JMAT

Journal of Advanced and High-Performance Materials

for the building and infrastructure community

An official publication of the National Institute of Building Sciences Advanced Materials Council

Winter 2011

The Next Wave of Innovation

JMAT

Published for:
The National Institute of Building Sciences
Advanced Materials Council
1090 Vermont Avenue, NW, Suite 700
Washington, DC 20005-4950
Phone: (202) 289-7800
Fax: (202) 289-1092
nibs@nibs.org
www.nibs.org

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Matrix Group Publishing Inc.
Return undeliverable copies to:
5190 Neil Road, Suite 430
Reno, NV 89502
Tel: (204) 953-3120
Toll free: (866) 999-1299
Fax: (866) 244-2544
Email: sales@matrixgroupinc.net
Web: www.matrixgroupinc.net

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Editor-in-Chief
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ssavory@matrixgroupinc.net

Editor
Karen Kornelsen

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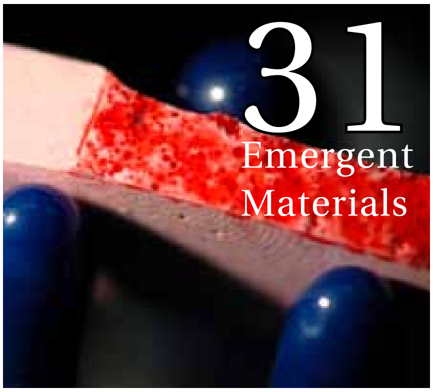

Messages:

On the cover:

The challenge facing researchers will be to develop advanced materials that will protect buildings from natural and manmade disasters while allowing designers to meet aesthetic, energy performance and sustainability goals.

Emergent Materials for Security, Energy and the Environment

Advanced materials can be used for more than structural applications. Security, energy and the environment will all benefit from further research in this area.

By Blaine Brownell, University of Minnesota, School of Architecture

THE TERM "ADVANCED MATERIALS" may be applied to a variety of high-performance materials designed to meet a wide array of functional objectives. The designation is typically associated with materials designed for robust structural or security applications, including products created for military or aerospace uses. While this remains a primary focus, there has also been a growing trend to address energy conservation and environmental remediation objectives in the development of advanced materials.

These additional aims represent the responsible acknowledgment of resource depletion and biodiversity loss, and the recognition of these goals allows for a broader and more holistic view of advanced materials—highlighting promising intersections and synergies between the different objectives of security, energy and the environment. The following themes of performance, response, energy, optimization and remediation may be used to categorize advanced materials that address these objectives and their relationships. The first three themes address material technologies that may be used to reduce security threats to buildings and infrastructure. The last two themes highlight ways to improve existing security-focused materials' environmental performance.

PERFORMANCE

Throughout human history, material innovation has been defined by the persistent testing of limits. Advanced materials focused on performance are stronger, lighter, more durable and more flexible than their conventional counterparts. These materials are notable because they surpass known boundaries, making previous standards obsolete. The ongoing pursuit of thinner and more porous products allows for resource conservation—with implications for both energy and the environment. Although these materials are generally expensive and difficult to obtain, many of these products are being developed for a broad market.

High-performance textiles like Zetix, for example, offer superior protection against explosive events such as car bombs, IEDs, industrial accidents, hurricanes and tornadoes (FIGURE 1). Manufactured from monofilament polyester elastomers wrapped with ultra-high molecular-weight polyethylene (UHMWPE) and woven together with ballistic-Nylon, Zetix textiles may be used for window protection, blast screens and fragmentation liners, as well as body armor enhancements. Zetix addresses a limitation of most blast-defense systems, which are only capable of coping with a single explosive event. The unusual construction of the Zetix fabrics means that they effectively "vent" much of the blast energies through lessening the load on the support structure. As a result, they offer a multiple-blast event solution for natural or human-initiated disasters.

Reinforced concrete also has witnessed gains in mechanical performance and material productivity. These are important accomplishments in light of concrete's high embodied-energy and carbon footprint. CarbonCast, for example, is a precast-concrete technology that uses a carbon-fiber grid for secondary reinforcing or shear transfer. Because carbon fiber reinforcing resists corrosion, CarbonCast precast products require less concrete cover, resulting in added durability, lighter weight and improved sustainability over traditional precast concrete. In addition, the reduction of concrete enables the integration of insulation, which can increase R-values of wall panels. CarbonCast cladding panels can weigh up to 66 percent less than conventional precast panels. This weight reduction permits engineers to reduce substructure or specify smaller cranes for lifting the panels into place.

