of structures and decks, etc.
- Thermal analysis of entire flight deck use may also reveal that Vikodeck™ may be a more cost- and weight-effective solution

5.5 Munitions Transport & Storage

Rubber composite technology for ammunition protection, containment, transport, and storage has made significant advancements within defense in the past 30 years. One product, Viking Protector™, is a revolutionary concept for the protection of explosives and weapon systems against fire, shock and mechanical damage during handling, storage and transportation. The concept uses FIRESTOP™ technology combined with other materials, to provide custom designed protection of explosives.



Protector NAMMO M72 Missile System

Protector™ can be custom designed to meet differen criteria for specific explosives and weapon systems, such as the U.S. Navy's JSOW AUR Canister, the NAMMO M72 Missile System (shown here), ammunition and projectiles, during loading, off-loading and onboard storage. Protector™ provides increased safety for personnel in a low-weight, easy to handle, reusable and maintenance free system that has been tested and approved.

Viking Protector™ dimensions are dependent on individual specifications and for the type of protection required. Protective layers are dependent on type of protection required. NAMMO M72 protective layers consist of:

- Steel inner-layer
- Layer of fiber glass
- FireStop™ rubber + others
- Wall thickness approximately 15-20mm

5.6 Noise, Anti-vibration, Seals, & Signature Reduction

Rubber, to metal bonded engineered products, anti-vibration mountings and suspension components continue to be designed, developed, and marketed today for protection of maritime vessels. Seals offer a flexible connection between rigid metal sections. They connect modules and maintain fireproof portioning. The flexible seals are able to handle large displacements, absorb misalignments and angular deviations, and eliminate stress concentrations. They also eliminate propagation of vibrations and dynamic loads. Flexible seals are made in any shape and size that fits design requirements. The seals are easily bolted to all kind of structures and are the first choice in any modification process. Applications, features and advantages include:

Door Seal and Drain Gully

- Weather barriers
- Fire barriers
- Door, hatch, and scuttle seals
- Flexible module connections
- Closes open spaces and gaps
- Custom manufactured to any shape and size
- Problem solver for the engineering organization
- Prevents stress and strain in structures
- Tolerance absorbing element

There are several new products and materials being introduced for use today in signature management applications. These include syntactic foams and advanced rubber composites that provide acoustic damping properties in addition to other functionality. Microspheres provide an ultralow density substrate for deposition of functional coatings. Some examples of this technology include:

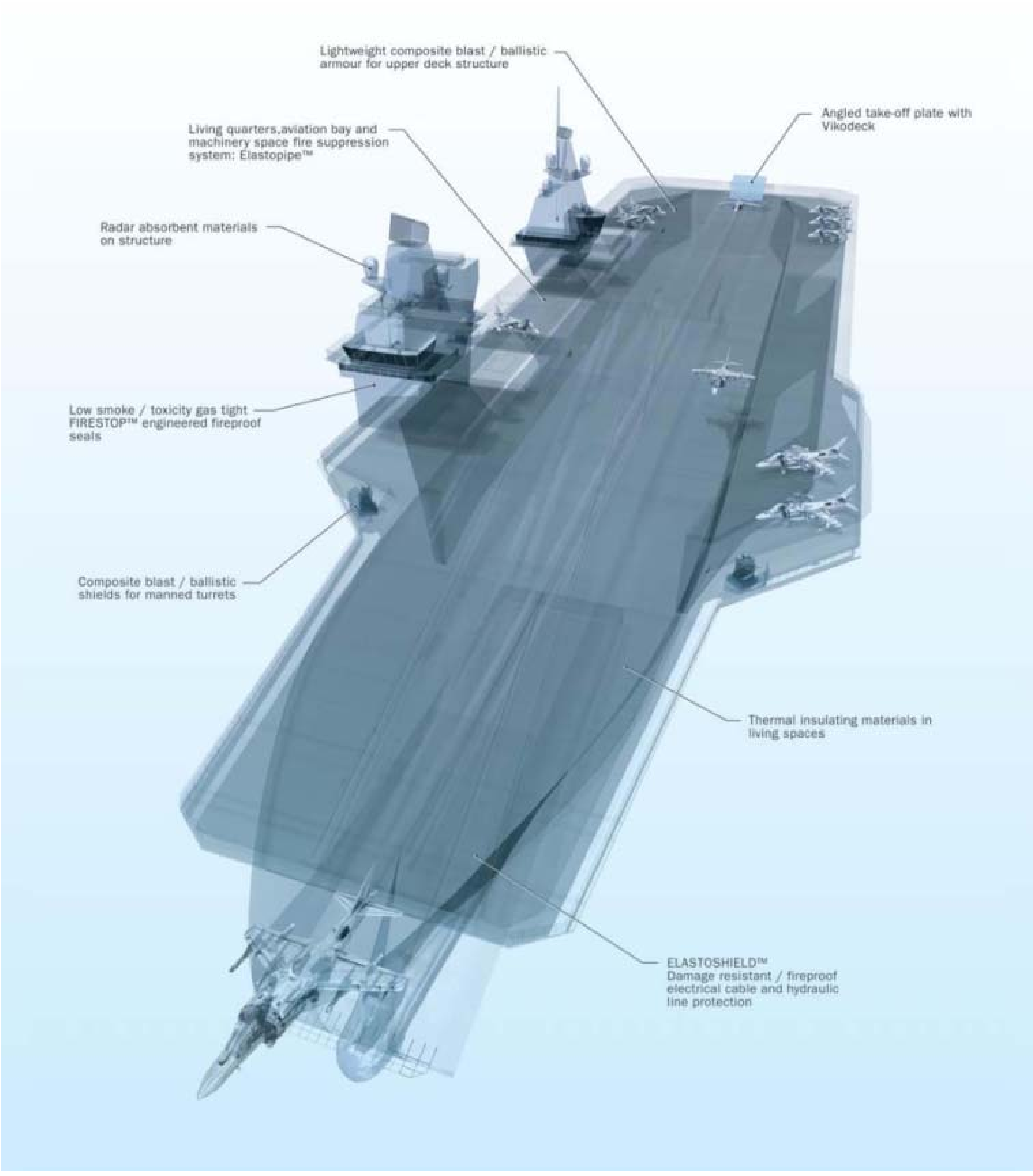
- Silver (Ag) coated microspheres were the first in a series of coated microspheres introduced in 2007. Silver is a very versatile material, as such it has a wide-range of applications including signature management (radar cross-section), electrical conductivity in paints and coatings, and flow tracers. When viewed under side-light stereoscope, silver coated microspheres show very high optical reflectivity (high mirror finish). These silver coated microspheres range in packing factor from 53 – 62%. Silver content is available from 5 – 30 wt%.

