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SMART MATERIALS FOR FUTURE

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ABSTRACT

This paper presents a simple overview of the technology. After defining what is meant by 'smart materials', it describes a smart structure and its components, and provides a few examples. This is part of an ongoing work on the use of smart materials for applications in engineering. A more detailed insight into smart structures and their applications is given elsewhere. One of the first attempts to use the smart materials technology involved materials constructed to do the work of electromechanical devices. Since then, many types of sensors and actuators have been developed to measure or excite a system. This technology is still in its infancy and the scientific community is just beginning to scratch the surface of its potential. With a bit of imagination one can see enormous benefits to society.

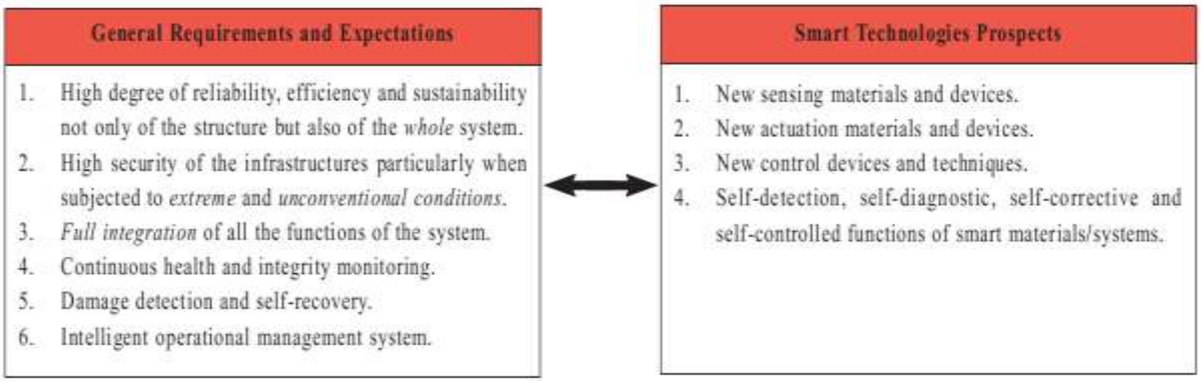
Keywords: Piezoelectric, Alloys, Smart Materials, Mechanical

I INTRODUCTION

Smart or intelligent materials are materials that have the intrinsic and extrinsic capabilities, first, to respond to stimuli and environmental changes and, second, to activate their functions according to these changes. The stimuli could originate internally or externally. Since its beginnings, materials science has undergone a distinct evolution: from the use of inert structural materials to materials built for a particular function to active or adaptive materials, and finally to smart materials with more acute recognition, discrimination and reaction capabilities. To encompass this last transformation, new materials and alloys have to satisfy a number of fundamental specifications.

The world has undergone two materials ages, the plastics age and the composite age, during the past centuries. In the midst of these two ages a new era has developed. This is the smart materials era. According to early definitions, smart materials are materials that respond to their environments in a timely manner. [2-7].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)

The definition of smart materials has been expanded to materials that receive, transmit, or process a stimulus and respond by producing a useful effect that may include a signal that the materials are acting upon it. Some of the stimuli that may act upon these materials are strain, stress, temperature, chemicals (including pH stimuli), electric field, magnetic field, hydrostatic pressure, different types of radiation, and other forms of stimuli [1].Today the drive to innovation is stronger than ever. Novel technologies and applications are spreading in all fields of science. Consequently, expectations and needs for engineering applications have increased tremendously, and the prospects of smart technologies to achieve them are very promising. Figure 1.1 summarizes these inter-relationships. [6]



General Requirements and Expectations

1. High degree of reliability, efficiency and sustainability not only of the structure but also of the *whole* system.
2. High security of the infrastructures particularly when subjected to *extreme* and *unconventional conditions*.
3. *Full integration* of all the functions of the system.
4. Continuous health and integrity monitoring.
5. Damage detection and self-recovery.
6. Intelligent operational management system.

Smart Technologies Prospects

1. New sensing materials and devices.
2. New actuation materials and devices.
3. New control devices and techniques.
4. Self-detection, self-diagnostic, self-corrective and self-controlled functions of smart materials/systems.

Figure 1.1 Smart System for Engineering Application

II CLASSIFICATION OF SMART MATERIALS

- 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.
- Electrostrictive: This material has the same proper-ties 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.
- 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.)
- 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.)