Traditional concrete has many problems including the lack of durability and sustainability, failure under severe loading and the resulting expenses of repair. University of Michigan has developed a new type of fiber-reinforced concrete that looks like regular concrete, but is 500 times more resistant to cracking and 40 percent lighter in weight. As a result, the so-called Engineered Cement Composite (ECC) has been nicknamed "bendable concrete," and it defies common expectations related to conventional mechanical behavior in concrete.

This performance is made possible by tiny fibers accounting for two percent of volume, in addition to the use of smaller aggregate. Because of its long life, ECC is expected to cost less over a structure's lifecycle. According to lead researcher Victor Li, "the broad field of micromechanics has tried to understand how composite materials behave. We went one step further and used the understanding as a material design approach in the development of ECC." (Victor Li's article on ECC is found on page 16 of this magazine.)

RESPONSE

Responsive material systems are endowed with the ability to undergo a physical metamorphosis based on environmental stimuli—such as architectural surfaces that flex and "breathe" in the presence of polluted air. These surfaces may also possess the ability to self-heal, especially in situations that anticipate high physical stresses or require ultra lightweight components. The collective promise of such technologies is that our constructed environment will become smarter, at least in the sense that it will actively alert us to a variety of measurements that we do not currently monitor well. Building surfaces will also become more interactive, expanding interface design beyond the product scale to architectural and urban scales.

The self-repairing capability of new advanced materials not only suggests reduced maintenance and replacement, but also increased durability and longevity. Moreover, self-repairing materials can be lighter than their conventional counterparts, thus reducing embodied energy and greenhouse gas production.

One target application for such materials is aircraft and marine vessels that are significant contributors to global warming. Airplane vapor trails release carbon dioxide (CO_2) as well as other pollutants, and ships expend large amounts of energy as they carry most of the world's cargo. Many of the polymer composites typically used for such modes of transporation are over-engineered to avoid structural failure, a fact that reduces the advantage of such light-weight constructions. Natural Process Design's Self-Repairing Polymer Composites are made from graphite oil, resulting in lighter material. In a recent project for the United States Air Force, the composite portion of the airplane fuselage was made to be 30 percent lighter than conventional materials based on the use of Self-Repairing Polymers. If this material can be successfully implemented in traveling craft, a significant reduction in CO_2 contributions will be possible. A subsequent phase of research could address building panels made of self-repairing composites, which would similarly reduce the building's CO_2 footprint while ensuring a more durable building shell.

Self-healing plastics offer benefits for a broad range of polymer-based applications. Structural polymers are susceptible to damage such as cracks that form deep within the structure where detection is difficult and repair is almost impossible. Once cracks have formed within polymeric materials, the integrity of the structure is significantly compromised. Inspired by biological systems in which damage triggers a healing response, Scott White, from the Beckman Institute at the University of Illinois, developed a structural polymeric material with the ability to autonomically heal cracks (FIGURE 2). The incorporation of a microencapsulated healing agent and a catalytic chemical trigger within an epoxy matrix accomplishes this healing process. An approaching crack ruptures embedded microcapsules, releasing healing agent into the crack plane through capillary action. Polymerization is triggered by contact with the embedded catalyst, bonding the crack faces. Although this material is still under development in laboratory conditions, its eventual application in the form of self-repairing polymeric panels for architectural cladding is a compelling vision.