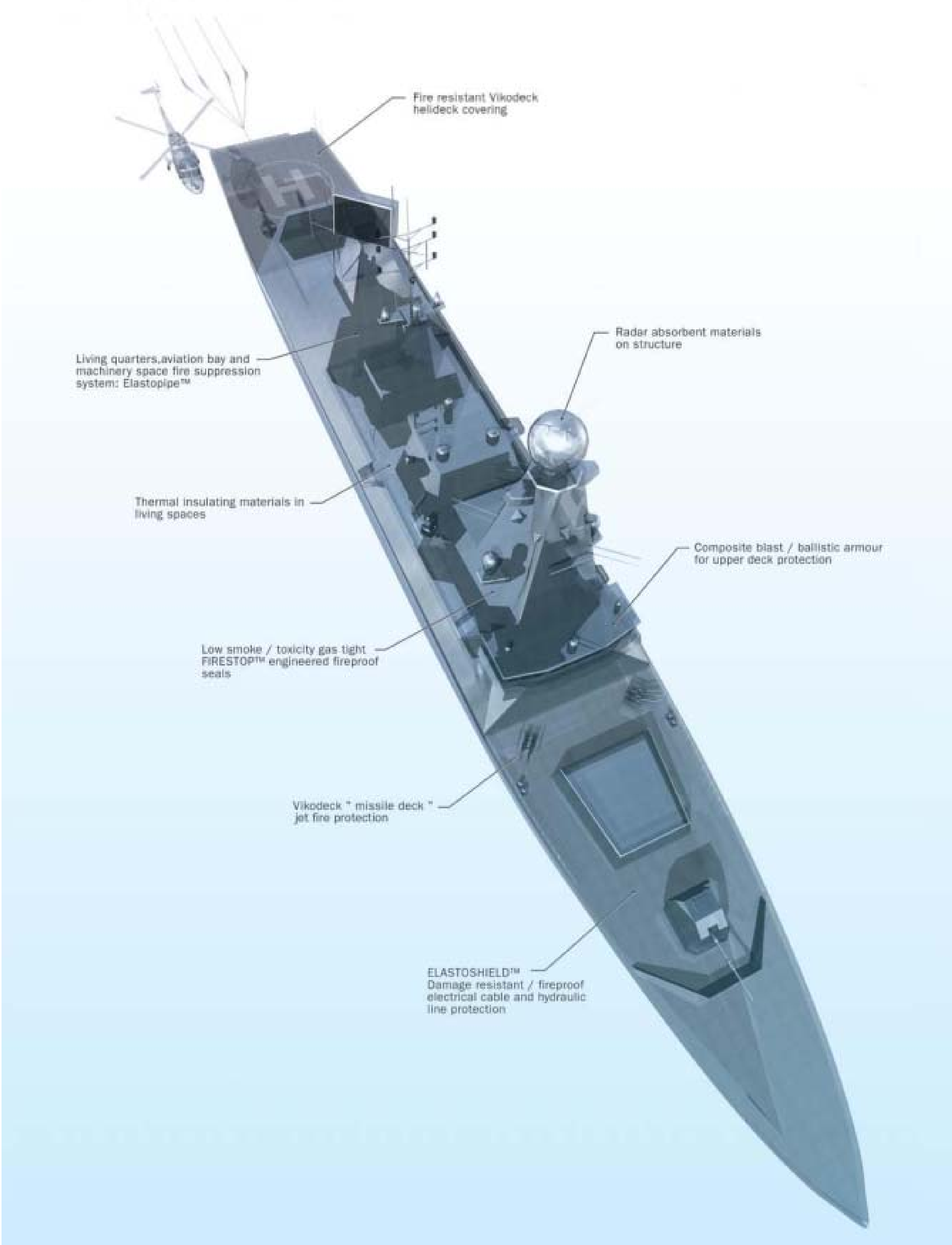
- Titanium dioxide, or titania (TiO_2) is another functional coating material in development. It is commonly used in signature management, photocatalytic and lightweight pigments.

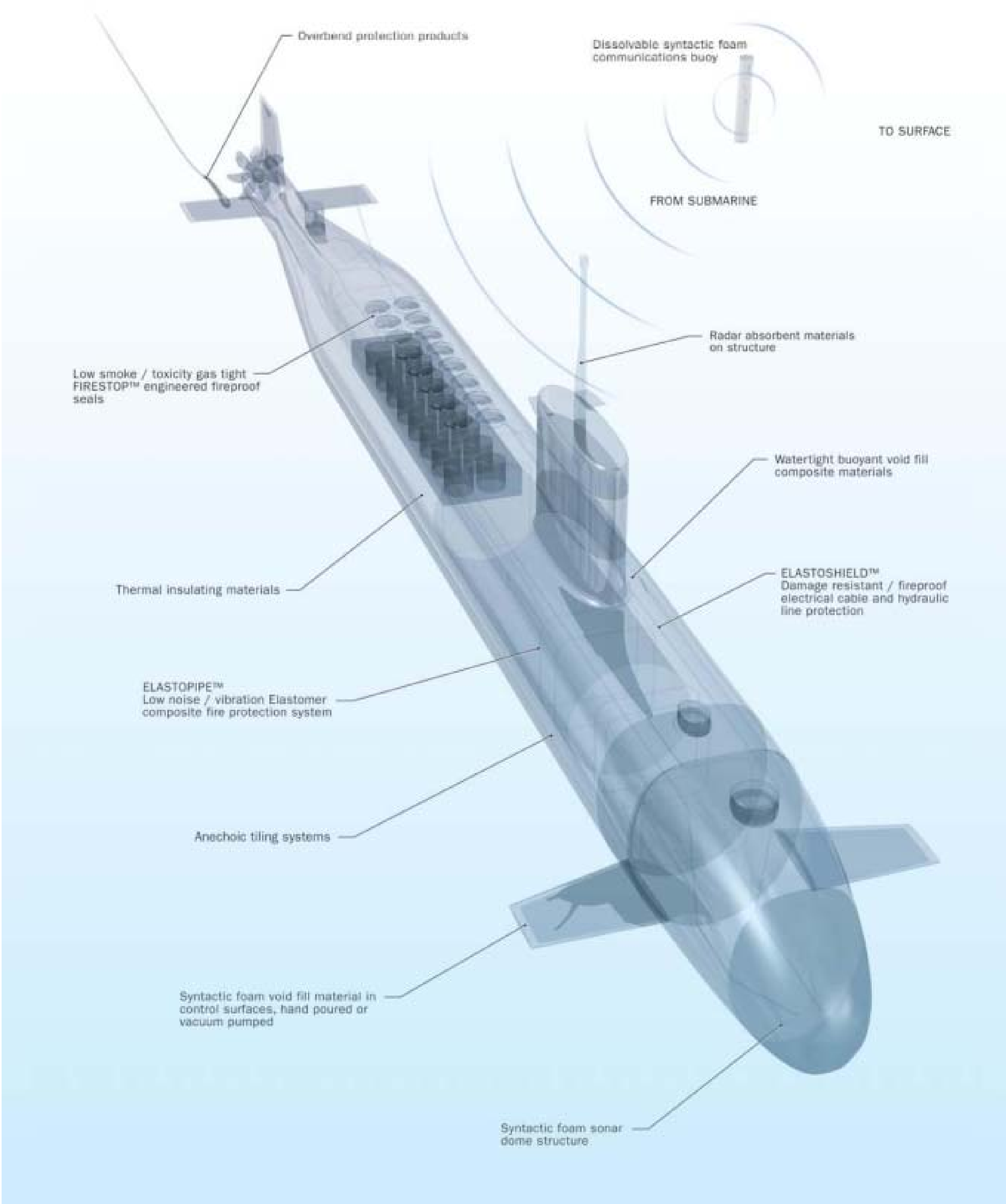
- In addition, rubber composites, whose properties contain the ability to be chemically adjusted, are currently in use in the British Astute Class and French Scorpene Class submarines for noise reduction and hull and sail acoustic dampening.

