FINAL REPORT

STATE-OF-THE-ART SURVEY OF ADVANCED MATERIALS AND THEIR POTENTIAL APPLICATION IN HIGHWAY INFRASTRUCTURE

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ABSTRACT

In the last two decades, advances in science and technology have led to the creation of materials with properties so unique that they offer applications previously unheard of. This study attempted to identify such materials that might have applications in highway infrastructure that could lead to savings for the Virginia Department of Transportation (VDOT) and other transportation agencies. This search, which may have been the first among state transportation agencies, identified 47 materials in various stages of development. Not surprisingly, many of the materials are considered either “blue sky” materials or materials that do not yet have any practical applications in transportation. However, several offer reasonable potential applications in transportation.

Ratings of the 47 materials by VDOT’s Materials Division and Structure & Bridge Division identified 7 materials with an average rating greater than 2.5 (on a scale of 1 through 5) in terms of their potential for VDOT:

1. biosensor for lead
2. elastomeric coating for blast protection
3. SAFER (Steel and Foam Energy Reduction) barrier
4. urethane coating for cathodic protection
5. smart fibers
6. smart paints
7. smart polymeric coatings.

Ratings by the two divisions identified 7 other materials with either an average rating of 2.5 or a rating of 4 or more by either division:

1. electrically conductive concrete
2. microencapsulated fire-extinguishing agent
3. piezoelectric paint
4. self-healing coating
5. self-healing concrete
6. chemiluminescent lightsticks
7. soil-decontaminating nanoparticles.

An additional material with potential, mussels’ glue, was identified after the aforementioned ratings were made.

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INTRODUCTION

The nation's highway infrastructure is built using a variety of materials, the quantity of which is staggering. Since these materials deteriorate and fail with time, material replacement represents a major portion of the cost to maintain or rebuild these assets. For this reason, the development and use of durable and cost-effective construction materials and systems are important, as civil infrastructure constitutes a major portion of the nation's wealth. Therefore, it behooves public transportation agencies to be watchful for the development of new materials that have qualities superior to those of current materials to allow for designing a future infrastructure that will exceed present performance and functional life—at lower long-term cost.

In the last two decades, advances in science and technology have led to the creation of new materials with properties so new and unique that they offer potential applications previously unheard of. In other cases, although the materials have been used in other fields, they are "new" to the transportation field. This report uses the word "new" in the latter sense. A good example of new materials that have been the subject of much recent government-funded research is composite materials, mainly fiber-reinforced plastics.[1] Because of their attractive characteristics, which include high strength-to-weight ratios, impact resistance, and corrosion resistance, they have already been applied in construction.[2] Other noteworthy examples are the several new reinforcing bars introduced in the last 3 to 4 years. These bars have already been shown to have a higher corrosion resistance than the bars currently used, and they show promise of yielding sizeable savings to transportation agencies in many parts of the nation.[3] The potential savings to the Virginia Department of Transportation (VDOT) and other transportation agencies could be significant if such new materials are able to outperform and, thereby, replace materials currently being used; to offer solution to long-standing problems; or to have entirely new beneficial applications in the operation and maintenance of highway infrastructure.

PURPOSE AND SCOPE

The purpose of this study was to identify and assess new materials that could have beneficial and cost-saving applications in transportation and to determine if any developmental work needed to be undertaken to bring the applications of such materials to fruition. To ensure the search for new materials was thorough, a wide scope was used to identify and create a list of candidate materials. The only limitations were that a material could not be a complex device, such as a micro-electromechanical system, and that in the future the material could benefit VDOT.

METHODOLOGY

To achieve the study objective, three tasks were performed.

1. *Identify the advanced materials.* An extensive survey of various information sources, including literature and websites of various research organizations (both national laboratories and academics) and commercial companies in the United States and other countries, of relevant reports and publications was conducted.

2. *Determine the present applications and associated cost of the identified materials.* The research organizations and/or commercial entities that were developing the different advanced materials were identified. In addition, attempts were made to establish how these materials were already being applied or their projected applications and to determine the unit cost for each application by contacting the respective developing organizations and/or companies directly or through the Internet. If cost data were not available, contact information for the materials is provided in the Appendix.

3. *Identify applications for advanced materials that would benefit VDOT.* The information collected for the identified materials was sent separately to VDOT's State Materials Engineer and VDOT's State Structure and Bridge Engineer who were asked to rate the potential of the materials for applications in VDOT. Each was asked to have the appropriate member of their staff review and rank the list of candidate materials. They were asked to rate the materials on a scale of 0 to 5 ranging from no potential, to very low, to low, to high, to very high.

RESULTS AND DISCUSSION

Advanced Materials Identified

Approximately 47 new materials were identified and are listed in Table 1. The Appendix provides details on their characteristics, potential uses, stage of development, etc.

Although they have been in existence for some time, it is questionable whether the chemiluminescent lightsticks and the piezoelectric materials should still be considered new. However, these two materials are still finding innovative applications in the transportation field and, therefore, were included in this study. Because of their unique behaviors, some of the identified materials are dubbed by some as "smart materials" because they can be engineered to

Table 1. Potentials of Identified Advanced Materials for Future Applications in VDOT

Material	Rating of Potential Application		
	Materials	Structure & Bridge	Average
Biosensor for Lead	3	5	4.0
Elastomeric Coating for Blast Protection	3	4	3.5
SAFER (Steel and Foam Energy Reduction) Barrier	4	3	3.5
Urethane Coating for Cathodic Protection	2	5	3.5
Smart Fibers	3	3	3.0
Smart Paints	3	3	3.0
Smart Polymeric Coatings	3	3	3.0
Electrically-Conductive Concrete	2	3	2.5
Microencapsulated Fire-Extinguishing Agent	3	2	2.5
Piezoelectric Paint	4	1	2.5
Self-Healing Coating	3	2	2.5
Self-Healing Concrete	2	3	2.5
Chemiluminescent Lightsticks	4	0	2.0
Improved Photovoltaic Cells	3	1	2.0
Magnetorheological Material	1	3	2.0
Multiwall Nanotubes	0	4	2.0
Soil-Decontaminating Polymeric Nanoparticles	4	0	2.0
Thermal-Stress-Mitigation Microcapsules for Concrete	3	1	2.0
Carbon Nanotubes	3	0	1.5
Contracting Textiles	3	0	1.5
Electronic Textiles	3	0	1.5
Electrorheological Material	1	2	1.5
Light Guide	3	0	1.5
Photoluminescent Materials	3	0	1.5
Polymer Gels	3	0	1.5
Self-Healing Composite	2	1	1.5
Smart Bricks	2	1	1.5
Thermal Shape-Memory Alloy	1	2	1.5
Aerogels	1	1	1.0
ALON (Polycrystalline Aluminum Oxynitride)	2	0	1.0
Gecko Tape	2	0	1.0
Integrated Wire	1	1	1.0
Pressure-Sensitive Paints	1	1	1.0
Ferromagnetic Shape-Memory Alloy	1	0	0.5
Insulating Paint Additives	1	0	0.5
Low-Voltage Polymer Heater	1	0	0.5
Magnetocaloric Materials	1	0	0.5
Magnetostrictive Elastomers	1	0	0.5
Magnestrictive Metal	1	0	0.5
Nano-Velcro	1	0	0.5
Piezoelectric Materials	1	0	0.5
Plastic Solar Energy Cells	1	0	0.5
Shape-Memory Polymer	1	0	0.5
Smart Dusts	1	0	0.5
Transparent Transistor	1	0	0.5
Biodegradable Plastics	0	0	0.0
Metallic Carbon Nanotubes	0	0	0.0

produce a unique beneficial response when changes occur in its surrounding environment—a characteristic not found in many materials.[4] Examples of current applications of smart materials include smart spoons made of temperature-responsive polymer that changes color with temperature, shrink-wrap films, self-expanding stents, and flexible cellular antennas, all of which have clearly demonstrated the beneficial nature of the novel materials from which these products are made.[5-9] Another material that has already found application in transportation is piezoelectric material as sensors for weigh-in-motion and structural monitoring.[5,9]

Five of these materials are given names (such as smart bricks, smart dusts, etc.) that describe them, without ambiguity, as smart, although it is debatable whether they really are, especially the smart bricks. As the descriptions of their characteristics in the Appendix would show, these materials have been modified, each in a particular manner, to simply exhibit a unique response to particular stimuli. For example, the smart bricks are simply bricks incorporated with sensors, microprocessors, transmitters, etc., to measure and transmit the temperature, vibration, and movements of buildings in which they are embedded. If the surrounding brick material were taken away, what would be left would be basically a sensor system, which, conceptually, is similar to the systems (of various degrees of sophistication) that have been developed recently at the University of Virginia (in collaboration with the Virginia Transportation Research Council [VTRC] and the Federal Highway Administration [FHWA]) and Stanford Research Institute.[33-35] The smart fibers are simply optical fibers whose surfaces are appropriately modified at chosen intervals to change their light transmission characteristics at those spots, so that those spots are basically tiny sensors for detecting the presence of undesirable chemicals, moisture, strain, etc., in their surroundings. Truly smart materials must have not only the intrinsic or extrinsic abilities to respond to stimuli and environmental changes, but also the abilities to activate compensating adjustments according to these changes. None of the five so-called smart materials really complies with the second requirement. However, this is not to say that they do not offer unique applications. The smart bricks, smart fibers, and smart paints can be further developed for applications in monitoring the long-term health or integrity of civil structures such as bridges.

Several of these advanced materials can be used as sensors and actuators that when combined with microprocessors and embedded in appropriate materials will create smart structures that can sense undesirable changes in their environment, process these data, and automatically prompt adjustments or countermeasures in a controlled manner, as do living systems in nature. Such smart structures (airplanes, buildings, and bridges) can adjust to undesirable conditions (such as severe winds, earthquakes, etc.) and maintain the required safety level. Once the sensors detect unusual behaviors in the structure and relay their responses to the microprocessors, the microprocessors analyze these responses and use control theory to command the actuators to alter the characteristics (such as stiffness or damping) and the response (such as strain or shape) of the structure in a controlled manner. An example of this type of application that is mundane in nature is a “smart” tennis racket, which integrates piezoelectric composites with microchips. With the piezoelectric material, the racket transforms the mechanical energy from the ball impact into electrical energy that is relayed to the microchip. The latter, which is integrated in the racket handle, analyzes the electrical signals and immediately re-orients the direction of the force, stiffens the racket for ultimate power, and eliminates vibrations.