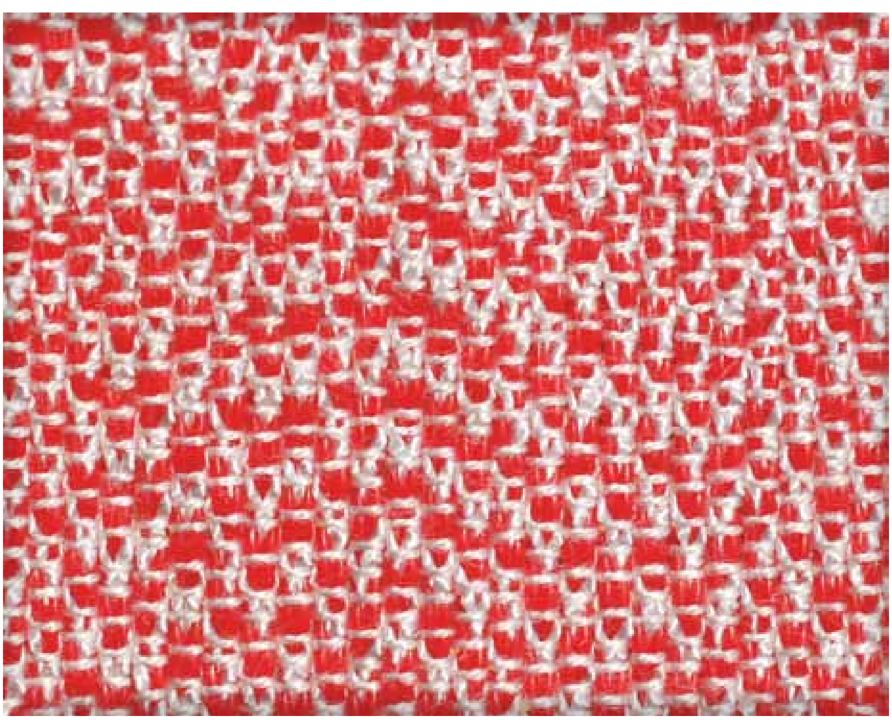

Figure 1. Zetix, which is made by Auxetix Ltd., is an example of a high-performance textile.

Shape-memory materials allow for the development of objects and surfaces that can actively respond to shifting environmental conditions. Developed by Soo-in Yang and David Benjamin, Kinetic Glass is a responsive surface that reacts to environmental conditions and changes shape via curling or opening and closing gills. The surface is thin, lightweight and transparent with no motors or mechanical parts. The system may be used with a variety of switches or sensors and controlled via microprocessors and complex algorithms, allowing one to perform a variety of applications. In one case, the system can detect unhealthy levels of CO_2 in interior spaces. Kinetic Glass "breathes" when high levels are encountered, enhancing air movement and signaling the problem to building occupants.

ENERGY

With so much attention being paid to greenhouse gas-related emissions and imminent fuel supply limits, energy has become a pressing topic of concern. Predictions of global peak oil inspire both the search for alternative fuel sources as well as the conservation of energy in all of its uses. Energy itself is now a major security issue and bio-based fuel sources such as ethanol, biodiesel and biomass have begun to replace a small percentage of petroleum-derived sources.

Meanwhile, renewable energy industries such as solar and wind power are propelled by increased market support and government subsidies. Predictions of future energy delivery models indicate a profound transformation from central, long distance-based service models to highly dispersed, community-based frameworks. Such models will require buildings to be more active participants in energy production, and new technologies promise to add energy-harnessing functionality to architectural surfaces—thus diversifying, stabilizing and increasing the security of a building's "energy portfolio."

Building-integrated renewable energy technologies supply much-needed energy without requiring an investment in additional building surfaces. Made from single crystalline silicon, Sphelar has the durability and reliability of conventional silicon-based photovoltaics (PV), yet the micro-spherical shape of cells makes it lightweight and extremely pliable. Manufactured by Kyosemi, Sphelar has a high photoelectric conversion efficiency, omnidirectionality, module transparency, and configurability in series or parallel circuits. Sphelar modules can be easily integrated with curtain walls, windows, roofing materials and canopies. The technology is also ideal for ubiquitous computing and electronics, because the micro spherical particles are smaller and more effective than conventional photovoltaics.

Wind energy-harnessing capabilities may also be integrated within building surfaces. Grow is a hybrid energy-delivery device inspired by ivy. Grow's "leaves" are flexible organic photovoltaic panels that capture solar energy and convert it into electricity. Each leaf is attached by way of a robust piezoelectric generator at the leaf's stem. When the leaves flutter in the wind, the stems flex to produce electricity while also creating a provocative kinetic experience. Grow's modular system is designed to be attached to any building surface that receives sunlight and wind.

In addition to harnessing new forms of power, conservation is also a powerful tool for energy savings and security. Architectural core daylighting has been identified as a beneficial form of conservation, maximizing the delivery of sunlight to interior spaces during daytime hours. Parans Daylight AB has developed a sunlight transmission system for buildings that consists of light-collecting panels, light-transporting cables and light-emitting luminaires. SkyPort collecting panels contain two layers of optics and are easily mounted to any roof structure. Captured sunlight is transported via bundled fiberoptic cables. The luminaires emit this sunlight as a mixture of parallel light beams and ambient light. The Parans system allows building occupants to monitor the weather even in the absence of windows or skylights, thus reestablishing a connection with the outside environment.

OPTIMIZATION

Energy considerations are obviously not limited to fuel and building operation concerns; the power required during material manufacture and processing is also under scrutiny. Low-embodied energy and zero-energy processes are slowly beginning to replace conventional methods requiring large amounts of energy. The most interesting of these involve biochemical and exothermic procedures whereby materials self-assemble according to predetermined chemical processes. Repurposing waste materials via low energy preparations is another means for reducing energy while limiting the waste stream burden.

