Smart Materials and Products for Intelligent future, Automotive, Robotics, Aerospace and Defence Industry

Smart materials or Active materials or Functional materials are designed materials that have diverse, dynamic features that enable them to adapt to the environment. They have one or more properties that can be significantly changed in a controlled fashion by external stimuli, the stimulus and response may be mechanical, electrical, magnetic, optical, thermal, or chemical.

Numerous examples already exist. In recent MADMEC competition, a team of PhD students, developed a hydrogel that can be added to the surface of windows, making them switch from transparent to opaque in response to temperature. The hydrogel relies on a custom mixture of polymers that turns opaque as it absorbs heat – up until about 34 degrees Celsius – and then turns transparent and releases heat in response to cooling temperatures. "On a cold day, it's going to be clear, and on warmer day, if it gets really hot out, it's going to become opaque," said team member Seth Cazzell, a PhD student in DMSE. "What we have is this passive, self-shading device that responds to ambient temperature." Another US university project developed liquid crystal technology where liquid crystal display intensity. changes instantly according to the external light intensity.

There have been predictions that by 2025 there can be as many as 100 billion connected IoT devices or network of everyday objects as well as sensors that will be infused with intelligence and computing capability while controllable via the Internet. These devices may include food items, home appliances, plant control systems, equipment monitoring and maintenance sensors, industrial robots, and personal devices such as smart watches, digital glasses and fitness monitoring products. Smart materials are one of the enabling technologies of this intelligent future.

Military and aerospace also have large demand for smart materials and devices including smart self-repair, smart clothing such as cloaking suits, winglets in aeroplanes that adapt automatically to changing flight conditions and adaptive hull structures for ships. The technology has been used in the head up displays of fighter pilot helmets to enable them to see the visual display even under conditions of rapid change in light intensity like going from bright sunlight into cloud or from cloud into bright sunlight. Smart materials could change shape to unfold a solar panel on a space satellite without need of a battery-powered mechanical device.

Smart materials include self-healing materials, coatings with damage sensing, chemical sensing, friction changing, hydrophobicity changing capabilities, and also materials with several “smart” capabilities. They derive smart properties from structural patterning, often at the micro- or nanoscale, of already known material chemistries.

Engineers create programmable silk-based materials with embedded, pre-designed functions

Tufts University engineers have created a new format of solids made from silk protein that can be preprogrammed with biological, chemical, or optical functions, such as mechanical components that change color with strain, deliver drugs, or respond to light, according to a paper published online this week in Proceedings of the National Academy of Sciences (PNAS).

To develop these materials, the engineers began with silk cocoons and dissolved the silk fibers in a solution to create water suspensions of proteins, which were then re-assembled in solid block forms. They manipulated the bulk materials with water-soluble molecules to create multiple solid forms, from the nano- to the micro-scale, that have embedded, pre-designed functions.

For example, the researchers created a surgical pin that changes color as it nears its mechanical limits and is about to fail, functional screws that can be heated on demand in response to infrared light, and a biocompatible component that enables the sustained release of bioactive agents, such as enzymes.

Silk's unique crystalline structure makes it one of nature's toughest materials. Fibroin, an insoluble protein found in silk, has a remarkable ability to protect other materials while being fully biocompatible and biodegradable."Structural proteins are the building blocks of nature," Omenetto said. "Silk, in particular, possesses compelling properties," including its durability and biocompatibility. "We usually experience silk as a fibrillar material," Omenetto said, "but this format comes from the spinning process to which the protein undergoes in the spinneret of caterpillars and spiders

"The ability to embed functional elements in biopolymers, control their self-assembly, and modify their ultimate form creates significant opportunities for bio-inspired fabrication of high-performing multifunctional materials," said senior and corresponding study author Fiorenzo G. Omenetto, Ph.D

Researchers develop shape-changing smart material

Washington State University researchers have developed a unique, multifunctional smart material that can change shape from heat or light and assemble and disassemble itself. This is the first time researchers have been able to combine several smart abilities, including shape memory behavior, light-activated movement and self-healing behavior, into one material.