Several of these new materials (such as the carbon, the metallic carbon, and the multiwall nanotubes) belong in the new nanotechnology—technologies associated with materials and processes at the nanometer, i.e., 10^{-9} m, scale. These materials have properties that are unusual, e.g., light yet very strong; have excellent electrical conductivity but very low friction; interlock strongly, etc. However, by nature of the processes by which these materials are made, they are now extremely expensive.

Interestingly, approximately 46, 36, 16, and 2 percent of all these new materials are the results of developmental or research efforts undertaken in academia, industry, national laboratories, and independent research organizations, respectively. Since practically all research efforts in the materials science in academia are funded by government research grants, taken together with the achievements in the national laboratories, it is very likely that the government (mostly, the United States) is responsible for 62 percent of the new materials, perhaps more, because some of these industrial companies are spin-offs from academia. This figure is not very different from a recent report that 57 percent of the organizations involved in the development of materials the writer categorized as smart were universities and national laboratories.[36]

Not surprisingly, many of the materials are still in the laboratory stage and not yet available commercially. However, several of these, as is discussed later, would not require much further development to bring them from laboratory to trials in the real world.

As the reader will notice, information on the costs of many of the materials was extremely difficult to obtain or estimate because they are new or, as in many cases; are not commercially available yet; or are still being developed or studied.

Many of the new materials can be categorized into the following seven groups:[11,12]

1. *Interactive thin layers.* These materials, which are much smaller in dimension along one axis when compared with the other two axes, interact with their environment and have responses that can be beneficial in particular applications. Some of their potential applications include pH sensitive sensors and paints, liquid crystal displays (electrochromic materials), water shrinkable film, and pressure indicating film.[13-15]

2. *Shape memory materials*. The uniqueness of shape memory alloys (SMA) and shape memory polymers (SMP) is that they can be trained to retain memory of two different shapes, changing from a temporary shape to a predefined shape when exposed to change in temperature.[6,12] Another advantageous trait of SMA is the ability to withstand a high degree of elastic strain when exposed to the appropriate temperature. Therefore, these materials are also classified as thermo-responsive materials. Best known among these are the SMAs, which include the widely known Nitinol (a Ni-Ti alloy) and the lesser known Au-Cd, Ag-Cd, Cu-Sn, Cu-Al-Ni, and Cu-Zn-Al alloys. The SMPs, however, have two advantages when compared with their metal counterparts: they are more deformable and generally less expensive.[16] Examples applications of these are vital parts in airplane and helicopters, couplings, fasteners, and “intelligent” fabrics that allow heat to pass through as the temperature rises.[6,7] One highly successful application is as orthodontic arch wires, which, in contrast to

stainless steel wires, will gradually return to their shape, thereby exerting a small and constant force on the misaligned teeth.

3. *Rheological materials.* These materials are also known as field-responsive fluids, which are either magneto- or electro-rheological fluids, which can change in viscosity or state (i.e., from liquid to solid) reversibly when subjected to a magnetic or electric field, respectively.[17] Because the viscosity can be varied, these fluids provide a practical solution for active vibration control. This has led to the use of these materials as shock and vibration absorbers. Potential applications include uses in blast resistance and seismic designs, exercise equipments, etc.[17-21]

4. *Self-healing materials.* Each of these materials relies on previous knowledge of the damage mechanisms to which it is susceptible and it contains an encapsulated healing agent. The agent is released when the damage occurs, and the injury "heals," thus increasing the materials' functional life. Self-healing studies have been performed on polymers, composites, and coatings.[22-28]

5. *Magnetostrictive materials.* When subjected to a magnetic field, the size of these ferromagnetic materials will change slightly. This characteristic can be used to create actuators or to serve as the basis of a technique for nondestructive evaluation to evaluate the strain in steel pipes without requiring a couplant.[29-31]

6. *Piezoelectric materials.* When a piezoelectric material is subjected to deformation, it gives off a small but measurable amount of electricity. Conversely, when a small amount of electricity is passed through the material, the material increases in size (up to a 4 percent change in volume). Because of this property, these materials, in films, are already widely used as sensors, such as ultrasonic transducers, strain gages, and microphones.[9,32] In the form of fibers, the materials have potential applications in health monitoring of bridges, buildings, and utility poles.

7. *Smart gels.* These gels are engineered to shrink or swell by a factor of 1,000 and are designed to absorb or release fluids in response to the presence of any chemical or physical stimuli. These gels are being applied in such areas as agriculture, food, drug delivery, cosmetics, and prostheses.

Rated Potentials for Application of Advanced Materials Identified

The results of the ratings for potential by VDOT's Materials and Structure & Bridge Divisions are presented in Table 1, where the 47 materials are listed in decreasing order of their average rated potentials.

These results revealed some interesting points. First, when the ratings by personnel in the Materials Division were averaged, the average would be higher than the averaged rating corresponding to the ratings by personnel in the Structure & Bridge Division. The difference is more a reflection of the differences in the responsibilities of the two divisions than anything else. By the nature of their respective responsibilities, the interests of the personnel in the Materials

Division are broader than those in the Structure & Bridge Division, who would be more focused on materials related to various highway structures and bridges. Two specific cases are the large differences in their respective ratings for the soil-decontaminating polymer nanoparticles, which have potential applications in remediation of soil contaminated by hazardous chemicals, and chemiluminescent lightsticks, which have potential safety applications in construction work zones. Both received a rating of 4 by the Materials Division and 0 from the Structure & Bridge Division.

On the other hand, two materials received the highest rating of 5 from the Structure & Bridge Division and lower ratings (a 3 and a 2) from the Materials Division. It is likely that this reflects the urgency with which the former division views the problem areas in which these two materials (the biosensor for lead and the urethane coating for cathodic protection) have potential applications. The multiwall nanotubes received a rating of 4 from the Structure & Bridge Division, for its potential application as a better bearing lubricant to replace polytetrafluoroethylene (PTFE, trademarked as Teflon®), and a 0 from the Materials Division. Overall, 11 materials received ratings from the two divisions that differed by at least 3.

The rheological and the shape-memory materials, which have applications in countermeasure systems for buildings and bridges in earthquake-prone areas were not rated high for applications in Virginia, which is not earthquake prone. However, as the Structure & Bridge Division commented in their rating of these materials, this may be different under the new guidelines being prepared by the American Association of State Highway and Transportation Officials.

Seven Top-Rated Advanced Materials

Based on the average of the scores given by the Materials and the Structure and Bridge Divisions, seven materials received ratings greater than 2.5 in terms of their potential application for VDOT:

1. biosensor for lead
2. elastomeric coating for blast protection
3. SAFER (Steel and Foam Energy Reduction) barrier
4. urethane coating for cathodic protection
5. smart fibers
6. smart paints
7. smart polymeric coatings.

Biosensor for Lead

As Table 1 shows, the biosensor for lead received the highest average rating: 4. This material is being developed by a team at the University of Illinois at Urbana-Champaign to meet the need for a comparatively sensitive and yet simple and inexpensive method for detecting lead. The prefix *bio* denotes the biological nature of the sensor, which is a combination of nanoparticles (13 billionths of a meter in diameter) of gold and a solution of a lead-specific synthetic DNA. The synthetic DNA causes the nanoparticles of gold to aggregate in clusters that give off a blue color. When this comes in contact with lead, the DNA breaks apart, which in turn causes the aggregation of gold nanoparticles to fail and generate a color shift to red. In addition, the intensity of the red color is directly proportional to the amount of lead present, thereby providing the basis for a quantitative measure of lead.

A prototype test method based on a solution of this biosensor was able to detect lead in paint as low as 20 parts per billion, far below the safety limits used by the U.S. Environmental Protection Agency. Although already relative simpler than the methods used currently (such as anodic stripping voltammetry, electrothermal vaporization atomic adsorption, and x-ray fluorescence spectrometry), the research team hopes to develop this into a method using paper strips with the biosensor deposited on their surface so that the strips can be used to detect lead in a manner similar to the use of litmus or pH papers.

As it is, the prototype test method is already useful for testing old paints or coatings on structural steel for the presence of lead. Therefore, it is one new material that can be assessed by field trials for its cost-effectiveness.

Elastomeric Coating for Blast Protection

Developed by the U.S. Air Force Research Laboratory, this elastomeric coating is formulated for spray application on walls of structures to improve their blast resistance. For extra strength, high-strength fibers can be added to the formulation. An obvious application of this material is in blast protection of major vehicular tunnels in Virginia, many of which are under navigable waters, as these can be considered potential targets of attacks by terrorists. VDOT's Structure & Bridge Division indicated that the Association of American State Highway and Transportation Officials (AASHTO) is developing blast design and protection guidelines for tunnels. Although this material may not prevent damage caused by bomb blasts in such tunnels, it likely could minimize the effects of such blasts and, thereby, facilitate speedy resumption of traffic operation.

SAFER (Steel and Foam Energy Reduction) Barrier

An ideal safety barrier must be able to absorb or attenuate the very high energy resulting from vehicular impact, safely redirect the direction of an errant vehicle along the line of the barrier, and prevent crossover of the vehicle into the path of oncoming vehicles. The desirable result is to provide protection to the driver and passengers inside the errant vehicle with minimum damage to the roadway and interruption to traffic. The safety barriers being used on highways today are commonly made of steel, concrete and steel, or molded plastic barrels filled with an energy-absorbing material such as sand or water. Aside from their shortcomings, the use of these barriers has not been entirely successful in accidents involving tall vehicles carrying heavy loads.

Recently, new designs that use sandwich panels made with a facing material (such as aluminum, fiber-reinforced plastic, or wood) and a core made of either honeycombed materials (such as aluminum, Nomex, Aramid, etc.) or foam materials (such as polyurethane, polyvinylchloride, etc.) have been introduced. The SAFER barriers, also called soft walls, are somewhat similar to these panels but are made of a steel skin or tubing and a backing of polystyrene blocks. Since these barriers have been used successfully in motor speedways, they may have applications in highways, even for bridge parapets. Their effectiveness in various highway applications must be established and their costs must be compared with those for other barriers.

Urethane Coating for Cathodic Protection

Despite having limitations, galvanic or sacrificial cathodic protection (CP) has recently emerged as the preferable mode of CP for reinforced concrete over the impressed-current mode, mainly because it does not require a direct current power source and the concomitant electrical control equipment. The anode system that is becoming popular for use with this mode of CP on concrete bridge substructures is a thermal-sprayed Zn-In-Al coating. However, this coating system requires very experienced applicators, which, in turn, leads to a high application cost.