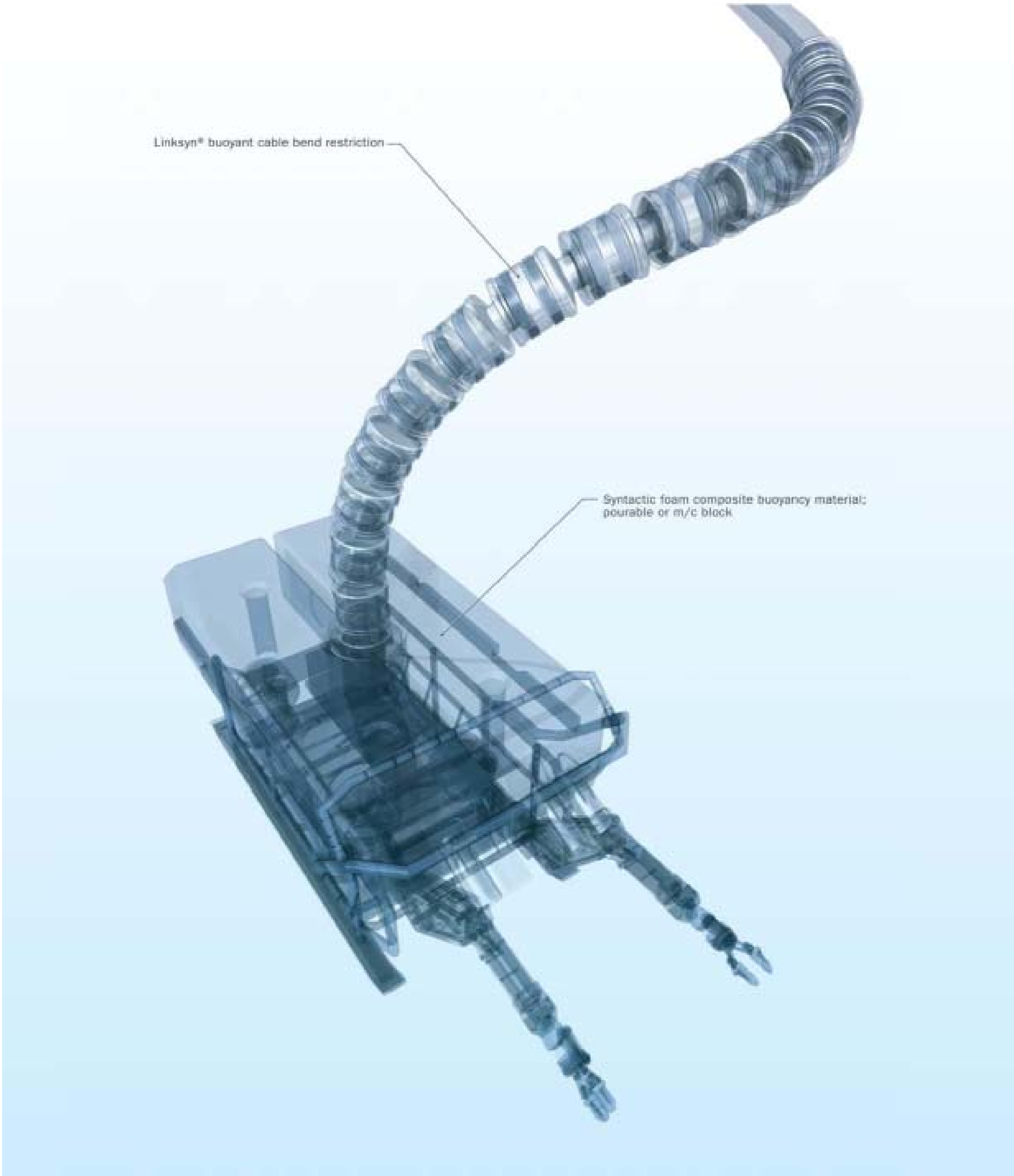
6.0 Summary

As discussed, advancements in high-performance composites play an important role in the protection of maritime vessels. The alternatives of products and materials to protect surface and subsea vessels is unlimited with the continuing development and improvement of new and existing technologies. Trelleborg Offshore Boston, Inc. (previously known as Trelleborg Emerson & Cuming, Inc.) is a recognized world-leader in the design, development, and manufacturing of high-performance microspheres and syntactic foam composites used in products for surface, marine, and deep water subsea applications. Trelleborg Offshore Boston, Inc. is a part of Trelleborg's Global Industrial Group which also specializes in advanced polymer, elastomer, and rubber composite solutions that seal, damp and protect in demanding industrial and defense market environments. As depicted in the following maritime vessel diagrams, these products currently play a major protective role in maritime vessel safety. For more information on Trelleborg Offshore products, please contact Mr. Paul E. Warth at paul.warth@trelleborg.com (+1 774-444-5242) or Mr. Gary M. Gladysz at gary.gladysz@trelleborg.com (+1 774-719-1417) and visit www.trelleborg.com/aem or www.trelleborg.com/emerson.


Lightweight composite blast / ballistic armour for upper deck structure
Angled take-off plate with Vikodeck
Living quarters,aviation bay and machinery space fire suppression system: Elastopipe™
Radar absorbent materials on structure
Low smoke / toxicity gas tight FIRESTOP™ engineered fireproof seals
Composite blast / ballistic shields for manned turrets
Thermal insulating materials in living spaces
ELASTOSHIELD™ Damage resistant / fireproof electrical cable and hydraulic line protection


Fire resistant Vikodeck
helideck covering
Radar absorbent materials
on structure
Living quarters,aviation bay and
machinery space fire suppression
system: Elastopipe™
Thermal insulating materials in
living spaces
Composite blast / ballistic armour
for upper deck protection
Low smoke / toxicity gas tight
FIRESTOP™ engineered fireproof
seals
Vikodeck " missile deck "
jet fire protection
ELASTOSHIELD™
Damage resistant / fireproof
electrical cable and hydraulic
line protection


Overbend protection products
Dissolvable syntactic foam communications buoy
TO SURFACE
FROM SUBMARINE
Low smoke / toxicity gas tight FIRESTOP™ engineered fireproof seals
Radar absorbent materials on structure
Watertight buoyant void fill composite materials
Thermal insulating materials
ELASTOSHIELD™ Damage resistant / fireproof electrical cable and hydraulic line protection
ELASTOPIPE™ Low noise / vibration Elastomer composite fire protection system
Anechoic tiling systems
Syntactic foam void fill material in control surfaces, hand poured or vacuum pumped
Syntactic foam sonar dome structure


Linksyn® buoyant cable bend restriction
Syntactic foam composite buoyancy material;
pourable or m/c block