Strong Enviroboard (SEB) is a multifunctional wallboard and floorboard composed of magnesium oxide, aerated rock and recycled cellulose from furniture manufacturing. When layers of ingredients are poured into a mold, the composition bonds exothermically at room temperature, thus requiring no added energy. SEB is made completely of nontoxic materials and cannot grow mold because it is not affected by water. SEB has virtually no thermal expansion and is immune to freeze-thaw cycles. The combination of SEB with liquid mineral-system coatings offers a 100 percent breathable, fire proof, mold proof and waterproof interior or exterior wall without primer.

The reincorporation of waste materials into new products is seen as both a diversion of material from the waste stream as well as a savings in the embodied energy that would be invested in new materials. Fly ash, for example, is the waste product of burning coal that is largely comprised of carbon and contains many heavy metals. Fly ash is often combined with cement as an additive, but only up to a certain

Figure 2. An example of a self-healing polymer, created at the Beckman Institute, University of Illinois.

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percentage of concrete may be fly ash. Dr. Carolyn Dry has developed a method of fabricating building panels and insulation out of nearly 100 percent fly ash in order to sequester these heavy metals so that they do not leach out and pollute the environment. Essentially cooking the ash into a solid, Dry utilizes a flux that allows processing at lower temperatures—thus using less energy and chemicals. Components such as building panels, bricks and insulation may be produced without the need for binders such as cement.

The integration of high-performing chemical additives can enhance the multifunctional capabilities of building materials. Hycrete's Element is an environmentally friendly admixture that integrally waterproofs concrete used in commercial construction. Element eliminates the need for external membranes typically used to waterproof concrete, thereby making the concrete more-easily recyclable following demolition. This approach can eliminate thousands of pounds of volatile organic compounds (VOCs), CO2 and non-renewable content. Additionally, the admixture enhances structural durability by protecting against corrosion of steel rebar. In eliminating the need for a manually applied membrane, Hycrete Element can also save time in construction schedules. With typical membrane applications, contractors must often wait for the concrete to dry before a waterproofing sub-contractor can apply the membrane—even after rainfall and re-wetting. In contrast, Hycrete Element is dosed during concrete mixing and is not subject to weather delays.

REMEDIATION

An important sustainable design concern is indoor environmental quality, considering the high percentage of time people spend indoors. Off-gassing materials such as carpet and adhesives have been identified as contributors of harmful volatile organic compounds (VOC) to indoor air, and the reduction of VOCs has been a primary goal in environmental building programs. Further thinking about natural processes has resulted in products designed to undo the damage caused by polluting industrial practices. These so-called remediating materials photocatalyze airborne pollution and employ passive self-cleaning technologies to do more good than harm, rather than simply minimizing harm.

TX Active is a photocatalytic cement that decreases the harmful substances present in the air and preserves the finished surface of buildings. Incorporating titanium dioxide as its active ingredient, the cement reduces concentrations of airborne pollutants, such as nitrogen oxides and volatile organic compounds. The cement is specifically designed for high-profile architectural work and complies with European Standard EN 197/1 requirements. Concrete made with the cement has the same physical and mechanical properties as traditional concrete, with added self-cleaning properties.

Clemson-based Fieldoffice has developed a new wall system utilizing this cement, which the manufacturer predicts will reduce air pollution in urban areas by 50 percent when covering just 15 percent of urban surfaces. One recommended application is the replacement of existing highway barriers, which are wall systems designed to reduce noise and light pollution for adjacent neighborhoods. The new Superabsorber system not only mitigates these forms of pollution but also the more significant air pollution generated by vehicle emissions. The inclusion of this surface application on future concrete-barrier systems will produce a significant increase in photocatalyzation of air pollution in urban areas.

The study of biological behavior can reveal simple methods for performance enhancement in advanced materials. A team of scientists under Dr. Wilhelm Barthlott at the University of Bonn discovered the so-called "lotus effect" by learning from the lotus plant. The leaves of the lotus plant are immaculately clean after every rainfall because dirt and microorganisms are unable to obtain a hold on the microstructured, non-wettable surfaces of the leaves. As a result, rain simply washes dirt and other particles away. The Lotusan facade paint developed by the researchers is the first successful practical application of the lotus effect, and about four million square meters of facade surfacing have since been coated with Lotusan paint, which has reduced the typical energy, time and material expenditures associated with maintaining building exteriors.

CONCLUSION

As we monitor the frontiers of technological development, emergent materials offer promising capabilities for advanced and high-performance building applications. Given the pressing challenges we face on a number of fronts, it makes sense that we give priority to those materials that address multiple areas—especially opportunities for enhancing the most critical matters of security, energy and the environment. ■

Blaine Brownell is an architect and former Fulbright scholar with a research focus on emergent materials. He authored the Transmaterial series with Princeton Architectural Press, and is currently an assistant professor at the University of Minnesota - School of Architecture.