The special urethane coating, which was developed by the National Aeronautics and Space Administration (NASA) for use in galvanic CP of reinforced-concrete launching facilities in corrosive coastal areas, is basically a urethane coating incorporated with a hydroscopic compound and particles of an anodic metal. Since this material can be applied on the concrete surfaces to be protected with conventional paint sprayers, rollers, or brushes, the system is expected to be cheaper than the thermal-sprayed Zn-In-Al coating system. Apparently, NASA has already granted Cortec Corporation a license to commercialize this coating system.

Because CP has proven to be effective and useful for preventing existing concrete bridge piers from serious premature damage that can result from reinforcement corrosion, this potentially cheaper alternative anode system warrants serious additional consideration.

Smart Fibers

These fibers are simply optical-quality glass fibers with a modified surface—some at only one end and some at selected locations and intervals along each fiber—to change their light-transmission or reflection properties in response to a change in their surroundings, such as the force to which they are subjected, moisture content, pH, etc. As such, each fiber is useful for monitoring changes in any one of these parameters (to which it is designed to respond) in the surrounding in which it is embedded, as long as the expected range of changes is within the dynamic range of the fiber's response. These fibers have been modified to respond to the strain in its surrounding medium. As indicated by the fact that the contacts for this material are commercial companies, the technology is in various stages of maturity: it is ready for some applications but requires modifications for others. Development and evaluation of slightly different optical-fiber sensors by VTRC have been in progress since last year for monitoring the strains in different layers of asphaltic-concrete roadways.[37]

With some additional developments, mostly to facilitate the embedment and survivability of the fibers, these fibers would be applicable in health monitoring of critical components of modern bridges, such as the post-tensioned tendons, to alleviate the lack of a proven nondestructive inspection technique that is effective, convenient, and inexpensive. Similar sensors for moisture would be very useful, since this substance is a precursor to corrosion. A unique advantage of optical fibers is that numerous sensing spots can be engineered onto each single fiber at pre-determined locations or intervals so that once embedded, the fiber can sense changes in either strain, moisture, or any of the other applicable parameters at different areas in its surrounding medium. In view of this, the potential uses of fiber sensors such as these are truly significant and should be explored.

Smart Paints

Aside from the added silicon-microsphere sensors, these paints are just conventional paints or coatings. However, the concept of a paint that can monitor its own condition and its effectiveness in protecting the underlying steel substrate from corrosion and, therefore, provide a prediction of its remaining life is new and has tremendous potential in improving the effectiveness of managing coating programs for bridges and structures. This material is still approximately 3 to 5 years from field trials. However, this could provide VTRC with a unique opportunity to become actively involved in the needed additional development.

Smart Polymeric Coatings

These peelable coatings are being developed at the University of Texas at Tyler expressly for cleanup of working surfaces that are accidentally contaminated with radioactive materials. They are in the conceptual stage, and they may have potential application as a less-expensive alternative to the current expensive methods for removing lead in deteriorating leaded paints on bridges. A lead-removal method based on this concept would offer two inherent advantages: (1) the envelope or tent around a structure to contain the resulting lead-loaded debris generated by the current blasting methods would not be required, and (2) the breathing apparatus for workers required with the current methods would not be required.

Toward the development of such a method, it is necessary to identify a polymeric solution that can effectively “draw” the lead to its resulting coating before it is peeled off the structural steel. It may be desirable also to identify and incorporate a suitable color indicator for lead, which can vary the intensity of its characteristic color with the concentration of lead drawn from the structural steel. Then, issues such as the cost of separating the lead from the peeled coating or disposing of the coating-lead combination and other relevant issues need to be examined before the concept can reach fruition.

As suggested by a staff member of the Materials Division, this technology may have another very useful application: capturing soluble chloride, sulfates, and nitrates from the surface of old paints as part of the preparation of the steel substrate for the application of a new paint.[38] These ubiquitous soluble salts adversely affect the life of a new paint or coating if too much is left on the surface of the steel substrate immediately before the application of the new paint.[39] All existing methods for removing the chloride and other salts, which come mainly from power plant and incinerator emissions, have limitations in achieving this function.

Lower-Rated Materials with Potentials

At least seven other materials received an average rating of 2.5 or a rating of 4 by only one division and have the potential to benefit VDOT in the future. Although the multiwall nanotubes received a favorable ranking by the Structure & Bridge Division, they are not included in this list because current research with this material is focusing on applying it in the area of micro-electromechanical systems, and scaling up in size could create a challenge that would delay its use on a larger scale. Therefore, the use of this material by VDOT in the near future is unlikely.

The seven materials with potential for use are:

1. electrically conductive concrete
2. microencapsulated fire-extinguishing agent
3. piezoelectric paint
4. self-healing coating
5. self-healing concrete
6. chemiluminescent lightsticks
7. soil-decontaminating nanoparticles.

Electrically Conductive Concrete

The rating for this material might have been higher if the Materials Division and the Structure & Bridge Division had been provided more detailed information during the survey. The material is similar to the one resulting from a study conducted at VTRC in the 1980s to develop a concrete with significantly improved electrical conductivity that could be used as an overlay on bridge decks for effective distribution of current during CP. The study found that by adding high-modulus carbon fibers (with a nominal length of 6 mm) and slightly adjusting the concrete mix, the resulting concrete would be not only lighter and stronger (with regard to both compressive and tensile strength) but also significantly more conductive.[40,41] Subsequent investigations by others have revealed that such material has another characteristic behavior: its electrical conductivity changes with the load to which it is subjected simply because the load disturbs the contacts between the individual carbon fibers.[42,43] As such, this material can be used as a structural material that is lighter and stronger than conventional concrete, as well as a piezoelectric sensor for monitoring strain and damage in concrete. Further, concrete incorporated with carbon fibers, as with other fibers, would have a significantly lower tendency to form cracks.

In addition, the material exhibits a relatively high reflectivity for radiowaves. Because of this property, such conductive concrete might be used for lateral guidance of vehicles in future automatic highways.[44] These applications and advantages are in addition to those listed in the Appendix for this material.

Microencapsulated Fire-Extinguishing Agent

Invented by NASA, this microencapsulated fire-extinguishing agent uses water rather than halons to extinguish fires. As discussed in the Appendix, the microencapsulating material ensures that the water penetrates to the base of the flame before it transitions from the liquid to the vapor phase. The water vapor then limits the fire's oxygen supply, but unlike halon flame suppressants, this technology is non-toxic and environmentally safe. Therefore, this material might be useful for increasing the safety of VDOT's tunnels for the numerous motorists who pass through daily.

Piezoelectric Paint

As described in the Appendix, this material can serve not only as a coating for protecting a wide range of structures, but also simultaneously as an indicator of the strain present in the structures on which it is applied.[45] Although this application is potentially very beneficial, the material received markedly different ratings of 4 and 1 from the Materials Division and the Structure & Bridge Division, respectively. A potential application in VDOT that was not mentioned in the list of applications is the coating of critical components of thousands of signal-light structures, particularly those that are subjected to stresses associated with excessive vibrations of this type of structure or support.

Self-Healing Coating

This material has been under development by the U.S. Army Construction Engineering Research Laboratory for preventing premature coating deterioration resulting from abrasion or scratches. It is uncertain whether this coating would be of benefit to VDOT. Failures of coatings on structural steel components in bridges generally fall into two categories: (1) premature rust, which arises from excessive residual salt being left on the steel surface before a new coating is applied, and (2) catastrophic failure arising from an incompatibility between the old and the new coatings. However, the working mechanism of the self-healing coating, i.e., release of healing compounds when microcapsules containing these compounds are abraded, is particularly applicable to epoxy-coated bars. The major problems encountered before such bars are embedded in concrete are careless handling by construction workers and contact with concrete consolidators or vibrators, both causing abrasion damage to the epoxy coating.

Self-Healing Concrete

Work at the University of Illinois has shown benefit in adding an encapsulated healing compound to concrete.[28, 46] Both corrosion mitigation (using a time-release corrosion inhibitor) and crack sealing studies have demonstrated these materials to have the potential for increasing the life of reinforced concrete structures. In addition, the healing compounds should not alter the properties of freshly mixed concrete because they are not released until after the concrete has cured. However, the research performed in this area is limited and field studies using this technology were not found. This technology, nevertheless, could provide benefit as an admixture for concrete when the potential for chloride-induced corrosion is a concern.

Chemiluminescent Lightsticks

Although chemiluminescent lightsticks are not new, a new color has been developed (lime green) for used where increased visibility is required. After a review of the characteristics provided in the Appendix, the lightstick was deemed to have the potential for helping motorists detect highway workers in and around work zones under low-light conditions.

Soil-Decontaminating Nanoparticles

Even though other methods exist for soil remediation, such as bioremediation, the use of polymeric nanoparticles could provide an additional tool when dealing with soil particles with tightly adherent contaminants.[47] In addition, it is possible that the nanoparticles could be tailored for a particular set of soil-decontamination conditions.[48]

An Additional New Material with Potential

Indicative of the speed with which new materials are being created and announced in a wide range of literature sources, one additional new material surfaced while the 47 already-identified new materials were being rated: mussels' glue.

Mussel's glue is the biological substance that blue mussels (*Mytilus edulis*) rely on to attach themselves strongly to any objects. A team of researchers from Purdue University discovered that it is formed when gelatin-like proteins that the mussels excrete react with iron in the water to cause the proteins to crosslink.[49] Since the mussels can adhere strongly even to nonstick surfaces such as polytetrafluoroethylene, the researchers are optimistic that their work could lead to alternative non-polymer-based coatings with extremely high adhesion characteristics. According to the report, work is in progress to synthesize these proteins and use them to develop new antifouling and rustproof coatings with exceptional adhesion. Thus no commercial applications that may result from the additional research in this area are envisioned for at least a decade or two.

CONCLUSIONS

- Of the 48 new materials identified, many are either "blue sky" materials, even for non-transportation applications; not yet commercially available; or still too expensive.

- Several new materials were rated to have a reasonably good potential for transportation-related applications. Among these, the SAFER (steel-and-foam energy reduction) barrier (for preventing fatalities during vehicle crashes with traffic barriers) and the urethane coating for CP (of concrete bridge piers) are ready for immediate application or at least serious trials.

