A REVIEW ON INTRODUCTION, CLASSIFICATION AND APPLICATIONS OF SMART MATERIALS

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ABSTRACT

Smart materials are now a day's being used in all spheres of human life. Smart materials are common name for a wide variety of different substances. The general feature of all of them is the fact that; one or more properties might be significantly changed in a controlled fashion by external stimuli. The present era is considered to be the smart materials age. Earlier, smart material was defined as the material, which responds to its environments in a timely manner. However, the definition of smart material has been expanded to the "Materials that can significantly change their mechanical, thermal, optical, or electromagnetic properties, in a predictable or controllable manner in response to environment", such that they receive, transmit, or process a stimulus and respond by producing a useful output. This paper contains a review on the introduction of smart materials and their classification and different applications in various fields.

Keywords: Actuators, External Stimuli, Piezoelectric, Smart Materials

1. INTROUCTION

Smart or intelligent materials are those, which respond to stimuli and environmental changes and activate their function according to changes.Smart material related technologies have been drawing an increasing amount of attention from researchers in related fields worldwide.In the past decade, smart materials and structures have been one of the most progressive fields of research. Recently developed materials and devices have been used to address many challenges in aerospace, mechanical, bionics and medical technologies [1].The progress made in developing advanced materials and devices is impressive and encouraging. The research areas of smart materials and structures are recognized as an essential aspect of smart technologies.Therefore, this paper focuses on review of smart material technologies.In the section, current progress in the field of smart materials and structures is presented. The papers reviewed cover the most recent research results in the development of several different kinds of smart materials. In addition, possible applications of the smart materials are also included.

In the last ten decades, the materials have become multifunctional and required the optimization of different characterization and properties. In the processes of 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 [2] 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, electricity, magnetic fields, chemicals, hydrostatic pressure and nuclear radiation. The associated changeable physical properties could be shape, stiffness, viscosity or damping. Takagi [3] 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 [4]. Self-adaptation characteristics of smart structures are of great benefit that utilizes the embedded adaptation of smart materials by changing their properties.Smart materials can detect faults and cracks and therefore are useful as a diagnostic tool. 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.

1.1. Components of Smart System

1) **Data transmission (sensory nerves):** The purpose of these parts is to forward the raw data to the local and or central command and control units.
2) **Data acquisition (tactile sensing):** The aim of this component is to collect the raw data needed for an appropriate sensing and monitoring of the structure. e.g. fiber optic sensing[5], [6]&[7].
3) **Command and control unit (brain):**The role of this unit is to manage and control the whole system by analyzing the data reaching the appropriate conclusion and determining the actions requires.
4) **Data instruction (motor nerves):**The function of this part is to transmit the decisions and the associated instructions back to the member of the structure.
5) **Action devices (muscles):**The purpose of these parts is to take action by triggering the controlling devices[8].

2. CLASSIFICATION OF SMART MATERIAL

Smart materials are classified into two categories either active or passive. Fairweather[9] defined active smart materials as those materials which possess the capacity to modify their geometric or material properties under the application of electric, thermal or magnetic fields, thereby acquiring an inherent capacity to transduce energy.On the other part, the materials, which are not active, are called passive smart materials. Although smart, they lack the inherent capability to transduce energy. Fiber optic material is a good example of a passive smart material. Such materials can act as sensors but not as actuators or transducers.Smart materials can be classified as mentionedbelow.

1. Piezoelectric materials
2. Electrostrictive materials
3. Magnetostrictive materials
4. Rheological materials
5. Thermo-responsive material
6. Electrochromic materials
7. Fullerences
8. Biomimetic materials
9. Smart gels

2.1. Piezoelectric materials.

When subjected to an electric charge or variation in voltage, piezoelectric material will undergo some mechanical change, and vice versa. These events are called the direct and converse effects.A piezoelectric disk generates a voltage when deformed[10].

