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SMART MATERIALS [SMS] FOR TODAY'S SMART CITIES: THE DAWN OF A NEW SMART ERA

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Abstract: - An overview is presented of the current research and development of smart materials, including shape-memory alloys, shape-memory ceramics, shape-memory polymers, smart planes, intelligent houses, shape memory textiles, micromachines, self-assembling structures, color-changing paint and nano systems. Th smart materials exhibit some novel performances, such as sensoring (thermal, stress or field), large-stroke actuation, high damping, adaptive responses, shape memory and superelasticity capability, which can be utilized in various engineering approaches to smart systems. Smart Materials has emerged as a very innovative product and brought a revolution in many fields including automobile industry, smart architecture and on the whole developing a new Smart City. This paper also includes a case study of the Smart City: London as well as a smart car which can be developed using smart materials.

Keywords: Smart Materials, shape changing materials, Smart City London, Smart Car

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INTRODUCTION

The vocabulary of the material world has changed dramatically since 1992, when the first 'smart material' emerged commercially in, of all things, snow skis. Defined as 'highly engineered materials that respond intelligently to their environment', smart materials have become the 'go-to' answer for the 21st century's technological needs.

NASA is counting on smart materials to spearhead the first major change in aeronautic technology since the development of hypersonic flight, and the US Defense Department envisions smart materials as the linchpin technology behind the 'soldier of the future', who will be equipped with everything from smart tourniquets to chameleon-like clothing. At the other end of the application spectrum, toys and equipment as ubiquitous as laser printers and automobile airbag controls have already incorporated numerous examples of this technology during the past decade. It is the stuff of our future even as it has already

percolated into many aspects of our daily lives.

Materials like Shape memory alloys and superelastic alloys respond to temperature changes and mechanical stresses in non-conventional and highly amazing ways. Therefore, they are called "Smart Materials". It is now generally accepted that a smart structure is a structure system with macroscopically embedded or built-in sensors, actuators and is usually monitored or controlled by an external microprocessor or a computer. A smart or intelligent material refers to the material which has intrinsic sensing, actuating and controlling or information-processing capabilities in its microstructure. The smart materials and structures are supposed to be able to respond to environmental changes at the most optimum conditions and manifest their own functions according to the changes, that is, they can respond in a pre-determined manner and extent in an appropriate time with an environmental stimulus and then revert to their original states as soon as the stimulus is removed. [11] Shape-memory materials (SMMs) are one of the major elements of intelligent/smart composites because of their unusual properties, such as the shape-memory effect (SME), pseudoelasticity or large recoverable stroke (strain), high damping capacity and adaptive properties which are due to the (reversible) phase transitions in the materials. SMMs may sense thermal, mechanical, magnetic or electric stimulus and exhibit actuation or some pre-determined response, making it possible to tune some technical parameters such as shape, position, strain, stiffness, natural frequency, damping, friction and other static and dynamical characteristics of material systems in response to the environmental changes. To date, a variety of alloys, ceramics, polymers and gels have been found to exhibit SME behavior. Both the fundamental and engineering aspects of SMMs have been investigated extensively and some of them are presently commercial materials. Particularly, some Smart Materials can be easily fabricated into thin films, fibers or wires, particles and even porous bulks, enabling them feasibly to be incorporated with other materials to form hybrid composites. [11]

This paper consists of a review of smart materials and their types, their applications for Today's Smart City with a case study of the Smart City: London and a case study on today's smart car which can be based on the smart materials like shape memory alloys.

2. Major Types of Smart Materials

Smart materials may be easily classified in two basic ways. In one construct we will be referring to materials that undergo changes in one or more of their properties – chemical, mechanical, electrical, magnetic or thermal – in direct response to a change in the external stimuli associated with the environment surrounding the material. Changes are direct and reversible – there is no need for an external control system to cause these changes to occur. A photochromic material, for example, changes its color in response to a change in the amount of ultraviolet radiation on its surface. The phase transformations in the shape-memory materials are accompanied by remarkable or even drastic changes in the physical and mechanical properties, such as yield stress, elastic modulus, hardness, damping, shape recovery, thermal conductivity, thermal expansion coefficient, resistivity, magnetic susceptibility, flexibility, vapour permeability, shape fixity and dielectric constant, enabling the materials to exhibit some novel functions or making them adaptable to the external changes in temperature, stress, magnetic or electrical field. In general, the following features or inherent primitive intelligence of smart materials may be utilized in various envisaged engineering approaches for smart systems:

2.1. Type 1 Smart Materials

2.1.1. Thermochromic – an input of thermal energy (heat) to the material alters its molecular structure. The new molecular structure has a different spectral reflectivity than does the original structure; as a result, the material's 'color' – its reflected radiation in the visible range of the electro-magnetic spectrum – changes.