The work is led by Michael Kessler, professor and Berry Family director and in the WSU School of Mechanical and Materials Engineering (MME), and Yuzhan Li, MME staff scientist, in collaboration with Orlando Rios, a researcher at Oak Ridge National Laboratory.

The team worked with a class of long-chain molecules, called liquid crystalline networks (LCNs), which provide order in one direction and give material unique properties. The researchers took advantage of the way the material changes in response to heat to induce a unique three-way shape shifting behavior. They added groups of atoms that react to polarized light and used dynamic chemical bonds to improve the material's reprocessing abilities. "We knew these different technologies worked independently and tried to combine them in a way that would be compatible,'' said Kessler.

The resulting material reacts to light, can remember its shape as it folds and unfolds and can heal itself when damaged. For instance, a razor blade scratch in the material can be fixed by applying ultraviolet light. The material's movements can be preprogrammed and its properties tailored.

Military and Aerospace Applications

The demand for smart materials is being consistently driven by the growing need for such materials from the Military & Aerospace sector. Materials with enhanced functional properties such as shape memory, electrochromism and piezoelectricity, are gaining demand in the Automotive and Aerospace industries.

Piezoelectric materials are widely used in sensors and help in measuring fluid density, the force of impact, and fluid composition. These materials help in controlling the airflow across the wings of an aircraft and maintaining it during take-off and landing. Furthermore, these materials are also used to solve common problems with the aircraft, such as engine vibration, high cabin noise levels, ice formation on wings, flow separation due to turbulence, and control surfaces in cold climatic conditions. Also, piezoelectric materials find extensive applications in military and defense sector like smart sensors, smart nanorobotics, smart combat suits, and smart skins.

In aerospace, smart materials could find applications in ‘smart wings’, health and usage monitoring systems (HUMS), and active vibration control in helicopter blades.

In 2014 GM began adopting a shape-memory wire in the Corvette C7 in place of a motorized actuator which reduced vehicle weight as well as mechanical complexity by replacing a complex assembly with a single substance.

Morphing Wing

A traditional aircraft is optimized for only one or two flight conditions, not for the entire flight envelope. In contrast, the wings of a bird can be reshaped to provide optimal performance at all flight conditions. Any change in an aircraft’s configuration, in particular the wings, affects the aerodynamic performance, and optimal configurations can be obtained for each flight condition. Morphing technologies offer aerodynamic benefits for an aircraft over a wide range of flight conditions. The advantages of a morphing aircraft are based on an assumption that the additional weight of the morphing components is acceptable.

“Smart” materials and structures have the advantages of high energy density, ease of control, variable stiffness, and the ability to tolerate large amounts of strain. These characteristics offer researchers and designers new possibilities for designing morphing aircraft.

Shape memory alloys have attracted a great interest by many researchers as a promising morphing wing material because of its shape recovery upon application of voltage. Shape memory concept refers the property of a material or an alloy which regains its original shape when external load or electrical energy is applied. The design possibilities in the field of aerospace engineering are advanced by the unique thermal and mechanical properties of shape memory alloys now a day to improve the aerodynamic efficiency.

The types of morphing wings can be classified with regards to two purposes. The first one is to change the wing shape for the operating conditions or to improve the mobility. These morphing aircraft can perform multiple flight missions that are difficult to achieve using the fixed wing shape. The other one is to maximize the aerodynamic efficiency by substituting the section that causes aerodynamic losses.

BAE is building explosion-proof military tanks that ‘bounce back’ into shape

In military operations worldwide, the threat of explosives disabling convoys of armoured vehicles looms large. Many vehicles already have pretty formidable armour to protect them from blasts but despite this protection, the suspension is often destroyed on impact, rendering the vehicle immobile and a sitting duck.

Aerospace and defence firm BAE Systems is using a bendable titanium alloy made from the same type of material used in flexible glasses, which enables the vehicle’s suspension to return to its normal form after impact.

The design of the memory metal suspension was inspired by the hard shells and flexible legs of ironclad beetles. The insect’s exoskeletons are among the hardest of all arthropods.