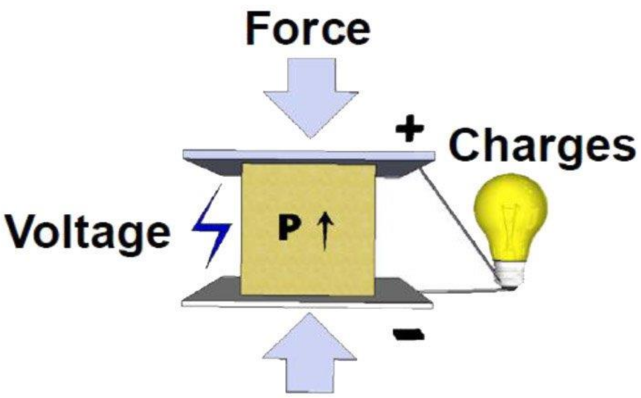

Figure 1. Piezoelectric Materials

2.2. Electrostrictive materials.

This material has the same properties as piezoelectric material, but the mechanical change is proportional to the square of the electric field. These characteristic will always produce displacements in the same direction [11].

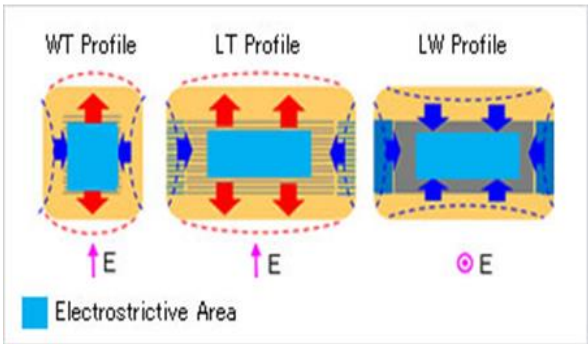

Figure 2. Electrostrictive Materials

2.3. Magnetostrictive materials

When subjected to a magnetic field, and vice versa, these materials will undergo a change and induce mechanical strain; consequently it can be used as a sensors and actuators.A magnetostrictive material consists of tiny ferromagnets. These ferromagnets are usually of iron, nickel or cobalt and have small magnetic moments as a result of their “3d” shells that are not completely filled with electrons. Essentiallytheferromagnets act like tiny permanent bar magnets.

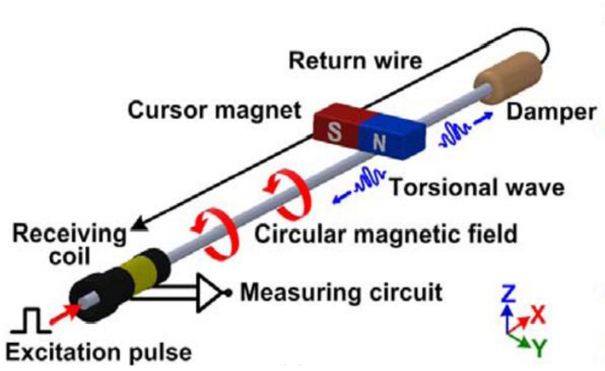

Figure3. MagnetostrictiveMaterials

2.4. Rheological materials

These are in liquid phase which can change state instantly through the application of an electric or magnetic charge. These fluids may find application in brakes, shock absorber and dampers in automotive.

Generally, a rheological material is a material which can change its physical state very quickly in reaction to a stimulus. Rheological materials only react when an electric or magnetic field is applied. The material always changes between a liquid and a solid state. While rheological materials that react to an electric field is called Electro-**Rheological Fluid(ER**);have some specific uses.**Magneto-Rheological Fluids (MR)** materials are more practical. Unlike ER materials, they function in the presence of impurities and only low voltages are needed to stimulate them.