2.1.2. Magnetorheological – the application of a magnetic field (or for electrorheological – an electrical field) causes a change in micro-structural orientation, resulting in a change in viscosity of the fluid.

2.1.3. Thermotropic – an input of thermal energy (or radiation for a phototropic, electricity for electrotropic and so on) to the material alters its micro-structure through a phase change. In a different phase, most materials demonstrate different properties, including conductivity, transmissivity, volu-metric expansion, and solubility.

2.1.4. Shape memory – an input of thermal energy (which can also be produced through resistance to an electrical current) alters the microstructure through a crystalline phase change. This change enables multiple shapes in relationship to the environmental stimulus.

2.2. Type 2 Smart Materials.

2.2.1. Photovoltaic – an input of radiation energy from the visible spectrum (or the infrared spectrum for a thermo-photo-voltaic) produces an electrical current (the term voltaic

refers more to the material which must be able to provide the voltage potential to sustain the current).

2.2.2. Thermoelectric – an input of electrical current creates a temperature differential on opposite sides of the material. This temperature differential produces a heat engine, essentially a heat pump, allowing thermal energy to be transferred from one junction to the other.

2.2.3. Piezoelectric – an input of elastic energy (strain) produces an electrical current. Most piezoelectrics are bi-directional in that the inputs can be switched and an applied electrical

current will produce a deformation (strain).

2.2.4. Photoluminescent – an input of radiation energy from the ultraviolet spectrum (or electrical energy for an electro-luminescent, chemical reaction for a chemoluminescent) is

converted to an output of radiation energy in the visible spectrum.

2.2.5. Electrostrictive – the application of a current (or a magnetic field for a magnetostrictive) alters the inter-atomic distance through polarization. A change in this distance changes the energy of the molecule, which in this case produces elastic energy – strain. This strain deforms or changes the shape of the material.

3. Applications: Smart City.

3.1. Applications in Architecture:

The use of materials that change their properties in reaction to heat, moisture or light can “revolutionize” architecture in developing today’s Smart City.

3.1.1. Buildings of the future can change colour, size, shape and opacity in reaction to stimuli. Architects can design buildings that change their geometry according to the weight of the people inside.

3.1.2. Shape changing window panes and glasses according to the sun rays, window shades that turn up or down automatically sensing the heat in the room.

3.1.3. Shape changing roofs that change their shapes according to the rain or heat.

3.1.4. Case Study: Smart City: London

Home to world-leading academic institutions and the ‘Tech City’ cluster, London has access to some of the best specialist talent in the world. It has capabilities to develop next generation data science infrastructure and the services that will flow from it. It has ideal test-bed markets too. London’s citizens are early adopters of technology, engaged and prepared to move to a new era, already using intelligent products, technologies and services swiftly, and at scale.

3.1.4.1. Innovate UK and the Engineering and Physical Sciences Research Council (EPSRC) invested up to £6 million in collaborative research and development (R&D) projects to encourage the development of smart products that use a combination of functional, hybrid and multiple materials.

3.1.4.2. Medical devices

Shape memory alloys, metal alloys that can be arranged to have a geometrical memory, are used to good effect in many areas of the human body, exploiting the unusual properties of the metal. Cardiovascular disease and orthopedic trauma and disease use shape memory alloys to open up blocked arteries, reduce and stabilize bone fractures and minimally invasive treatment, using stent/grafts to address aneurismal, particularly abdominal and thoracic aneurysms that occur in the aorta. Although the preferred metal alloy consists of almost equal proportions of nickel and titanium, the reactivity of titanium to oxygen, produces a resilient titanium oxide on the surface of the alloy, this is another form of diffusion barrier and a film that prevent intimate contact between the alloy and surrounding tissue. The memory recovery of Ni|Ti has been used to good effect for a unique steerable catheter project, funded in part by UK’s NHS: the rationale for this is to enable a catheter to pass through difficult anatomy, often too challenging for the medical specialist to attempt. The device has small pieces of shape memory alloy disposed at its tip, each piece of metal is electrically heated, as it become warm; it deflects the catheter tip in a controllable and precise way. The physical properties and biological response of medical devices made from Ni\Ti shape memory alloy have been investigated and characterized in ETC. In addition, several diverse industrial applications have been created.