Memory metal is presently used in bendable glasses and underwire bras and is a type of shape-memory alloy. These resiliant yet lightweight materials can be bent in any direction but will still return to their original shape. This is down to their superelasticity where the molecules inside the material pull back together after being moved and separated.

AFRL shape memory alloy (SMA) actuated release devices

The Air Force Research Laboratory (AFRL) has been actively developing low-shock, non-pyrotechnic spacecraft release devices to mitigate problems with traditional pyrotechnic devices. Specifically, pyrotechnic devices produce high shock, contamination, and have costly handling requirements due to their hazardous nature.

AFRL have provided funding for development and test of several shape memory alloy (SMA) actuated release devices. Through both ground testing and on-orbit performance, these devices have been shown to reduce shock by at least an order of magnitude, while remaining comparable in size and mass to pyrotechnic devices. The success of the low-shock devices is expected to pave the way for numerous applications, such as picosats, large spacecraft release, and fairing and stage separation.

Defence Research Establishment Ottawa, is investigating Smart structure technologies, based on a network of sensors and actuators, to increase the performance versatility and the structural stability of space structures. Large flexible space structures are required for phased arrays in space-based radar. These large space structures perform precision operations that require control of both rigid-body and elastic deformations.

EU-funded ADAM4EVE project for maritime

The EU-funded ADAM4EVE project, which ended in December 2015, has identified more than 20 innovative results that will pave the way for the development of new, adaptive, modern and efficient ship designs. Smart materials have been used to improve the ship’s performance as well as reduce the amount of energy needed for heating, cooling and passenger comfort.

Adaptive rudder-propeller can improve the manoeuvrability of a vessel. The rudder-propeller will allow the vessel to operate at design pitch when manoeuvring in port or locked at a 90-degree pitch in vertical plane in a seagoing condition.

Another development conceived by the project involved creating adaptive damping systems for thrusters in order to increase comfort levels on cruise vessels. Bow thrusters often produce high levels of noise and vibration but the easily-installed active control system reduces vibrations in areas where local modes are matched with the bow thruster excitation frequency

Results include adaptive windows for sailing yachts that allow the user to adapt the transparency of the yacht's windows to increase or reduce sunlight. Other results, for example adaptive hull structures, have proven to be feasible, but will require further research, development and testing before being ready for market introduction.

DARPA

The DARPA currently supports several programs with a focus on smart materials and structures. The Smart Materials and Structures Demonstration projects aim to show the value of smart materials-based actuation systems in realistic applications. The Compact Hybrid Actuators Program (CHAP) efforts focus on the development of new types of useful electro-mechanical and chemo-mechanical actuators that exceed the specific power and power density of traditional electromagnetic and hydraulic-based actuation systems by a factor of ten for a range of applications.

NASA's INSPACE

Furst, professor of chemical and biomolecular engineering and principal investigator of NASA's InSPACE (Investigating the Structures of Paramagnetic Aggregates from Colloidal Emulsions) project are creating smart materials based on self-assembly, having small building blocks that come together and arrange on their own to rapidly manufacture themselves.

The InSPACE project is using magnetorheological (MR) fluids in microgravity environment of space to study self-assembly. Under Earth's gravity, the magnetic particles are usually sitting against the bottom of their container, and the friction may prevent the chains from warping the way they do in space.

Artificial Camouflaging Skin

Researchers from the University of Bristol have created an artificial skin based on electroactive dielectric elastomer, a soft, compliant smart material, mimicking the biological chromatophores responsible for camouflaging of the squid. Chromatophores are small pigmented cells embedded on cephalopods skin which can expand and contract and that work together to change skin colour and texture.

Aaron Fishman, Visiting Fellow in Engineering Mathematics, said: “Our ultimate goal is to create artificial skin that can mimic fast acting active camouflage and be used for smart clothing such as cloaking suits and dynamic illuminated clothing.”The cloaking suit could be used to blend into a variety of environments, such as in the wild. It could also be used for signalling purposes, for example search and rescue operations when people who are in danger need to stand out.”