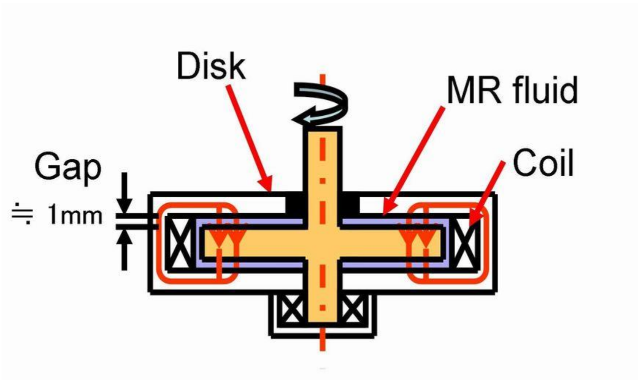

Figure 4. Rheological Materials

2.5. Thermo-responsive material.

Thermo-responsive is the ability of the material to change properties in response to changes in temperature. They are useful in thermostat and parts of automotive and air vehicles.They are also called temperature-responsive materials.Thermo-responsive materials are polymers that exhibit a drastic and discontinuous change of their physical properties with temperature.Thermo-responsive polymers belong to the class of stimuli-responsive materials, in contrast to temperature-sensitive (for short, thermo-sensitive) materials, which change their properties continuously with environmental conditions. In a stricter sense, thermo-responsive polymers display a miscibility gap in their temperature-composition diagram. Depending on whether the miscibilitygap is found at high or low temperatures, an upper or lower critical solution temperature exists respectively.

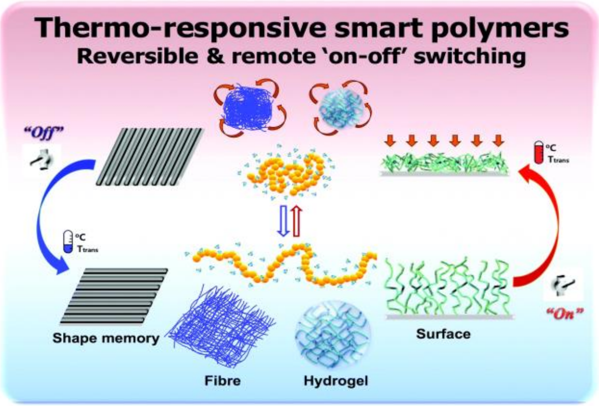

Figure5. Thermo-Responsive Material

2.6. Electrochromic materials

Electrochromic is the ability of material to change its optical properties when voltage is applies across it.They are used in LCDs and cathode in lithium batteries.

Electrochromism is the phenomenon displayed by some materials of reversibly changing color stimulated by redox reactions.Various types of materials and structures can be used to construct electrochromic devices. Electrochromic displays are based on any material that changes color depending on the applied potential.

Figure 6 a. Electrochromic Virtual Window Blind On An Aircraft Cabin Window

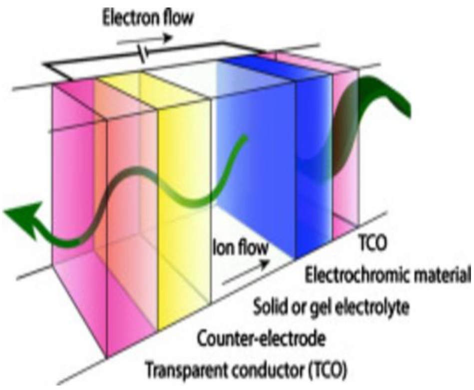

Figure6b. Electrochromic Device

2.7. Fullerenes

These are spherically caged molecules with carbon atoms at the corner of polyhedral structure consisting of pentagons and hexagons. These are usually used in polymeric matrices used in smart systems. They are used in electronic and microelectronic devices [11].

A form of carbon having a large spheroidal molecule consisting of a hollow cage of sixty or more atoms, of which buckminsterfullerene was the first known example. Fullerenes are produced chiefly by the action of an arc discharge between carbon electrodes in an inert atmosphere.