3.1.4.3. Automating the application of smart materials for protein crystallization

The fabrication and validation of the first semi-liquid non-protein nucleating agent to be administered automatically to crystallization trials is reported. This research builds upon prior demonstration of the suitability of molecularly imprinted polymers (MIPs; known as `smart materials') for inducing protein crystal growth. Modified MIPs of altered texture suitable for high-throughput trials are demonstrated to improve crystal quality and to increase the probability of success when screening for suitable crystallization conditions.

3.1.4.4. Lambs Industries in London have developed a completely new generation of smart materials that combine touch sensitivity with luminosity, based on latest developments in polymeric piezo materials and flexible OLEDs.

They are known as Light Touch Matters.

3.1.4.5. The wearable-technology wizards at Cute Circuit have unveiled ready-to-wear versions of the label’s scene-stealing creations, including a knee-length interpretation of Perry’s LED-studded Met Gala gown from 2010. Much like the original, the K-Dress features hundreds of rainbow-colored LEDs tucked within hand-pleated folds of silk chiffon and taffeta. At the command of a built-in USB controller, the lights flash and strobe in a pattern of your choosing, lasting up to two hours on a single charge.

3.2. Applications in Automobile industry:

The properties inherent in shape memory alloys and polymers have the potential to be game-changers in the automotive advanced materials field, eventually leading to vehicle subsystems that can self-heal in the event of damage, or that can be designed to change color or appearance. Considering there are about 200 motorized movable parts on the typical vehicle that could be replaced with lightweight smart materials, SMMs can bring significant mass reduction in today’s smart cars. This removes unwanted mass, which can help improve vehicle performance and fuel economy.

3.2.1. Case Study: Smart Car:

3.2.1.1. Actuator:

Actuators are devices which perform a task, like moving an object, either on demand or in response to certain changes in their environment (temperature, pressure, etc). In a modem car more than 100 actuators are used to control engine, transmission and suspension performance, to improve safety and reliability and enhance driver comfort. Most of these actuators today are electric motors, solenoids, thermo bimetals, wax motors, vacuum or pressure actuators. Shape memory actuators can be used in two basically different ways: as thermal or as electrical actuators.

Thennal actuators combine the sensing and the actuating functions, responding to a temperature change by changing shape and generating a force.

The function of electrical actuators, on the other hand, is simply to move an object or perform a task on demand. Usually, a current is passed through the shape memory actuator, internally heating it above Af to recover its shape.

Using Lightweight shape memory alloy wire in place of a heavier motorized actuator to open and close the hatch vent that releases air from the trunk. This allows the trunk lid to close more easily than on the previous models, where trapped air could make the lid harder to close.

Potential applications of shape memory thermal actuators in automobiles: (1) radiator shutter; (2) fan cutch; (3) fuel management; (4) climate control; (5) engine control; (6) brake ventilation; (7) transmission control/rattling noise reduction; (8) suspension adjustment.

Potential applications for electrical shape memory actuators in automobiles: (1) fog lamp louver (2) engine hood lock; (3) retractable headlight; (4) fuel management; (5) engine control; (6) transmission control; (7) climate control; (8) wiper pressure control; (9) rear-view mirror adjustment; (10) seatbelt adjustment; (II) central locking system; (12) shock absorber adjustment; (13) filler inlet lock; (14) trunk lock

3.2.1.2. Louver System:

To control of the airflow into the engine, a shape memory alloy-activated louver system can be used. This smart material functions to reduce the cooling airflow into the engine compartment and reduces aerodynamic drag. The result is improved aerodynamics and drag reduction and rapid warm-up during cold engine start up.

3.2.1.3. Air Dams:

While air dams are frequently damaged by low-speed impacts during parking situations and certain objects like ramps, snow, and ice, an "active" air dam that is activated by a shape memory alloy can be developed. The active air dam can monitor vehicle speed, and with the use of 4-wheel drive (4WD) configuration, the vehicle lowers or raises the air dam to improve the vehicle's aerodynamic drag.

3.2.1.4. Grab Handle:

A grab handle can be designed that also uses shape memory alloys to move into position by using a temperature-activated shape memory combined with the changes in the handle's stiffness.

3.2.1.5. Steering innovation in vehicle design

A 4 Wheel drive can be designed with the use of smart materials with a center of turning circle at 180 C. This helps the vehicle to move sideways which is easier for small parking spaces.