2.1 Piezoelectric Materials

The simplest definition of piezoelectric materials can be obtained by first dividing the word into piezo and electric.Piezo is from the Greek word piezein, which means ‘‘to press tightly or squeeze.’’ Combining pieze in with electric, we have ‘‘squeeze electricity.’’The history of piezoelectric materials is relatively simple and only the highlights will be presented. In 1880, Pierre and Paul-Jean Curie showed the piezoelectric effect in quartz and Rochelle salt crystals. Their first observations were made by placing weights on the faces of particular crystal cuts, like the X-cut quartz plate, detecting charges on the crystal surfaces, and demonstrating that the magnitude of the charge was proportional to the applied weight. This phenomenon has become known as the direct-pressure piezoelectric effect. In 1881 G. Lippmann predicted that a crystal such as quartz would develop a mechanical strain when an electric field was applied. In the same year the Curies reported the converse pressure piezoelectric effect with quartz and Rochelle salt. They showed that if certain crystals were subjected to mechanical strain, they became electrically polarized and the degree of polari-zation was proportional to the applied strain. The French inventor Langevin developed the first SONAR using quartz crystals in 1920. During the 1940s researchers discovered and developed the first polycrystal line, piezoelectric ceramic, barium titanate. A significant ad-vantage of piezoelectric ceramics over piezoelectric crystals is their ability to be formed in a variety of shapes and sizes. In 1960, researchers discovered a weak piezoelectric effect in whalebone and tendon that led to intense search for other piezoelectric organic materials. And in 1969, Kawai found very high piezoelectric activity in polarized polyvinylidene flu-oride (PVDF). [7, 8]

2.2 Electrostrictive

Piezoelectric materials are materials that exhibit a linear relationship between electric and mechanical variables. Piezoelectricity is a third-rank tensor. Electrostrictive materials also show a relationship between these two variables. However, in this case, it is a quadratic relationship between mechanical stress and the square of electrical polarization. Electrostriction can occur in any material and is a small effect. One difference between piezoelectric and electrostrictive materials is the ability of the electrostrictive materials to show a larger effect in the vicinity of its Curie temperature. Electrostriction is a fourth rank tensor property observed both in centric and acentric insulators. This is especially true for ferroelectric materials such as the members of the perovskite family. Ferroelectrics are ferroic solids whose domain walls have the capability of moving by external forces or fields. In addition to ferroelectrics, the other principal examples of ferroic solids are ferromagnetics and ferroelastics, both of which have potential as smart materials. Other examples of electrostrictive materials include lead manganese niobate-lead titanate (PMN–PT) and lead lanthanium zirconate titanate (PLZT).

An interesting application of electrostrictive materials is in active optical applications. During the Cold War, the satellites that flew over the Soviet Union used active optical systems to eliminate atmospheric turbulence effects. Electrostrictive materials have the ad-vantage over piezoelectric materials of being able to adjust the position of optical components due to the reduced hysteresis associated with the motion. Work on active optical systems has continued. Similar multilayer actuators were used to correct the position of the optical elements in the Hubble telescope. Supermarket scanners use actuators and flexible mirrors to read bar codes optically.[9]

2.3 Magnetorestrictive materials

Magnetorestrictive materials are materials that have the material response of mechanical deformation when stimulated by a magnetic field. Shape changes are the largest in ferro-magnetic 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. The microscopic properties of a ferromagnetic solid are different than for a ferromagnetic solid. The magnetic dipoles of a ferromagnetic solid are aligned parallel. The alignment of dipoles in a ferromagnetic solid can be parallel or in other directions.[10],[11],[12]

Magnetorestrictive materials are usually inorganic in chemical composition and are alloys of iron and nickel and doped with rare earths. The most effective magnetorestrictive material is another alloy developed at the Naval Ordinance Laboratory, TERFENOL-D. It is an alloy of terbium, dysprosium, and iron. The full effect of magnetorestriction occurs in crystalline materials. One factor preventing magnetorestrictive materials from reaching com-mercial significance has been cost. Over the past three decades there has been a great deal of development of giant magnetorestrictive materials, colossal magnetorerestrictive materials,and organic and organometallic magnets.[10,13]

2.4 Shape Memory Alloys

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. These materials undergo a thermomechanical change as they pass from one phase to another. The crystalline structure of such materials, such as nickel–titanium alloys, enters into the martensitic phase as the alloy is cooled below a critical temperature. In this stage the material is easily manipulated through large strains with a little change in stress. As the temperature of the material is increased above the critical temperature, it transforms into the austenitic phase. In this phase the material regains its high strength and high modulus and behaves normally. The material shrinks during the change from the martensitic to the austenitic phase.[10,11,12]

Nickel–titanium alloys have been the most used shape memory material. This family of nickel–titanium alloys is known as Nitinol, after the laboratory where this material was first observed (Nickel Titanium Naval Ordinance Laboratory). Nitinol has been used in military, medical, safety, and robotics applications. Specific applications include hydraulic lines on F-14 fighter planes, medical tweezers and sutures, anchors for attaching tendons to bones, stents for cardiac arteries, eyeglass frames, and antiscalding valves in water faucets and showers. [10, 14, 15]

In addition to the family of nickel–titanium alloys there are other alloys that exhibit the shape memory effect. These alloys are silver–cadmium, gold–cadmium, copper–aluminum–nickel, copper–tin, copper–zinc, combinations of copper–zinc with silicon or tin or aluminum, indium–thallium, nickel–aluminum, iron–platinum, manganese–copper, and iron–manganese–silicon. [16]