- Elastomeric coating for blast protection and the microencapsulated fire-extinguishing agent could potentially aid in reducing damage due to a catastrophic event. The VDOT tunnels could possibly benefit the most from the microencapsulated fire-extinguishing agent.

- Other materials, such as the lead biosensor and the smart fibers, are purely sensors for specific applications, with the latter material having a wider potential because the fibers can be tailored to respond to particular parameters.

- When formulated with the right coating system, the smart paint and piezoelectric paint can be both a protective coating and a sensor. The former is designed to monitor its remaining life or effectiveness in protecting the metal substrate on which it is applied, and the latter is designed to monitor the stress the metal substrate is undergoing. There is no reason each coating should be limited to its respective purpose. It is possible to formulate a coating system that serves both purposes.

- The conductive concrete is already useable as a structural material and a structural sensor. However, its real value is probably in aiding vehicular control in future automated roadways.

- Although the peelable smart polymeric coating was developed for cleaning radioactive substances from contaminated working surfaces, the concept can be extended to removal of lead and/or soluble salts on coated steel bridge components. However, such transportation-related applications of this concept would require identification of the component materials required for the coating to attain these capabilities.

- A few other materials should not be ignored. These include self-healing coatings and self-healing concrete.

RECOMMENDATIONS

1. *In the near future, VTRC should explore and analyze the lead biosensor, SAFER barrier, urethane coating for CP, smart/piezoelectric coating, microencapsulated fire-extinguishing agent, and the smart polymeric coating or appropriate modifications of these materials or their basic underlying concepts.* The analysis should include a cost analysis and information regarding the potential benefits to VDOT. To ensure success, some of these efforts would require highly interdisciplinary collaboration encompassing physics, chemistry, mechanics, computing, electronics, and different engineering disciplines.

2. *For the long term, VTRC should conduct a follow-up survey of a similar nature in 10 to 20 years.* Since the new materials created by science and technology have been prolific in the last two decades, there is no reason not to expect the same in the next 20 years. Such a follow-up survey would ensure that any future advanced material with potential or the discovery of new ways to use old materials is not missed.

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APPENDIX

ADVANCED MATERIALS IDENTIFIED
(Arranged in Alphabetical Order)

1. AEROGELS

Characteristics: These are sturdy amalgams of highly porous glass (silica) and plastic that are created by crosslinking (tying together chemically) strings of nano-sized glass particles with polyisocyanate, which is one of the two components of polyurethane. According to a description provided in technology transfer literature from the Lawrence Berkeley National Laboratory on nanocomposite aerogels, aerogels are typically composed of 5 percent solid (2 to 4 nanometers in size) and 95 percent fine pores and have very low density (0.1 g/cc) with an "internal" surface area of about 900 m^2/g.[50] The material is as light as air but 100 times more resistant to "breakage" and totally insensitive to moisture. It also has a high resistance to heat transfer.[50]

Potential Uses:

1. Strong building materials
2. Building materials for lighter and safer aircraft and space vehicles
3. High impact–resistant material for automobile bumpers
4. Durable tires
5. Excellent insulation for windows, refrigerators, and bottles (i.e., Thermos type containers)

Contact/Inventor: Nicholas Leventis, Ph.D., Chemistry Department, University of Missouri at Rolla, Rolla, MO 65409; Tel: 573-341-4391; Email: leventis@umr.edu.

2. ALON (POLYCRYSTALLINE ALUMINUM OXYNITRIDE)

Characteristics: ALON is a very durable optical (transparent) ceramic with a high degree of transparency from the ultraviolet through the mid-infrared wavelengths. It has excellent mechanical (hardness) and optical properties. Its properties are isotropic, making it scaleable by conventional powder-processing methods. Therefore, it can be produced cost-effectively. Depending on the applications, it can provide savings in reduced weight by 50 percent weight.

Potential Uses:

1. Various lighting applications
2. Underwater sensors
3. Scratchproof lenses

Stage of Development: Commercially available from Surmet Corporation, 33 B Street, Burlington, MA 01803; Tel: 781-272-3969; URL: http://www.surmet.com/contact.html.

Contact/Inventor:

1. Timothy C. Davis, Surmet Corporation, 33 B Street, Burlington, MA 01803; Tel: (781)272-3969; URL: http://www.surmet.com/contact.html.
2. Dr. Pete Meltzer, Jr., Anteon Corporation, 3211 Jermantown Road, Suite 700, Fairfax, VA 22030; Tel: 703-246-0200; URL: http://www.anteon.com/index.htm.
3. Amy Homer, Raytheon Company, 870 Winter Street, Waltham, MA 02451-1449; Tel: 781-860-2424; URL: http://www.raytheon.com/.

3. BIODEGRADABLE PLASTICS

Characteristics: Unlike the conventional plastics, which are made from petroleum products, these environmentally friendly plastics are made from corn and other natural products. In the production of one of these new materials, sugars from corn are fermented and then transformed into high-performance polymers called polylactides. Fibers are then extruded from these polylactides to make biodegradable plastics.

Potential Uses:

1. Biodegradable plastic components
2. Biodegradable trash bags

Stage of Development: Commercially available from various suppliers depending on the application.

Contact/Inventor:

1. Cargill Dow LLC, 15305 Minnetonka Boulevard, Minnetonka, MN 55343; Tel: 952-742-0400, URL: http://www.cargilldow.com/corporate/.
2. Novamont SPA, Via G. Fauser 8, 28100 Novara, Italy; Tel: +39.0321.6996.11; Email: info@materbi.com; URL: http://www.novamont.com/.
3. Barry Adamson, Executive Director, Multi-Community Diversified Services Inc., 901 N. Main, McPherson, KS 67460-2841; Tel: 620-241-6693; Email: mcds01@midusa.net.

4. BIOSENSOR FOR LEAD

Characteristics: This biosensor is obtained by attaching a fluorophore/quencher pair to highly selective DNA molecules that have a strong affinity for a particular metal ion, in this case, lead ions. In the presence of lead, this biosensor interacts with it to produce a red fluorescence instead of remaining blue. Modifications to this sensor design could allow for detection of other ions such as mercury, cadmium, and zinc, which are all toxic above particular concentrations. Tests by the inventor have shown that this colorimetric biosensor can be used for semi-quantitative detection of lead in existing paints, in a fashion similar to that of pH indicators, without the use of any instrument. All that is required is a small chip of the paint (a needle hole size should be sufficient), which is treated with a vinegar-like solution to extract the lead from the paint. If there is lead in the paint, the sensor will turn red in less than 5 minutes after a small drop of the paint extract is added. Otherwise, the biosensor will remain blue.

Potential Use: Field test for lead paint on questionable steel structures.

Stage of Development: Functional technology but not commercially available.

Contact/Inventor: Yi Lu, Professor, Department of Chemistry, University of Illinois at Urbana-Champaign, A322 Chemical & Life Sciences Lab, 600 South Mathews Avenue, Urbana, IL 61801; Tel: 217-333-2619; Email: yi-lu@uiuc.edu.

5. CARBON NANOTUBES

Characteristics: These nanotubes are carbon molecules with a closed-cage structure that is sometimes called fullerenes or Buckytubes. This material conducts electricity better than any known nanoscale material (1 billion amp/cm^2) and has a tensile strength on the order of 50 GPa (7.2 million psi).

Potential Uses:

1. High-strength fibers in composite materials
2. High-strength conductive polymers
3. Solar energy converters
4. Strong lithium ion batteries

Cost: Current cost is about $500/g, because the current pilot plant produces only about 200 g (7 oz) per day. The industry hopes that with new plants, it will be possible to offer production quantities at a much lower price by 2005.

Contact/Inventor:

1. Ken McElrath, Carbon Nanotechnologies Inc., 16200 Park Row, Houston, TX 77084-5195; Tel: (281)492-5707; URL: http://www.cnanotech.com/pages/about/4-5_contacts.html.
2. Yasuhito Umechi Sumitomo Corporation, 1-8-11, Harumi, Chuo-ku, Tokyo 104-8610, Japan; Tel: +81-3-5166-3094; URL: http://www.sumitomocorp.co.jp/english/index.htm

6. CHEMILUMINESCENT LIGHTSTICK

Characteristics: Lightsticks make use of a chemiluminiscent material that forms when proper reactants are mixed and react with one another. The product emits light as the result of a chemical reaction. The working life of a lightstick is limited by the amount of the packaged reactants. Typically, the lightsticks glow for approximately 2 hours and have a visibility of up to 1 mile. They are waterproof, windproof, non-toxic, and non-flammable glow sticks.

Potential Uses:

1. Emergency light sources (without batteries) for traffic accident sites
2. Work zone safety devices

Stage of Development: Commercially available from Omniglow Corporation.

Contact/Inventor: Omniglow Corporation, 96 Windsor Street, West Springfield, MA 01089; Tel: 800-762-7548; Email: customerservice@omniglow.com.

7. CONTRACTING TEXTILES

Characteristics: These textiles are made of fibers approximately 50 µm in diameter and have a tensile strength of 1.8 GPa. They also have favorable toughness and contract slightly when charge injected.

Potential Uses: Composite material for structural application.

Stage of Development: Research and Development.

Cost: Currently cost prohibitive.

Contact/Inventor: Ray H. Baughman, Robert A. Welsh Professor of Chemistry, Department of Chemistry and NanoTech Institute, University of Texas at Dallas, P.O. Box 830688, Mail Stop BE26, Richardson, TX 75083-0688; Tel: 972-883-6538; Email: Ray.Baughman@utdallas.edu.

8. ELASTOMERIC COATING FOR BLAST PROTECTION

Characteristics: This is a spray-on elastomer that can be used with or without high-strength fabric to retrofit concrete block walls, reinforced concrete, lightweight structures (e.g., trailers), etc., for improving the blast resistance of these structures.

Potential Use: Improve resistance of roadway tunnels to explosions, especially for countering potential acts of terrorism.

Stage of Development: Functional technology but not commercially available.

Contact/Inventor: Robert J. Dinan, Jon R. Porter, and Timothy Anderl, Air Force Research Laboratory, Materials and Manufacturing Directorate, AFRL/PA, 1864 4th St., Bldg. 15, Room 225, WPAFB, OH 45433-7131; Tel: 972-883-6538; Email: afrl.pa.dl.all@wpafb.af.mil; URL http://www.afrl.af.mil/contact.html.