3.2.1.6 Compression and expansion of chassis:

To increase or decrease the chassis of the car smart materials can be used that helps in movability in small places.

3.2.1.7. Sensitive Governor Valve

One successful application is a temperature sensitive governor valve, which controls the shifting pressure in automatic transmissions. At low temperatures, the spring force of a steel bias spring is higher than that of the Ni·Ti shape memory spring in the martensitic state. Consequently, the steel spring can compress the Ni·Ti spring, pushing the moveable piston of the valve into the 'closed' position for this particular application, When the temperature of the transmission and the transmission fluid increases to operating temperature, the Ni·Ti shape memory spring in the martensitic state. This expands, overcoming the steel spring force, and eventually, pushing the piston into the 'open' position. This pressure regulating valve improves the cold start performance of the transmission, allowing smoother shifting at low temperatures (Figure 5). Other shape memory governor valves control the warm up phase of automatic transmissions, reducing smog emission and fuel consumption.

4. Technical challenges and perspectives

Among the smart materials, SMAs have the largest output energy density, and can provide the greatest displacements or strokes. However, shape-memory materials do have some shortcomings to be overcome before their engineering significance is more widely recognized in the industrial world. The problems addressed range from fundamental to engineering aspects: fabrication and processing of demanding high quality and low-cost materials; precise prediction and modeling of the material behavior and optimal design; controlling the microstructures and, above all, tailoring some crucial technical parameters such as characteristic transformation temperatures within desirable range; clear understanding of the origins of such issues as hysteresis, phase instabilities and ageing effects, degradation and fatigue, etc. In addition to the efforts to improve the even commercial materials, new shape-memory materials with higher technical quality should be designed and developed to meet the increasing demand of the Hi-tech society. Of particular technical significance are new shape-memory materials that can provide large displacements, huge stresses and exhibit superior dynamic response. This can be approached in two ways. The first route is to incorporate SMMs with other structural or functional materials to form hybrid composites which will benefit from individual component materials, thereby achieving compromised but optimized overall performance of the component materials system. For instance, the main disadvantages of SMAs are there in superior dynamic response and low efficiency. Meanwhile, the conventional piezoelectric or electrostrictive ceramics have a superior dynamic response but their displacements are quite small and most of them are very brittle. Combining SMAs with piezoelectric or magnetostrictive materials, field-activated smart composites can be designed, which may generate a larger displacement than conventional piezoelectric ceramics or magnetostrictive materials and have an improved dynamic response as compared to monolithic SMAs. More recently, some pioneers have explored the technical feasibility of smart thin-film heterostructures by depositing the SMA thin films on piezoelectric or magnetostrictive substrates. However, the complexity of the fabrication processing and the interface bonding and dynamic coupling of dissimilar components remain tough issues for the composites [213]. The alternative is to improve the monolithic shape memory materials by employing new processing techniques or to design a new generation of shape-memory materials. The development of deposited thin-film shape-memory alloys, as we described above, is one of the efforts directed to this objective. Also worth mention are the recently developed porous shape-memory alloys [214, 215]. Bulk Ti—Ni alloys with different porosity, exhibiting superelasticity and shape-memory effect; have been successfully manufactured via the powder metallurgical route. The porous SMAs are very desirable for some biomedical applications because the alloys have good biocompatibility and their porous structure favors in-growth of living tissues and firm fixation. Naturally, it reminds us of bone — a typical biometric model. Bone is also porous; moreover, it exhibits pyro electricity and piezoelectricity, and maintains the skeletal homeostasis and mineral homeostasis for the body [1]. After the model, biometric artificial bone materials based on the porous SMAs and other advanced materials may be developed. For instance, micro balloons or micro tubes coated by some functional material layers can be constructed in the porous SMAs which may provide a suitable substrate or skeleton to grow hetero structures with certain intelligence. In principle, the deformation of the poly domains in the ferromagnetic and ferroelectric materials by applying external fields can be controlled just the same way as the stress-induced deformation of the marten sites in ferroelastic SMAs. The next challenging objective, therefore, is to explore new potentially commercial materials wherein the martensitic-like transformations and the reorientation of the domains can be induced by magnetic fields or electric fields at ambient temperatures. The design concepts and strategies for finding new ferromagnetic and ferroelectric shape-memory materials have been proposed [142, 205—211]. In this aspect, the remarked common features shared by several smart material systems, and the successful development story of the giant magnetostrictive materials Terfenol-D [176, 216—218] may offer some clues or inspirations.

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