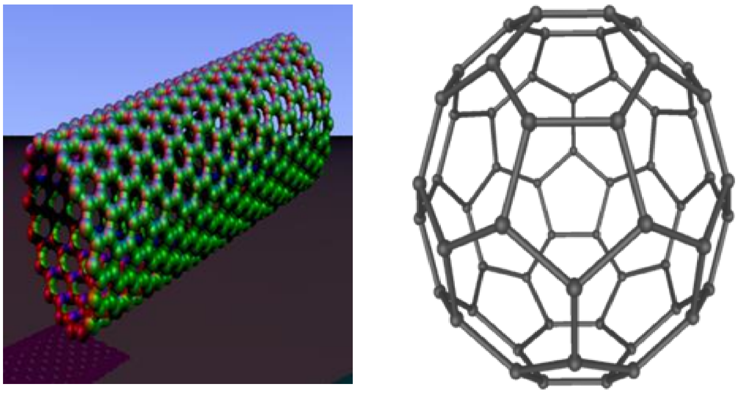

Figure7.Fullerences

2.8. Biomimetic materials

Biomimetic are materials developed using inspiration from nature. This may be useful in the design of composite materials. Natural structures have inspired and innovated human creations. Notable examples of these natural structures include: honeycomb structure of the beehive, strength of spider silks, bird flight mechanics, and shark skin water repellency.

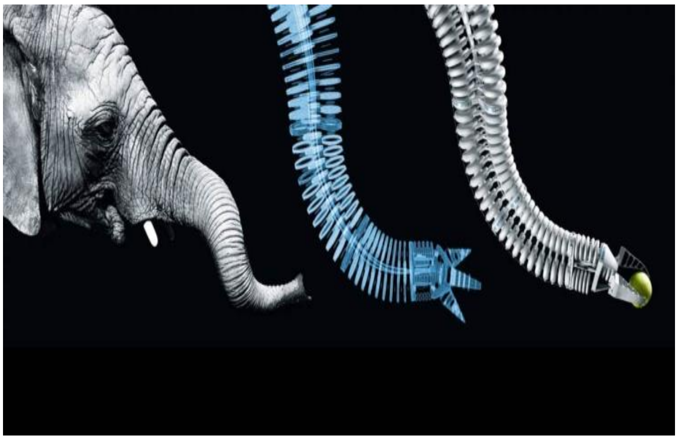

Figure8. Biomimetic Materials

2.9. Smart gels

A gel is a solid jelly-like material that can have properties ranging from soft and weak to hard and tough. Gels are defined as a substantially dilute cross-linked system, which exhibits no flow when in the steady-state. Gels are mostly liquid, yet they behave likesolids due to a three-dimensional cross-linked network within the liquid. It is the crosslinking within the fluid that gives a gel; its structure and contributes to the adhesive stick. In this way gels are a dispersion of molecules of a liquid within a solid in which liquid particles are dispersed in the solid medium.

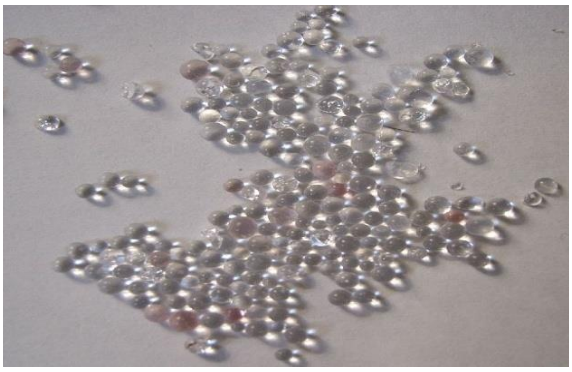

Figure9. Smart Gels

3. WORKING OF SMART MATERIAL

When the smart material in twinned martensite phase undergoes external stress, it transforms to detwinnedMartensite phase as indicated in Fig.10. There is no temperature change during this transformation.When the detwinnedMartensite material undergoes an increase in temperature, the detwinnedMartensite transforms to Austenite. Austenite will go back to twinned Martensite when the temperature goes down.