9. ELECTRICALLY CONDUCTIVE CONCRETE

Characteristics: The improved electrical conductivity is obtained by adding into ordinary portland cement concrete mixes either of the following: steel shavings and steel fibers, carbon or graphite fibers, or coke breeze.

Potential Uses:

1. Current-distribution overlays for impressed-current cathodic protection of concrete structures
2. Heated concrete surfaces
3. Grounding platform for transmission towers
4. Electrostatic-proofing concrete floors

Stage of Development: Ready for application.

Contact/Inventor:

1. Christopher Y. Tuan, Associate Professor, Department of Civil Engineering, 203F Peter Kiewit Institute, University of Nebraska–Lincoln, Omaha, NE 68182-0178; Tel: 402-554-3867; Email: ctuan@unomaha.edu; URL: http://www.conductive-concrete.unomaha.edu/.
2. James J Beaudoin, Ph.D., Group Leader, Durability & Repair of Concrete Structures, Institute for Research in Construction, Room 171, Building M-20, 1200 Montreal Road, Ottawa ON K1A 0R6, Canada; Tel: 613-993-6749; Email: Jim.Beaudoin@nrc-cnrc.gc.ca.
3. Gerardo G. Clemeña, Principal Research Scientist, Virginia Transportation Research Council, 530 Edgemont Road, Charlottesville, VA 22903; Tel: 434-293-1949; Email: Gerardo.Clemena@VDOT.Virginia.gov.

10. ELECTRONIC TEXTILES

Characteristics: E-textiles are made by integrating different components into a fabric to provide specific desired functionality while not becoming cumbersome. Components incorporated include microwires, fiber optics, and microelectronics. By varying the components added, e-textiles could be designed to perform different functions such as wireless communication, data collection, and sensing.

Potential Uses:

1. Heated clothing
2. Transmitter/receiver-clothing
3. Safety clothing
4. Lightweight light-emitting panel that allows for identification at a greater distance
5. Sensors for detection and mapping

Contact/Inventor:

1. Sundaresan Jayaraman, Professor, Georgia Institute of Technology, School of Textile & Fiber Engineering, 801 Ferst Drive, NW, MRDC 1, Atlanta, GA 30332-0295; Tel: 404-894-2490; Email: sundaresan.jayaraman@tfe.gatech.edu.
2. Softswitch Ltd, Little Lane, Ilkley, West Yorkshire, LS29 8UG, U.K.; Tel: +44 1943 603703; Email: info@softswitch.co.uk,; URL: http://www.softswitch.co.uk/SOFTswitch.html.
3. International Fashion Machines, Suite 2B, 32R Essex Street, Cambridge, MA, 02139; Tel: 617-547-6312; Email: info@ifmachines.com; URL: http://www.ifmachines.com/eplaid.html.
4. Peter Athanas, Professor, Department of Electrical and Computer Engineering, 340 Whittemore, Virginia Polytechnic Institute & State University, Blacksburg, VA 24061; Tel: 540-231-7010; Email: athanas@vt.edu; URL: http://www.ccm.ece.vt.edu/etextiles/.

11. ELECTRORHEOLOGICAL MATERIAL

Characteristics: The viscosity of an electrorheological fluid changes when subjected to an electric field. Since the viscosity can be varied, these fluids provide a practical solution for active vibration control.

Potential Uses:

1. Automotive shock absorbers
2. Seismic devices

Stage of Development: Commercially available from Smart Technology Limited.

Contact/Inventor:

1. Ping Sheng, Professor and Department Head, Director, Institute of Nano Science and Technology, Department of Physics, The Hong Kong University of Science & Technology, Clear Water Bay, Kowloon, Hong Kong; Email: sheng@ust.hk, URL: http://physics.ust.hk/department/staff.html.
2. A. Srikantha Phani, Cambridge University, Department of Engineering, Trumpington Street, Cambridge, CB2 1PZ, U.K.; Tel: +44 1223 765925; Email: skpa2@eng.cam.ac.uk.
3. Ali El Wahed, Department of Mechanical Engineering, University of Dundee, Dundee DD1 4HN, UK; Tel: 01382 344496; Email: a.elwahed@dundee.ac.uk.
4. Smart Technology Limited, Unit 41, Coleshill Industrial Estate, Coleshill, Birmingham, B46 1JT, U.K.; Tel: +44 (0) 1675 467900; Email: smart@smarttec.co.uk.

12. FERROMAGNETIC SHAPE-MEMORY ALLOY

Characteristics: This material responds to a magnetic field by changing from a temporary to a predefined shape. Therefore, these materials can produce a force, a displacement, or both.

Potential Uses: Actuators in control systems.

Contact/Inventor:

1. Mide Technology Corporation, 200 Boston Avenue, Suite 1000, Medford, MA 02155; Tel: 781-306-0609 x297; E-mail: contactus@mide.com; URL: http://www.mide.com.
2. Christine Peterson, Director, Federal Business Development–Civilian, SRI International, 1100 Wilson Blvd., Suite 2800, Arlington, VA 22209-2268; Tel: 703-247-8459; E-mail: christine.peterson@sri.com.
3. Minoru Taya, Professor and Director, Center for Intelligent Materials and Systems, Department of Mechanical Engineering, University of Washington, Box 352600, Seattle, WA 98195-2600; Tel: 206-685-2850; Email: tayam@u.washington.edu.
4. Koichi Tsuchiya, Associate Professor, Department of Production Systems Engineering, Toyohashi University of Technology, 1-1 Hibarigaoka, Tempaku-cho Toyohashi-shi Aichi, 441-8580 Japan; Email: tsuchiya@tutpse.tut.ac.jp.

13. GECKO TAPE

Characteristics: This is a dry, glueless adhesive created to simulate how geckos scuttle across sheer glass without falling. As discovered by biomimicry scientists in 2000, geckos make use of the relatively weak molecular forces (van der Waal forces) created when the billions of microscopic hairs per square inch of their feet come into contact with any surfaces, including glass. A key feature of this material is its ability to attach-detach repeatedly.

Potential Uses:

1. Climbing aid
2. Fasteners

Stage of Development: The first piece of this tape ever made is smaller than a postage stamp and can hold a Spider-Man action figure to the underside of a piece of glass. According to the scientists working on this, the plastic hairs on the gecko tape were not nearly as concentrated as the hairs on a gecko's feet. However, according to the scientists, the mechanism is scalable and, therefore, bigger strips have the potential to harness van der Waal forces to hold up larger objects, such as humans. In addition, the material is not yet durable.

Contact/Inventor: Andre Geim, Professor of Condensed Matter Physics, Department of Physics and Astronomy, University of Manchester, Oxford Road, Manchester, M13 9PL, U.K.; Tel: +44-0-161-275-4120; Email: geim@man.ac.uk. (Originally reported in the June 2003 issue of *Nature Materials*.)

14. IMPROVED PHOTOVOLTAIC CELLS

Characteristics: These solar cells absorb a larger spectral frequency than do previous solar cells, thereby improving efficiency.

Potential Uses:

1. Cheaper cathodic protection systems that require less maintenance
2. Portable rechargeable lights and displays

Stage of Development: Research and Development

Contact/Inventor:

1. Sam-Shajing Sun, Associate Professor of Chemistry, Director, Center for Organic Photonic Materials Research, Norfolk State University, 700 Park Avenue, Norfolk, VA 23504; Tel: 757-823-2993; Email: ssun@nsu.edu.
2. Martin Green, Director, University's Photovoltaics Special Research Centre, University of New South Wales, Sydney, N.S.W, 2052 Australia; Tel: 61 02 9385-4018; Email: m.green@pv.unsw.edu.au.
3. A. Paul Alivisatos, Professor of Chemistry, Department of Chemistry, Room 419, Latimer Hall, University of California, Berkeley, CA 94720-1460; Tel: 510-643-7371; Email: ALIVIS@uclink4.Berkeley.EDU.
4. Lynn Yarris, Media Coordinator, Lawrence Berkeley National Laboratory (Berkeley Lab), Berkeley, CA 94720; Tel: 510-486-5375; Email: LCYarris@lbl.gov.

15. INSULATING PAINT ADDITIVES

Characteristics: These are hollow ceramic microspheres, with the interior of the spheres in a vacuum. Nontoxic and inert, the material acts as a thermal barrier and barrier to UV rays and repels insects. They can be used as an additive for paint, coating, adhesive, masonry, or drywall and can be applied using standard techniques (including spraying).

Potential Uses:

1. Special coating for underground cables and pipes
2. Insulation for heated/cooled structures

Stage of Development: Commercially available from Hy-Tech Thermal Solutions.

Contact/Inventor: Hy-Tech Thermal Solutions, LLC, P.O. Box 216, Melbourne, FL 32902; Tel: 321-984-9777; URL: http://www.hytechsales.com.

16. INTEGRATED WIRE

Characteristics: This is a coaxial and concentric cable with double conductors. The resistivity of this wire changes with the material used, the length of the cable, and changes in the surrounding pressure. By applying currents to the inner and outer conductors and comparing their respective resistances, it is possible to check the integrity of this wire.

Potential Use: Self-checking sensors for applications in structural health monitoring.

Stage of Development: Available commercially from Cogent Enterprises, Inc., as Impress™.

Contact/Inventor: Cogent Enterprises, Inc., 38269 Mount Road, Suite 600, Sterling Heights, MI 48310; Tel: 586-978-8381; URL: www.cogententerprises.com.

17. LIGHT GUIDE

Characteristics: This material system is composed of three simultaneously extruded components: an acrylic polymer core, an outer polymethylmethacrylate cladding, and a reflector. The last allows light to radiate from the guide. The system can withstand temperatures ranging from -40° to +80°C and has good chemical resistance. When used with low-energy light sources such as light-emitting diodes, the system turns into low-energy lines of light.

Potential Uses:

1. Low-energy delineation of roadways and tunnels
2. Low-energy traffic guides for construction zones
3. "Remote" light sources for overhead traffic signs on freeways

Stage of Development: The basic light guide system is commercially available from Bridgestone Industrial Products America, Inc.

Contact/Inventor:

1. Bridgestone Industrial Products America, Inc., 402 BNA Drive, Suite 212, Nashville, TN 37217; Email: sales@luxaura.com; URL: http://www.luxaura.com/.
2. Advanced Delineation Systems Inc., 7-2062 Henry Avenue West, Sidney, British Columbia, Canada, V8L 5Y1; Tel: 250-655-4349; Email: info@delineationsystems.com; URL: http://www.delineationsystems.com/index.htm.