Challenges

Developing Smart materials and products have many challenges like novel fabrication techniques (e.g. dispersion, alignment); in-process metrology; material characterization and in-situ monitoring; yield optimization; accelerated life tests to determine material durability and techniques to advance disassembly and recovery at end of life

Optomec Breakthrough in 3D Printing

Enables Micron-scale Smart Structures

Optomec, a leading global supplier of production grade additive manufacturing systems for 3D printed electronics and 3D printed metals, today announced its Aerosol Jet Technology can enable 3D polymer and composite structures to be printed at the micron scale with embedded electronics. This breakthrough has significant potential to reduce the cost and size of next-generation products used in the electronics and bio-medical industries.

This new capability is enabled by combining Optomec's proven Aerosol Jet solution for fine feature printing with a proprietary in-situ curing capability for rapid on-the-fly solidification. Unlike other high resolution 3D printing approaches that deposit material globally, ie: in a powder bed, and then cure locally to define a pattern, the Optomec method relies on both local deposition and local curing. This makes the process more economical, in terms of material consumption, but is also key to enabling the highest resolution features available.

"This breakthrough in 3D printing technology extends additive manufacturing to the creation of micron scale, free-form polymer structures and smart devices," said Mike O'Reilly, Optomec Director Aerosol Jet Product Management. Early adopter customers have already developed innovative applications for smart devices and micro-fluidic applications. "We continue to place emphasis on innovation such as Aerosol Jet 3D micro-structure printing to address our customer's next generation product development challenges."

Using this process high aspect ratio, free-form 3D structures can be printed at the micron-scale, without the need for support structures, from materials including photopolymers and certain composites.

Additionally, the resulting structures can be metallized with conformal 3D conductive traces and printed functional components, such as antennas and sensors, to create fully functional 3D components all in one manufacturing machine. This direct digital approach optimizes the fabrication process, reducing manufacturing steps and material usage making Aerosol Jet 3D micro-structure printing a cost-effective, green technology.

Aerosol Jet 3D micro-structure printing is capable of ultra-high resolutions with lateral features sizes down to 10 microns, and lateral and vertical build resolutions from 1 micron to 100 nanometers respectively. Aspect ratios of more than 100:1 have been achieved. Additionally, such 3D micro-structures can be printed onto existing components and products, such as semiconductor chips, medical devices or industrial parts.

Future growth

Transparency Market Research (TMR), has published a new report titled "Smart Materials Market – Global Industry Analysis, Size, Share, Growth, Trends and Forecast, 2014 – 2020." According to the report, the global smart materials market was valued at US$ 27.74 Bn in 2013 and is projected to reach US$ 63.28 Bn by 2020, expanding at a CAGR of 12.5% between 2014 and 2020.

Technavio's market research analysts have estimated the global piezoelectric smart materials market to grow at an impressive CAGR of close to 13% over the forecast period. The increasing demand for piezoelectric smart materials from the military and aerospace sector is expected to drive the market for piezoelectric smart materials globally. The increasing demand for MEMS sensors, used in airbags and anti-lock braking systems, will translate into the demand for piezoelectric smart materials in the Americas. The market for piezoelectric smart materials will account for a market share of more than 47% until the end of 2020.

According to report published by Grand View Research, global smart coating market is expected to reach USD 11,676.0 million by 2024, owing to the rising demand from key end-user segments including military, aerospace, automotive, and healthcare. Growing application scope in end-use industries is attributed to superior properties including self-healing, self-cleaning and antimicrobial properties.

Key participants in the industry include BASF SE, DuPont, 3M Company, PPG Industries, Dow Chemicals, and Dow Corning, among others.

Smart Materials and Devices

Mostly, “smart” materials are embedded in systems whose inherent properties can be favorably changed to meet performance needs. There are four of these aspects of which at least one is incorporated in a functional smart-material based device: smart materials can be sensors or actuators, they can be controlled or they can have biomimetic characteristics, according to Seung-Bok Choi of Department of Mechanical Engineering, Inha University, Incheon, South Korea.