Not all combinations of the two or three elements yield an alloy with the shape memory effect; thus it is recommended to review the original literature. Several articles from Mitsubishi Heavy Industries describe the room temperature functional shape memory polyurethanes. To this writer, these papers only attest to the behavior of a polymer at its glass transition temperature. Thus if you wish to describe a polymer's behavior at its glass transition temperature and since the free-volume change is reversible, you may call it a smart polymer, a shape memory material, or a thermo responsive material. The unique characteristic of these polyurethanes is that their transition occurs in the vicinity of room temperature. [17, 18]

III APPLICATION OF SMART MATERIALS IN ENGINEERING

Smart materials find a wide range of applications due to their varied response to external stimuli. The different areas of application can be in our day to day life,aerospace, civil engineering applications and mechatronics to name a few. The scope of application of smart material includes solving engineering problems with unfeasible efficiency and provides an opportunity for creation of new products that generate revenue. Important feature related to smart materials and structures is that they encompass all fields of science and engineering.[19]

- **Structural Health Monitoring**

Embedding sensors within structures to monitor stress and damage can reduce maintenance costs and increase lifespan. This is already used in over forty bridges worldwide.

- **Self-Repair**

One method in development involves embedding thin tubes containing uncured resin into materials. When damage occurs, these tubes break, exposing the resin which fills any damage and sets. Self-repair could be important in inaccessible environments such as underwater or in space.

- **In the Field of Defense and Space**

Smart materials have been developed to suppress vibrations and change shape in helicopter rotor blades. Shape-memory-alloy devices are also being developed that are capable of achieving accelerated breakup of vortex waves of submarines and similarly different adaptive control surfaces are developed for airplane wings. Besides, present research is on its way to focus on new control technologies for smart materials and design methods for placement of sensors and actuators.

- **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 response is influenced by the radiation dose.

- **In Structural Engineering**

These materials also find application in the field of structural engineering. They are used to monitor the civil engineering structures to evaluate their durability. Not only the smart materials or structures are restricted to sensing but also they adapt to their surrounding environment such as the ability to move, vibrate and demonstrate various other responses. The applications of such adaptive materials involve the capability to control the aero elastic form of the aircraft wing to reduce the pull and improve operational efficiency, to control the vibration of satellites' lightweight structures, Smart structures are also being developed to monitor structural integrity in aircraft and space structures. Effort has been made to investigate certain piezoelectric materials to reduce noise in air conditioners. Besides, in civil engineering, these materials are used to monitor the integrity of bridges, dams, offshore oil-drilling towers where fiber-optic sensors embedded in the structures are utilized to identify the trouble areas.

- **Biomedical Applications**

In the field of biomedicine and medical diagnostics, still investigations are being carried out. Certain materials like poly-electrolyte gels are being experimented for artificial-muscle applications, where a polymer matrix swollen with a solvent that can expand or contract when exposed to an electric field or other stimulation. In addition, due to biodegradability of these materials, it may make ituseful as a drug delivery system.

- **Reducing Waste**

All over the world, the electronic wastes are the fastest growing components of domestic waste. During disposal and processing of such wastes, hazardous and recyclable materials should be removed first. Manual disassembly is expensive and time consuming but the use of smart materials could help to automate the process. Recently fasteners constructed from shape memory materials are used that can self release on heating. Once the fasteners have been released, components can be separated simply by shaking the product. By using fasteners that react to different temperatures, products could be disassembled hierarchically so that materials can be sorted automatically.

- **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.

- **Health**

Biosensors made from smart materials can be used to monitor blood sugar levels in diabetics and communicate with a pump that administers insulin as required. However, the human body is a hostile environment and sensors are easily damaged. Some researches on barrier materials are going to protect these sensors. Now-a-days different companies are developing smart orthopedic implants such as fracture plates that can sense whether bones are healing and communicate data to the surgeon. Small scale clinical trials of such implants have been successful and they could be available within the next five years. Other possible devices include replacement joints that communicate when they become loose or if there is an infection. Current technology limits the response of these devices to transmitting data but in the future, they could respond directly by self-tightening or releasing antibiotics. This could reduce the need for invasive surgery.

- **The Ageing Population**

There are now more people aged over 60 in almost every part of universe than children, creating a new market for products that make life easier for the elderly. Many of these could use smart materials and systems to include added functionality. For example, shape memory materials could be used in food packaging that automatically opens on heating for people with arthritis. Smart homes have been developed by researchers for people with dementia that uses sensors to monitor behavior and to ensure that the resident is safe.

IV CONCLUSION

.The future of smart materials and structures is wide open.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.The insights gained by gathering data on the behaviour of a material’s crystal inner structure as it heats and cools, deforms and changes, will speed the development of new materials for use in different applications.Structural ceramics, superconducting wires and nanostructural materials are good examples of the complex materials that will fashion nanotechnology.

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