18. LOW-VOLTAGE POLYMER HEATER

Characteristics: This is a carbon-based conductive polymer. It requires a power source of only between 6 to 48 V to produce a uniform temperature output (+/- 1.5 °C psm) that can range from ambient to 120 °C. One of its strongest assets is its flexibility, which permits it to follow the surface conformation of a variety of shapes. In many cases, it can function as an alternative to conventional heat source.

Potential Use: Temperature control for pipelines and storage tanks.

Stage of Development: Commercially available from Inditherm.
Contact/Inventor: Inditherm House, Houndhill Park, Bolton Road, Wath-Upon-Dearne, Rotherham, South Yorkshire, S63 7JY, U.K.; Tel: +44 (0)1709 761000; Email: info@indithermplc.com.

19. MAGNETOCALORIC MATERIALS

Characteristics: When subjected to an external magnetic field, the temperature of particular ferromagnetic materials, such as $Gd_5(Si_2Ge_2)$, can increase. Upon removal of the external magnetic field, the materials begin to cool. This unique behavior can be utilized for cooling by allowing a benign heat-transfer liquid to flow over a magnetocaloric material, after an external magnetic field is applied, followed by removing the magnetic field and repeating the cycle. The temperature of equivalent volumes can be cooled at a relatively higher efficiency using this approach than by the conventional cooling method.

Potential Uses:

1. Energy-efficient and environmentally friendly air conditioning
2. Portable refrigerators

Contact/Inventor: Karl Gschneider, Jr., Anson Marston Distinguished Professor, Senior Metallurgist, Iowa State University, Ames Laboratory, 255 Spedding, Ames, IA 50011-3020; Tel: 515-294-7931; Email: cagey@ameslab.gov; URL: http://www.metcer.ameslab.gov/.

20. MAGNETORHEOLOGICAL MATERIAL

Characteristics: The rheological properties of magnetorheological (MR) materials change when a magnetic field is applied. These materials include fluids, foams, and elastomers, with fluids being the most well known. Because these properties can be varied, these materials provide a practical solution for active vibration control.

Potential Uses:

1. Active vibration dampening, such as shock absorbers, seismic devices, etc.
2. Torque transfer devices
3. Variable stiffeners

Contact/Inventor:

1. J. David Carlson, Lord Corporation, Materials Division, 110 Lord Drive, Cary, NC 27511-7900; Email: dave_carlson@lord.com.
2. Gareth H McKinley, Institute for Soldier Nanotechnologies, Massachusetts Institute of Technology, Building NE47, 4th Floor, 77 Massachusetts Avenue, Cambridge, MA 02139; Tel: 617-258-0754; Email: gareth@MIT.EDU.
3. B. Stenberg, Department of Polymer Technology, KTH, Teknikringen 56-58, SE-100 44, Stockholm, Sweden; Tel: +46-8-790-8269; Email: stenberg@polymer.kth.se.
4. Pradeep P. Phulé, Professor, Department of Materials Science and Engineering, University of Pittsburgh, 848 Benedum Engineering Hall, Pittsburgh, PA 15261-2208; Tel: (412) 624-9736; Email: phule@engr.pitt.edu.

21. MAGNETOSTRICTIVE ELASTOMERS

Characteristics: These elastomers respond to external magnetic field by reversibly changing length or vice versa.

Potential Uses:

1. Actuators
2. Magnetoelastic pH sensor, by coating a magnetostrictive elastomer with a thin pH sensitive film, which would alter the vibrational frequency of the magnetostrictive material in response to the magnetic field, vice versa**.**

Contact/Inventor:

1. Mide Technology Corporation, 200 Boston Ave, Suite 1000, Medford, MA 02155; TEL: (781) 306-0609 x297; E-mail: contactus@mide.com, URL: http://www.mide.com
2. Craig Grimes, Department of Electrical Engineering, 453 Anderson Hall, Center for Micro-Magnetic and Electronic Devices, University of Kentucky, Lexington, KY 40506; Tel: 859-257-2300 ext 273; Email: grimes@engr.uky.edu; URL: http://www.electronicmaterials.com:80/buisnesses/sem/amorph/page5_1_2.htm.

22. MAGNETOSTRICTIVE METAL

Characteristics: The magnetic domains within ferromagnetic materials can be influenced by the strength of an external magnetic field and vice versa. These materials exhibit slight deformation as their magnetic domains rotate to align with the applied magnetic field. Conversely, straining these materials will alter the alignment of these magnetic domains and influence their response to a magnetic field.

Potential Uses:

1. Audio devices
2. Actuator
3. Active noise control
4. Non-destructive evaluation of strain in steel pipes without a couplant

Contact/Inventor:

1. Hegeon Kwun, Ph.D., Nondestructive Evaluation Research and Development Department, Nondestructive Evaluation and Technology Division, Southwest Research Institute, 6220 Culebra Road, San Antonio, TX 78228-0510; Tel: 210-522-3359; Email: hkwun@swri.org.
2. MTS Systems Corp.; Tel: 919-677-0100; Email: info@mtssensors.com. URL: http://www.sensorland.com.
3. Bryon Dudley, ETREMA Products, Inc., 2500 North Loop Drive, Ames, IA 50010; Tel: 515-296-8030; Email: bryon.dudley@etrema-usa.com.

23. METALLIC CARBON NANOTUBES

Characteristics: These materials are created by the introduction of heptagons and pentagons into a hexagonal, semi-metallic, graphite network or carbon nanotubes. These covalently bonded carbon materials are extremely light and strong (particularly in the planar directions) and are predicted to be superconductors.

Potential Uses:

1. High-strength conductive fibers
2. High-temperature electrical components (diodes), heaters, battery electrodes, lubricants, etc.

Contact/Inventor: Marvin Cohen, Ph.D., Lawrence Berkeley National Laboratory, Berkeley, CA 94720; Tel: 510-642-4753; Email: cohen@civet.berkeley.edu (U.S. Patent No. 5,993,697).

24. MICROENCAPSULATED FIRE-EXTINGUISHING AGENT

Characteristics: By microencapsulating water, it ensures that water is delivered to the base of the flame, so that the temperature of the flame is effectively reduced while the water vapor created reduces the oxygen supply to the fire. This approach significantly reduces the evaporation of the water before it reaches the base of the flame, and thereby improving the effectiveness of the fire-extinguishing agent.

Potential Use: Fire-extinguishing agent for confined spaces, such as in roadway tunnels.

Contact/Inventor: Clyde F. Parrish, AST Senior Chemist, John F. Kennedy Space Center, FL 32899; Tel: 321-867-8130 (Project: KSC-12236).

25. MULTIWALL NANOTUBES

Characteristics: These are custom-engineered multiwall carbon nanotubes that can perform as extremely low-friction-nanoscale linear bearings and constant-force nanosprings (that do not follow Hooke's law). Repeated extension and retraction of telescoping nanotube segments, inside a high-resolution transmission electron microscope, showed no wear and fatigue even on the atomic scale.

Potential Uses:

1. Extremely low friction nanoscale linear bearings and springs
2. Any application benefiting from wear-free surfaces.

Contact/Inventor: Alex Zettl, Professor, 341 Birge Hall, University of California at Berkeley, Berkeley, CA 94720, Tel: 510-642-4939; Email: azettl@socrates.berkeley.edu; URL: http://physics.berkeley.edu/research/zettl/.

26. NANO-VELCRO

Characteristics: Carbon nanotubes have a unique characteristic in that they interlock in a similar manner as Velcro, but would require a much larger force to separate. When made into a cloth or tape, this provides adhesion that would be stronger than that achieved using epoxy and would not be susceptible to moisture.

Potential Uses:

1. Super climbing aid
2. Super fasteners

Cost: This material is still too costly to be of practical use.

Contact/Inventor:

1. David Tománek, Professor of Physics, Physics and Astronomy Department, 4231 Biomedical and Physical Sciences Bldg., Michigan State University, East Lansing, MI 48824-2320; Tel: 517-355-9702; Email: tomanek@pa.msu.edu; URL: http://www.pa.msu.edu/~tomanek.
2. Young-Kyun Kwon, Department of Physics, University of California, Berkeley, CA 94720-7300; Tel: 510-428-5311; Email: ykkwon@civet.berkeley.edu;URL: http://civet.berkeley.edu/ykkwon/.

27. PHOTOLUMINESCENT MATERIALS

Characteristics: Photoluminescent materials absorb light and re-emit the light by glowing. Some of these materials can glow for 1 hour after being exposed to light for only 10 seconds. These materials require short exposure times to rejuvenate. They have demonstrated success in marking building exits and pathways, remaining bright and visible at 75 feet, even after as long as 90 minutes in the dark.

Potential Uses:

1. Self-powered reflective/photoluminiscence tape on worker uniforms
2. Better traffic lane markers
3. Work zone markers

Contact/Inventor:

1. Luna Technologies International, 19226 70th Avenue South, Kent, WA 98032; Tel: 888-955-8883; Email: Info@lunaplast.com; URL: http://www.lunaplast.com/.
2. Sherwin-Williams Industrial, 101 Prospect Avenue NW, Cleveland, OH 44115; Tel: 800-524-5979; URL: http://www.sherwin-williams.com/apps/pickpros/display.asp?type=data&id=610.
3. Omniglow Corporation, 96 Windsor Street, West Springfield, MA 01089; Tel: 800-762-7548; Email: customerservice@omniglow.com.

28. PIEZOELECTRIC MATERIALS

Characteristics: Piezoelectric materials generate an electrical output when subjected to a force or vice versa.

Potential Uses:

1. Active vibration dampening

2. Transducers for non-destructive evaluation (stress wave) test equipment
3. Self-heating/self-lighting shoes

Contact/Inventor:

1. Mide Technology Corporation, 200 Boston Avenue, Suite 1000, Medford, MA 02155; Tel: 781-306-0609, Ext. 297; Email: contactus@mide.com; URL: http://www.mide.com.
2. Gregory Carman, Professor, Mechanical and Aerospace Engineering Department, Henry Samuel School of Engineering & Applied Science, 38-137M Engineering IV, Box 951597, Los Angeles, CA 90095-1597; Tel: 310-825-6030; Email: carman@seas.ucla.edu.
3. Morgan Electro Ceramics Inc, Customer Services, 232 Forbes Road, Bedford, OH 44146-5418; Tel: 440-232-8600; Email: sales@morganelectroceramics.com.
4. EDO Corporation, EDO Electro-Ceramic Products, 2645 South 300 West, Salt Lake City, UT 84115; Tel: 801-486-7481; Email: sales@edoceramic.com.