Sensors are either bonded to the surface of a structural material or are embedded within a smart material to produce an electric signal proportional to the static or dynamic changes in the structural material.

Actuators are typically excited by an external stimulus, such as electricity, in order to change the stiffness and damping properties in a controlled manner. The control capability permits the dynamic behavior of the material to respond to an external stimulus according to a prescribed control algorithm associated to microprocessors.

Biomimetic characteristics are inspired by biological patterns in order to equip materials with the possibility of selfdiagnosis, self-repair, and self-degradation of a broad range of structural materials.

Smart materials and structures have widespread applications in

1. Materials science: composites, ceramics, processing science, interface science, sensor/actuator materials, chiral materials, conducting and chiral polymers, electrochromic materials, liquid crystals, molecular-level smart materials, biomaterials.
2. Sensing and actuation: electromagnetic, acoustic, chemical and mechanical sensing and actuation, single-measurand sensors, multiplexed multimeasurand distributed sensors and actuators, sensor/actuator signal processing, compatibility of sensors and actuators with conventional and advanced materials, smart sensors for materials and composites processing.
3. Optics and electromagnetics: optical fibre technology, active and adaptive optical systems and components, tunable high-dielectric phase shifters, tunable surface control.
4. Structures: smart skins for drag and turbulence control, other applications in aerospace/hydrospace structures, civil infrastructures, transportation vehicles, manufacturing equipment, repairability and maintainability.
5. Control: structural acoustic control, distributed control, analogue and digital feedback control, real-time implementation, adaptive structure stability, damage implications for structural control.
6. Information processing: neural networks, data processing, data visualization and reliability.

Classes of Smart Materials

The most promising materials with the above features are piezoelectric materials, magnetostrictive materials, magnetorheological (MR) fluids, electroactive polymers (EAPs), shape memory alloys, and electrostrictive materials.

Piezoelectric materials are materials that produce a voltage when stress is applied. Since this effect also applies in the reverse manner, a voltage across the sample will produce stress within the sample. Suitably designed structures made from these materials can therefore be made that bend, expand or contract when a voltage is applied. Piezoelectric materials are being used for contact sensors for alarm systems and in microphones and headphones.

Magnetorheological fluids are smart suspensions of soft magnetizable particles in non-magnetic liquid medium whose phase and rheological properties can be altered by an external magnetic field. They are commercially applied in a broad spectrum of areas due to their field-tunability. Shock absorbers, brakes, clutches, seismic vibration dampers, control valves, and precision polishing are just a few examples to illustrate their use.

Electroactive polymers are polymer-based composites in which electronic or ionic properties are embedded. EAPs exhibit a large displacement in response to external stimuli and hence can offer operational similarity to biological muscles. This is the reason why EAP materials have a really promising future in biologically inspired actuators.

They may drive various mechanisms for manipulation and mobility including microrobots, micro flying objects, tactile, and animatronic devices. Generally, the EAPs are divided into two major categories based on their activation mechanisms: electronic (driven by electric field or Coulomb forces) and ionic (involving mobility or diffusion of ions).

Article sources also include:

http://www.technavio.com/report/global-metals-and-minerals-piezoelectric-smart-materials-market

http://www.dailymail.co.uk/sciencetech/article-3408052/Robots-rot-Future-androids-biodegradable-smart-materials-decompose-like-humans.html

http://www.safety4sea.com/how-smart-materials-and-structures-can-be-used-by-european-shipbuilding-industry/

https://news.wsu.edu/2016/06/30/researchers-develop-shape-changing-smart-material/

https://www.novapublishers.com/catalog/product_info.php?products_id=4352

http://www.optomec.com/optomec-breakthrough-3d-printing-enables-micron-scale-smart-structures/

http://news.mit.edu/2016/materials-science-innovation-display-madmec-1012

https://www.yahoo.com/tech/engineers-create-silk-based-materials-195053532.html

http://www.dailymail.co.uk/sciencetech/article-3956736/BAE-building-explosion-proof-military-tanks-bounce-shape-inspired-ironclad-BEETLES.html