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Smart Materials & its Applications

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Abstract: Application of smart materials in various industries offer new opportunities for safety enhancement, life-cycle cost reduction, and performance improvement. Smart materials have been around for many years and they have found a large number of applications. The use of the terms 'smart' and 'intelligent' to describe materials and systems came from the US and started in the 1980's despite the fact that some of these so-called smart materials had been around for decades. Many of the smart materials were developed by government agencies working on aerospace and military projects but in recent years their use has transferred into the civil sector for applications in the construction, transport, medical, domestic areas, manufacturing. There are many groups of smart materials, each exhibiting particular properties which can be controlled in a variety of high-tech and everyday applications. This paper provides an overview of present smart materials and describes the different types of smart materials in terms of how they work, what types of materials are used and where they are used.

Keywords: life-cycle cost reduction, intelligent, high-tech

I. Introduction

Smart materials are materials that have one or more properties that can be significantly changed in a controlled fashion by external stimuli, such as stress, temperature, moisture, pH, electric or magnetic fields. For example, photochromic materials that change colour in response to light; shape memory alloys and polymers which change/recover their shape in response to heat and electro magneto-rheological fluids that change viscosity in response to electric or magnetic stimuli. Smart Materials can be used directly to make smart systems or structures or embedded in structures whose inherent properties can be changed to meet high value-added performance needs. Smart Materials technology is relatively new to the economy and has a strong innovative content. In construction, smart materials and systems could be used in 'smart' buildings, for environmental control, security and structural health monitoring e.g. strain measurement in bridges using embedded fibre optic sensors. Magneto-rheological fluids have been used to damp cable-stayed bridges and reduce the effects of earthquakes. In aerospace, smart materials could find applications in 'smart wings', health and usage monitoring systems (HUMS), and active vibration control in helicopter blades. In marine and rail transport, possibilities include strain monitoring using embedded fibre optic sensors. Smart material can exist in two phases at different temperatures: Austenite, which exists in high temperature, and Martensite, which exists in low temperature. When the external temperature or stress condition changes, these two phases will transform to the other phase, depending on what change appears. Smart material exhibits many special properties during the transformations between these two phases, such as shape memory effect, super elasticity effect, and two-way memory effect, etc.

With the development of material science, many new, high-quality and cost-efficient materials have come into use in various field of engineering. In the last ten decades, the materials became multifunctional and required the optimization of different characterization and properties. With the last evolution, the concept has been driving towards composite materials and recently, the next evolutionary step is being contemplated with the concept of smart materials. Smart materials are new generation materials surpassing the conventional structural and functional materials. These materials possess adaptive capabilities to external stimuli, such as loads or environment, with inherent intelligence. (Rogers, 1988; Rogers et al., 1988) defined smart materials as materials, which possess the ability to change their physical properties in a specific manner in response to specific stimulus input. The stimuli could be pressure, temperature, electric and magnetic fields, chemicals, hydrostatic pressure or nuclear radiation. The associated changeable physical properties could be shape, stiffness, viscosity or damping. Takagi (1990) explained it as intelligent materials that respond to environmental changes at the most optimum conditions and reveal their own functions according to the environment. Smartness describes self-adaptability, self-sensing, memory and multiple functionalities of the materials or structures. These characteristics provide numerous possible applications for these materials and structures in aerospace, manufacturing, civil infrastructure systems, biomechanics and environment. Self-adaptation characteristics of smart structures are a great benefit that utilizes the embedded adaptation of smart materials like shape memory alloys. By changing their properties, smart materials can detect faults and cracks and therefore are useful as a diagnostic tool. [1] This characteristic

can be utilized to activate the smart material embedded in the host material in a proper way to compensate for the fault. This phenomenon is called self-repairing effect.

II. Applications of Smart Materials

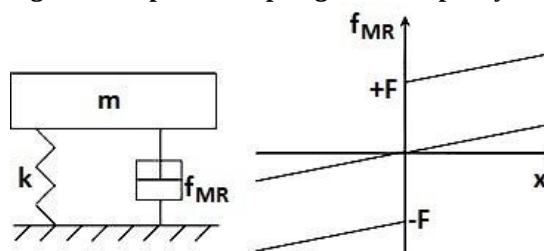
General Applications:

- Aerospace
- Mass transit
- Marine
- Automotive
- Computers and other electronic devices
- Consumer goods applications
- Civil engineering
- Medical equipment applications
- Rotating machinery applications

More specific applications:

- Sensors built into aircraft will let maintenance people know when repairs or more sophisticated inspections are required.
- In Nuclear Industries: Smart technology offers new opportunities in nuclear industrial sector for safety enhancement, personal exposure reduction, life-cycle cost reduction and performance improvement. However, the radiation environments associated with nuclear operations represent a unique challenge to the testing, qualification and use of smart materials. However, the use of such smart materials in nuclear facilities requires knowledge about the materials respond to irradiation and how this
- Reducing Food Waste: Food makes up maximum waste among all others. Most of the food grown for consumption is thrown away without consumption due to their reaching of expiry date. These dates are conservative estimates and actual product life may be longer. Manufacturers are now looking for ways to extend product life with packaging by utilizing smart materials. As food becomes less fresh, chemical reactions take place within the packaging and bacteria build up. Smart labels have been developed that change colour to indicate the presence of an increased level of a chemical or bacteria in it. Storage temperature has a much greater effect than time on the degradation of most products. Some companies have developed 'time-temperature indicators' that change colour over time at a speed dependent on temperature.
- Smart materials are beginning to play an important role in civil engineering designs for dams, bridges, highways, and buildings. Are useful also to remove corrosion of a Navy Pier and also engineers are introducing sheets of composites materials containing sensors that will alert maintenance engineers to the need for repairs.
- Other important industry that are including Smart Materials they are working in a project to develop smart car seats that can identify primary occupants and adapt to their preferences for height, leg-room, back support, and so forth.
- Technology also exists to enable cars to tell owners how much air pressure tires have, when oil changes are needed, and other maintenance information. Developing solid state and smart materials technologies will bring costs down.
- Another important application is using the MR (magneto-rheological) fluid. The MR damper developed at the Intelligent Structures and Systems Lab uses the mixed mode configuration as shown in Fig.1.1. The MR damper has a built-in MR valve across which the MR fluid is forced. The piston of the MR damper acts as an electromagnet with the required number of coils to produce the appropriate magnetic field. Also the MR damper has a run-through shaft to avoid an accumulator for the design of cars.

Fig1.1 A simple mass-spring-MR damper system



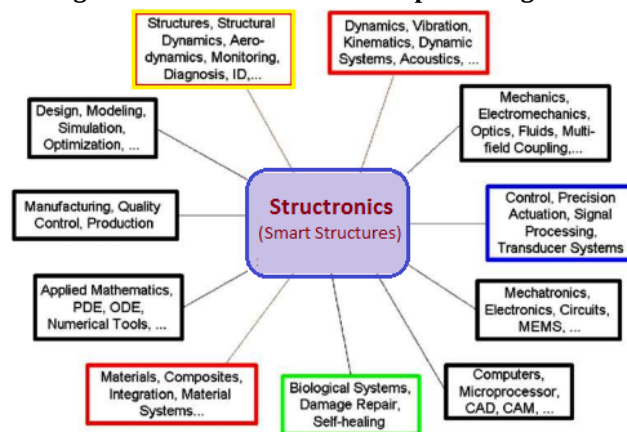
Other applications using MR fluids are:

- Since MR fluids have a very high yield stress they can be used to control the transmission of torque in rotating machinery too. For example, they may be used in an automotive power train to transmit torque from the engine to the transmission and the vehicle.

- Advanced Control System Design using MR dampers- MR dampers can also be used to achieve sliding mode control in vibrating systems like seat suspensions, vehicle suspensions, washing machines and prosthetic devices.
- Modeling and control of active spiral and patch antennas.
- Self-healing of Polymeric and Composite Materials :

The remarkable ability to cure wounds is one of the most important inherent properties of biological systems. A bio-inspired self-healing material is one with built-in capability to partially repair damage sustained during service. Usually, material properties degrade over time due to the initiation and subsequent growth of damage such as micro cracks. The biological world demonstrates a range of mechanisms that continuously sense and repair damage. In the materials science field, researchers are now attempting to engineer this type of behaviour into man-made materials, under the banner of “self-healing” materials. Self-healing structures are particularly important for Defence platforms consisting of polymeric materials and composites. The application of self-healing materials will help in the prevention of degradation, thus improving platform safety. [3, 4]

Fig.1.2 Structronics-a multidiscipline integration



Active controllable smart electro/magneto material provides new dimensions and design opportunities for precision & high performance devices, structures, mechatronic systems, and structronic systems. Integrating smart materials, sensors/ actuators, computers, control electronics, and artificial intelligence further enhances conventional mechatronic devices or systems to a new generation of fully integrated smart structures & structronic systems. Accordingly, the new smart structures and structronic systems technology represent a systematic synergistic integration of conventional disciplines & applications as shown in Fig. 1.2. [6]

III. Classification of Smart Materials

Smart materials can be grouped into the following categories:

- Piezoelectric*. When subjected to an electric charge or a variation in voltage, piezoelectric material will undergo some mechanical change, and vice versa. These events are called the direct and converse effects. The piezoelectric effect exists in a number of naturally occurring crystals, such as quartz, tourmaline, and sodium potassium tartrate. When a stress (tensile or compressive) is applied to a crystal with a center of symmetry, it will alter the spacing between the positive and negative sites in each elementary cell unit, thus causing a net polarization at the crystal surface.
- Electrostrictive*. This material has the same properties as piezoelectric material, but the mechanical change is proportional to the square of the electric field. This characteristic will always produce displacements in the same direction. Electrostrictive materials have the advantage over piezoelectric materials of being able to adjust the position of optical components due to the reduced hysteresis associated with the motion.
- Magnetostrictive*. When subjected to a magnetic field, and vice versa (direct and converse effects), this material will undergo an induced mechanical strain. Consequently, it can be used as sensors and/or actuators. (Example: Terfenol-D.). Magnetostrictive materials are materials that have the material response of mechanical deformation when stimulated by a magnetic field. Shape changes are the largest in ferromagnetic and ferromagnetic materials. The repositioning of domain walls that occurs when these solids are placed in a magnetic field leads to hysteresis between magnetization and an applied magnetic field. When a ferromagnetic material is heated above its Curie temperature, these effects disappear.
- Shape Memory Alloys*. When subjected to a thermal field, this material will undergo phase transformations which will produce shape changes. It deforms to its ‘martensitic’ condition with low temperature, and regains its original shape in its ‘austenite’ condition when heated (high temperature). (Example: Nitinol TiNi). The shape memory effect in metals is a very interesting phenomenon. Imagine taking a piece of metal and deforming it completely and then restoring it to its original shape with the application of heat.

Taking a shape memory alloy spring and hanging a weight on one end of the spring can easily illustrate this. After the spring has been stretched, heat the spring with a hot-air gun and watch it return to its original length with the weight still attached.

- v) *Thermoresponsive Materials*: Amorphous and semicrystalline thermoplastic polymeric materials are unique due to the presence of a glass transition temperature. Changes in the specific volume of polymers and their rate of change occur at their glass transition temperatures. This transition affects a multitude of physical properties. Numerous types of indicating devices could be developed based upon the stimulus–response (temperature-specific volume) behavior.
- vi) *Optical Fibres*. Fibres that use intensity, phase, frequency or polarization of modulation to measure strain, temperature, electrical/magnetic fields, pressure and other measurable quantities. They are excellent sensors.[5]

Table 1: A comparison of actuators for smart materials. [7]

	PZT G-1195	PVDF	PMN	TERFENOL DZ	NITINOL
Actuation Mechanism	Piezoceramic	Piezo Film	Electrostrictor	Magnetostrictor	Shape Memory Alloy
Max Strain (X 10 ⁻⁶)	1000	700	1000	2000	20000
Young's Modulus	9	0.3	17	7	{4(m) 13(a)}
Bandwidth	High	High	High	Moderate	Low
(m)= martensite (a) = austenite					

For Shape Memory Alloy smart materials actuation Mechanism the maximum strain is more than Piezoceramic but its bandwidth is low. As mention in above table1.the Young's Modulus is highest for PMN (lead magnesium niobate).

IV. Future trends in smart materials

The active materials and smart structures technology has meanwhile passed the border between the basic research and laboratory prototypes to industrial applications. Until now, the main driving forces are still military and aerospace applications, but more and more very exciting applications are reported as mentioned above. These developments show the great potential of smart structures concepts.

Issues of Smart Structures and Structronic Systems

- Nonlinear modelling, simulation and design tools/control structure interaction/benchmark problems
- System integration and system design criteria, standards, tools, limits,
- Material processing, new material with enhanced engineering proper- ties and temperature stability, restrictions, material library / database, diffusion-driven smart materials
- New material evaluation techniques, tools
- Product demos, new mechanisms, new materials applied to micro- electromechanical systems (MEMS)
- Applications to manufacturing
- Material incompatibility, material/structure integration,
- Micro-mechanics: bonding, fracture, fatigue, nonlinear behaviour, etc.
- Health monitoring and diagnosis, NDE/NDT (new modelling tools)
- Real-time system identification and control, implementation, electronics (power efficiency)
- Biological inspired structures, self-growth/repair
- Education (industry, public, government, students) network, web info, "system" approach
- Distributed control of continua (PDE) via structronics technology, demos [2]

V. Conclusion

The technology of smart materials by its nature is a highly interdisciplinary field. Starting from the field of basic sciences such as physics, chemistry, mechanics, computing and electronics it also covers the applied sciences and engineering such as aeronautics and mechanical engineering. This may explain the slow progress of the application of smart structures in engineering systems, even if the science of smart materials is moving very fast. In the present scenario, the most promising technologies for lifetime efficiency and improved reliability include the use of smart materials and structures. Understanding and controlling the composition and microstructure of any new materials are the ultimate objectives of research in this field and is crucial to the production of good smart materials. This paper provides an overview of a number of smart materials.

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