29. PIEZOELECTRIC PAINT

Characteristics: This material is formulated by replacing regular paint pigments with a fine-powder of lead-zirconate-titanate (PZT). When these crystals are stretched or squeezed, e.g., by vibration, they generate an electrical signal that is proportional to the force. By applying this paint on a surface and then aligning the PZT crystals at a right angle to the surface by applying a voltage to the paint, the material will produce an electrical signal in proportion to stress on the substrate, regardless of the direction of the stress.

Potential Use: Can be sprayed on the surface of structures such as bridges, aircraft, ships, and oilrigs to detect unusual stresses.

Stage of Development: At its present stage of development, such paint can be used as a sensor by combining a 50-micron-thick layer of this piezoelectric formulation sandwiched between two electrodes that can be configured from a 50-micron-thick layer of electrically conductive paint. These electrodes can be bonded to wires needed to transmit the sensor output with a conductive adhesive. This paint-sensor formulation is undergoing field testing on a bridge spanning the River Tyne in the U.K. According to its developer, the formulation’s curing time is too long, more than 3 days, to be practical. Therefore, the formulation requires slight modification.

Contact/Inventor: Jack Hale, Ph.D., Department of Mechanical, Materials and Manufacturing Engineering, University of Newcastle, Stephenson Building, Newcastle upon Tyne, U.K.; Tel: 0191 222 6208; Email: jack.hale@ncl.ac.uk; URL: http://www.staff.ncl.ac.uk/jack.hale/.

30. PLASTIC SOLAR ENERGY CELLS

Characteristics: A hybrid solar cell, made of tiny semiconductor nanorods dispersed in conjugated polymers, which offers the highest hole mobility found so far. High hole (and electron) mobility means that charges are transported faster, thereby reducing current losses. Sandwiched between electrodes, the hair-thin layer produces about 0.7 volt. The cell is inexpensive to produce, because it involves only solution processing at room temperature unlike today's silicon-based solar cells, which require sophisticated high-temperature processing inside clean rooms. It can be made larger than the current solar cells. It can be painted onto just about any surface, including plastic for unlimited flexibility, and provide power for a range of portable and even wearable electronic devices. However, its present efficiency is only about one tenth of the conventional semiconductor-based solar cells. However, according to the scientists, because of their simple structure, this technology has ample potential for improvement.

Potential Uses:

1. Cheaper solar cells
2. Solar cells on clothing to power LEDs, radios, small computer processors, etc.

Contact/Inventor: Paul Alivisatos, Ph.D., c/o Alivisatos Group, Box 101, Department of Chemistry, University of California, Berkeley, CA 94720, Tel: 510-643-7371; URL: http://www.cchem.berkeley.edu/~pagrp/paulbio.html.

31. POLYMER GELS

Characteristics: These materials change volume in response to changes in temperature, pressure, pH, solvent, light, electrical or magnetic fields, leading to the absorption or expulsion of chemicals in response to any of these stimuli.

Potential Uses:

1. Corrosion inhibitor delivery
2. Sensor/actuator
3. Thermal protected wetsuit, as in SmartSkin™

Contact/Inventor:

1. Mide Technology Corporation, 200 Boston Avenue, Suite 1000, Medford, MA 02155; Tel: (781) 306-0609 x297; Email: contactus@mide.com; URL: http://www.mide.com.
2. L. Andrew Lyon, Professor, Georgia Institute of Technology, School of Chemistry and Biochemistry, Atlanta, GA 30332-0400; Tel: (404) 894-4090; Email: lyon@chemistry.gatech.edu.

32. PRESSURE-SENSITIVE PAINT

Characteristics: The material is made by adding an organic dye to a polymer binder that is permeable to oxygen. The amount of oxygen that diffuses into the matrix increases as the atmospheric pressure increases. When the dye is exposed to UV or blue-green light (from b-g lasers), it is excited to a high-energy state from which it decays and glows. Based on the concept of oxygen quenching, the paint fluoresces an amount of light that is inversely proportional to the pressure on the substrate's surface. When paired with a charge-coupled device (CCD) camera and lighting systems, these materials can quickly show the pressure distribution across wind-tunnel models of airplanes, vehicles, and buildings at a relatively low cost.

Potential Use: Useful in the investigations of wind resistance and aerodynamics (airflow around) of models of tall bridges and buildings, airplanes, vehicles, etc.

Stage of Development: In use.

Contact/Inventor:

1. Bruce Carroll, Professor, Mechanical and Aerospace Engineering, University of Florida, P.O. Box 116250, Gainesville FL, 32611-6250; Tel: 352-392-4943; Email: bfc@ufl.edu; URL: www.aero.ufl.edu/~bfc.
2. Photometrics, 3440 East Britannia Drive, Tucson, AZ 85706; Tel: 520-889-9933; URL: www.photomet.com.
3. Princeton Instruments, a division of Roper Scientific, Inc., 3660 Quakerbridge Road, Trenton, NJ 08619; Tel: 609-587-9797; URL: www.prinst.com.

33. SAFER (STEEL AND FOAM ENERGY REDUCTION) BARRIER

Characteristics: This composite material, also called soft walls, consists of either a steel skin or steel tubing, depending on the anticipated impact energy, and backing made of polystyrene blocks. It is designed for attachment to concrete walls to increase the survivability of drivers in any collision with concrete walls by absorbing the extremely high energy resulting from such impacts. Developed by the Midwest Roadside Safety Facility (MwRSF), the energy created in severe collisions is absorbed by the crash barrier in two parts. First, some of the energy is absorbed by the deformation of the steel tubing and the inertia needed to cause the tubing to deflect, then, as the wall deflects, the foam-block backing absorbs the remaining impact energy. Currently, these types of barriers are already being used in some speedways and already demonstrated positive results during the September 4-6, 2003, NASCAR tripleheader. Although there were multiple collisions that weekend between the vehicles and the barriers, not one driver was seriously injured. According to NASCAR, this type of crash system will be installed at all facilities hosting Nextel Cup Series events by January 2005.

Potential Use: Crash barrier at highway locations where fatal vehicular collisions with concrete barriers occur due to poor roadway alignment.

Stage of Development: Already being used in some speedways.

Contact/Inventor: Dean L. Sicking, Professor and Director, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, W348 Nebraska Hall, Lincoln, NE 68588-0531; Tel: 402-472-9332; Email: dsicking@unlinfo.unl.edu.

34. SELF-HEALING COATING

Characteristics: This material is made by adding an encapsulated healing agent to a suitable coating formulation. When the resulting coating is damaged, the healing agent is released, thus healing the coating and increasing its functional life.

Potential Use: Self-healing coating system for structural steels on bridges.

Stage of Development: This coating is designed for the healing agent to be released when the capsules are abraded or scratched. It is uncertain to what extent this would be beneficial if applied on structural steel members, where abrasion is not the main mode of coating failure. Therefore, additional investigation is needed to determine if such coating is relevant to structural steels of bridges; if so, further development may still be necessary.

Contact/Inventor:

1. Ashok Kumar, U.S. Army Construction Engineering Research Laboratory, P.O. Box 9005, Champaign, IL, 61826-9005.
2. L.D. Stephenson, U.S. Army Construction Engineering Research Laboratory, P.O. Box 9005, Champaign, IL 61826-9005.

35. SELF-HEALING COMPOSITE

Characteristics: This composite material contains an encapsulated healing agent that performs its function in accordance with known damage mechanisms to which composite members are susceptible. The agent is released when the damage occurs, and the injury "heals," thus increasing the material's functional life.

Potential Use: Lightweight bridge structural members that repair themselves.

Contact/Inventor:

1. Scott R. White, Professor, Department of Aeronautical and Astronautical Engineering, University of Illinois at Urbana-Champaign, Urbana, IL 61801; Tel: 217-333-1077; Email: swhite@uiuc.edu.
2. Carolyn Dry, Professor, School of Architecture, University of Illinois at Urbana-Champaign, 106 Architecture Building, Champaign, IL 61820; Email: c-dry@uiuc.edu.
3. Nancy R. Sottos, Professor, Department of Theoretical and Applied Mechanics, University of Illinois at Urbana-Champaign, 216 Talbot Laboratory, MC-262, 104 South Wright Street, Urbana, IL 61801-2983; Tel: 217-333-1041; Email: n-sottos@uiuc.edu; URL: http://www.tam.uiuc.edu/directory/faculty/sottos.html.
4. Sia Nemat-Nasser, Professor and Director, Center of Excellence for Advanced Materials, Professor of Mechanical and Aerospace Engineering, University of California, San Diego, 9500 Gilman Drive, La Jolla, CA 92093-0411; Tel: 858-534-4914; Email: sia@ucsd.edu.

36. SELF-HEALING CONCRETE

Characteristics: This concrete contains encapsulated healing agents that perform their functions in accordance to known damage mechanisms to which concrete members are susceptible . The agents, which can be a corrosion inhibitor and a crack sealant, are released when damage occurs, thereby healing the damage and increasing the functional life of a concrete member.

Potential Use: Concrete bridge members exposed to harsh environments and heavy traffic loads.

Contact/Inventor:

1. Carolyn Dry, Professor, School of Architecture, University of Illinois at Urbana-Champaign, 106 Architecture Building, Champaign, IL 61820; Email: c-dry@uiuc.edu.
2. Victor C. Li, Professor, Department of Civil and Environmental Engineering, University of Michigan, 2326 G. G. Brown Building, Ann Arbor, MI 48109-2125; Tel: 734-764-3368; Email: vcli@engin.umich.edu.

37. SHAPE-MEMORY POLYMER

Characteristics: These materials respond to change in temperature by either changing from a temporary shape to a predefined shape or by becoming highly elastic. This material has high biocompatibility and a unique combination of strength and permeability. These materials can be manipulated more than their metallic counterparts can and are generally less expensive.

Potential Uses:

1. Couplings and fasteners
2. Temperature sensor/membranes
3. Artificial blood vessels and muscles

Contact/Inventor:

1. Mitsubishi Heavy Industries, Chiyoda-ku, Tokyo, Japan; URL: http://www.mhi.co.jp.
2. MnemoScience GmbH, Pauwelsstrasse 19, D-52074 Aachen, Germany; Email: info@mnemoscience.de; URL: http://www.mnemoscience.de/htme/start.htm.