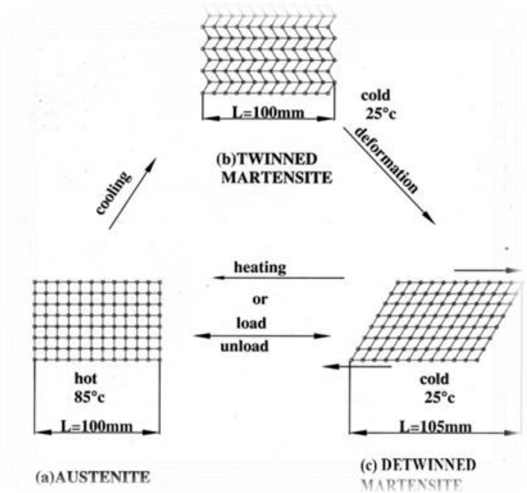

Figure 10. Schematic Of The Shape Memory Phenomenon

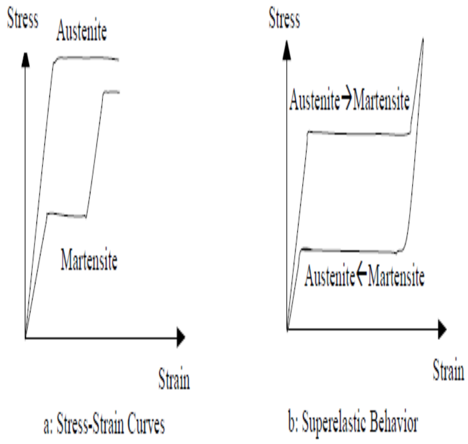

Figure 11.
Stress-Strain Relationship Of Austenite And Martensite

From the stress-strain point of view, smart materials act differently in Martensite and Austenite phases. Fig.11a shows the typical stress-strain curves of smart materials at these two phases. Fig.11 b shows the stress-strain relationship of the typical phase changes ofsuper elasticity smart materials under stress.The upper plateau represents the change fromAustenite to Martensite under stress while the lower plateau represents the reverse processMartensitetoAustenite. This property can be used to rehabilitate the cracking of concrete; whensuperelasticity smart material is used as the reinforcement bar.Super-elasticity material alsohas some other important features like hysteretic damping, highly reliable energy dissipationcapacity through repeatable phase transformation, excellent fatigue properties, and goodresistance to corrosion [12].

4. APPLICATION

Smart materials have found some commercial and industrial applications. Engineering applications can be broadly divided into two classes:
i) Sensors or sensing devices [13]&[14].
ii) Motors and actuators.
They have been applied in medicine (pediatric devices), civil engineering (building, dams, highways, and bridges), automotive industry (brakes, shock absorbers, smart cars and trucks), and skin-diagnostics. They are also used in making smart material interface and smart vacuum cleaner. The basic properties of smart materials, including super elasticity and shape memory [15]are leveraged in some of these applications.

1. Aircrafts
2. Orthopedic surgery
3. Dental braces
4. Robotics
5. Reducing vibration of helicopter blades.
6. Smart fabrics
7. Sporting goods
8. Smart glass
9. Seismic Rehabilitation of bridges.
10. Repair and Strengthening of concrete Structures

5. CONCLUSION

The dumb, conventional materials of the past are now becoming smart. Smart materials are the next generation materials that have a potential to impact on different fields including science, engineering, medicine, and automotive industry.They will have significant impact on civilization. The technology of smart materials is an inter-disciplinary, emerging field.Today, the most promising technologies for lifetime efficiency and improved reliability include the use of smart material and structures. Understanding and controlling the composition and microstructure of any new material are the ultimate objectives of research in these fields. New and advanced smart material will definitely enhance quality of our life.

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