38. SMART BRICKS

Characteristics: Each brick has a combined system of a thermistor, two-axis accelerometer, multiplexer, transmitter, and battery to measure a building's temperature, vibration, and movement. The system, which currently uses off-the-shelf components, can be adapted into many other materials, such as concrete blocks, laminated beams, structural steel, etc. According to its developer, he ultimately would "like to fit everything onto one chip and then put that chip on a piece of plastic, instead of silicon [which is rigid and brittle], to make it more robust."

Potential Use: Built-in sensors for civil structures and pavements.

Contact/Inventor: Chang Liu, Professor, University of Illinois at Urbana-Champaign, 313 Microelectronics Lab, 208 North Wright Street, Urbana, IL 61801; Tel.: 217-333-4051; Email: changliu@uiuc.edu; URL: http://www.ece.uiuc.edu/faculty/faculty.asp?changliu.

39. SMART DUST

Characteristics: The material is created by etching one side of each silicon chip with a chemical, generating a colored mirrored surface with tiny pores. This porous surface is then made hydrophobic, or water repellent, by allowing a hydrophobic chemical to bind to it. Afterward, the other side of the chip is etched to create a porous reflective surface of a different color, followed by exposing the surface to air so that it becomes hydrophilic, or attractive to water. Using vibrations, these chips are then broken into tiny pieces, each about the size of the diameter of a human hair. Each piece is then a tiny "sensor" with one side attracted to water and the other repelled by water but attracted to oily substances. The tiny chips are green on one side and red on the other. Each mirrored surface can be modified to find and stick to a desired target and to adjust its color slightly to let the observer know what it has found. These dual-sided particles are capable of collecting at a target and then self-assembling into a larger, more visible reflector that can be seen from a distance. The material represents the first step toward the development of robots the size of sand grains.

Potential Use: The tiny "sand-grain robots" could be used in such applications as pollution monitoring, medicine, and bioterrorism.

Contact/Inventor: Michael J. Sailor, Professor, Department of Chemistry and Biochemistry, 0358, University of California, San Diego, 9500 Gilman Drive, La Jolla, CA 92093-0358, Tel: 858-534-8188; Email: msailor@ucsd.edu; URL: http://chem-faculty.ucsd.edu/sailor/info/index.html.

40. SMART FIBERS

Characteristics: These are optical fibers modified to include tiny strain sensors, which are laid up in a composite laminate that can be up to 10 km (6.2 miles) long. Real-time strains can be monitored with the aid of a computer as a structural "health check" for detecting damage and optimizing maintenance. These minute optical-fiber sensor arrays are unaffected by electromagnetic interferences as other types of strain sensors are.

Potential Use: Health monitoring of bridges, aerospace structures, offshore oil platforms, etc.

Contact/Inventor:

1. Smart Fibres, Ltd., C3 Centennial Court, Easthampstead Road, Bracknell, Berkshire, England, RG12 1YQ; Tel: +44 (0) 1344 484111; Fax +44 (0) 1344 423241; Email: info@smartfibres.com; URL: http://www.smartfibres.com/

2. Micron Optics Inc., 1852 Century Place NE, Atlanta, GA 30345; Tel: 404-325-0005; Fax: 404-325-4082; Email: moi@micronoptics.com; URL: http://www.micronoptics.com/index.html

41. SMART PAINTS

Characteristics: The uniqueness of this paint system is the presence of a coating degradation sensor that is made of specially designed silicon microspheres. These silicon microspheres contain the required electronics to conduct impedance measurements using tiny pins that pierce the substrate from underneath and then relay the information using wireless data transmission. It is reported that these sensors can be applied during the coating operation and then used to monitor the electrical impedance between two elements within a sensor or between the sensor and the metal substrate. The information gathered is useful for monitoring the life of the coating and determining if it will need repair in the future.

Potential Use: Monitoring condition of coatings, especially those in difficult-to-reach areas.

Contact/Inventor: Sean Brossia, Mechanical and Materials Engineering Division, Southwest Research Institute, P.O. Drawer 28510, San Antonio, TX 78228-0510; Tel: 210-522-5797; Email: sean.brossia@swri.org; URL: http://www.pub.swri.edu/4org/d20/ebs/correval/default.htm.

42. SMART POLYMERIC COATINGS

Characteristics: These are strippable coatings made of polymeric solutions or dispersions that can be applied to a contaminated surface by brushing or spraying. As the coating cures or dries, the contaminants are drawn and fixed into the polymer matrix. Incorporation of a suitable indicator serves to provide a color indication that a specific contaminant has been drawn into the coating. The contaminant is then effectively removed, in some degree, from the substrate by stripping off the coating.

Potential Use: Economical removal of lead from deteriorating old paints on structural steels.

Stage of Development: So far, the development work on this material has been aimed at its applications in decontamination of surfaces contaminated with radioactive substances (such as uranium, plutonium, etc.). For application in removal of lead in old bridges, a search for coating materials and a lead indicator suitable for this specific application would be required.

Contact/Inventor: H. Neil Gray, Professor, Department of Chemistry, The University of Texas at Tyler, 3900 University Boulevard, Tyler, TX 78799; Tel: (903) 566-7209; Email: ngray@mail.uttyl.edu. (Smart Polymeric Coatings for Surface Decontamination, *Industrial & Engineering Chemistry Research*, Volume 40, 2001, pp. 3540-3546.)

43. SOIL-DECONTAMINATING POLYMER NANOPARTICLES

Characteristics: These polymeric nanoparticles can remove polycyclic aromatic hydrocarbons (PAH) from soil while not sticking to the soil particles themselves. The unique size of the particles ensures the bound PAH will pass through the soil when flushed with water.

Potential Use: Remediation of soil contaminated with PAH.

Contact/Inventor:

1. Leonard W. Lion, Hollister Hall, School of Civil and Environmental Engineering, Cornell University, Ithaca, NY 14853; Tel: 607-255-7571; Email: lwl3@cornell.edu.
2. Claude Cohen, Olin Hall, School of Chemical Engineering, Cornell University, Ithaca, NY 14853; Tel: 607-256-7292; Email: cc@cheme.cornell.edu.

44. THERMAL SHAPE-MEMORY ALLOY

Characteristics: This material responds to temperature change by either changing from a temporary shape to a predefined shape (shape memory) or becoming highly elastic (superelasticity). Therefore, at the appropriate temperature, these materials can produce a force, a displacement, or both. Wires made of this material can contract 4%. The material exhibits up to 8% recoverable strain.

Potential Uses:

1. Retrofitting of historic structures for earthquake protection by energy dissipation
2. Advanced composite structures
3. Couplings, fasteners, and expandable plugs
4. Temperature sensors
5. Actuators
6. Fishing lines

Stage of Development: Commercially available.

Contact/Inventor:

1. DYNALLOY, 3194-A Airport Loop Drive, Costa Mesa, CA 92626-3405; Tel: 714-436-1206
2. Nitinol Devices & Components (NDC), 15500 Wayzata Boulevard., Suite 768-218, Wayzata, MN 55391; Tel: 952-404-1421
3. Johnson Matthey San Jose—Nitinol Products, 1070 Commercial Street, Suite 110, San Jose, CA 95112; Tel: 408-727-2221
4. Memry Corporation, 3 Berkshire Boulevard, Bethel, CT 06801; Tel: 203-739-1100
5. Intrinsic Devices, Inc., 2353 Third Street, San Francisco, CA 94107-3108; Tel: 415-252-5902

45. THERMAL-STRESS-MITIGATION MICROCAPSULES FOR CONCRETE

Characteristics: These microcapsules, used as a concrete admixture, contain a hydration retarder. They are designed to release the retarder when the concrete reaches a particular early age temperature to prevent excessive or flush heating of the concrete.

Potential Use: Admixture for concrete being placed in massive concrete structures or members in the summer.

Stage of Development: Commercially available.

Contact/Inventor:

1. Hirozo Mihashi, Professor of Building Engineering, Department of Architecture, Urban Planning and Building Engineering, Tohoku University, Japan; Email:mihashi@timos.str.archi.tohoku.ac.jp : URL: http://timos.str.archi.tohoku.ac.jp/. homepage/english/intro/mihashi/MIHASHI'S.Eng.html.
2. M. Hanada, Three Bond Co., Headquarters and R & D Laboratory, 1456 Hazama-cho, Hachioji-shi, Tokyo 193-8533, Japan.

46. TRANSPARENT TRANSISTOR

Characteristics: This transparent transistor is an n-type semiconductor made of zinc oxide. Using zinc oxide resulted in a transistor that is not only transparent but is also safe and inexpensive to manufacture.

Potential Use: Display devices in car windshields or window glasses.

Contact/Inventor: John F. Wager, Professor, School of Electrical Engineering and Computer Science, Oregon State University, 220 Owen Hall, Corvallis, OR 97331-3211; Tel: 541-737-2994; Email: jfw@eecs.oregonstate.edu; URL: http://www.ece.orst.edu/~jfw/.

47. URETHANE COATING FOR CATHODIC PROTECTION

Characteristics: This material was developed by NASA and is licensed to Cortec Corporation, which is marketing it as GalvaCorr™. It is a urethane coating that contains a blend of anodic metal particles and a hydroscopic (moisture-attracting) compound, which are applied to concrete structures using sprayers, rollers, or brushes. Upon electrically connecting the coating to the reinforcing steel, the metallic particles in the coating behave anodically to provide cathodic protection to the bars. The coating has excellent adhesion and can be applied to vertical surfaces or even the underside of a structure. It is estimated that the coating can provide 5 to 7 years of effective protection, and additional life can be achieved by re-applying the material.

Potential Use: Galvanic cathodic protection of reinforced concrete substructures, i.e., without requiring power source.

Stage of Development: Commercially available.

Cost: The estimated coating material cost to protect a structure is $5.80 per square foot.

Contact/Inventor:

1. Louis MacDowell and Joseph Curran, O&C Bldg-Room 3141, Mail Code YA-F2-T, Kennedy Space Center, FL 32899; Tel: 321-867-4550; Email: corrosion@ksc.nasa.gov (Project: KSC-12049).
2. J. Jackson Meyer, Cortec Corp., 4119 White Bear Parkway, St. Paul, MN 55110; Tel: 651-429-1100, Ext. 185.