Smart Materials: New Trend in Structural Engineering

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Abstract

Smart materials, which have the functions of actuator, sensor, self-healing and so forth, are expected to be used not only as advanced functional materials but also as key materials to provide structures with smart functions. Smart systems sense changes in structure variations in vibration, noise or temperature, for example process the information and then respond appropriately to automatically correct possibly detrimental problems. They tell the structure to alter its properties to prevent damage, optimize performance, correct malfunctions or alert users to a needed repair.

Smart materials technology applies to a huge range of products including buildings, bridges, computers, cameras, aircraft, even skis. Think about the way in which excessive vibration in a machine on the shop floor may result in overheating, or parts that don't meet the manufacturer's specifications. Then, imagine the problems that could occur if a similar situation happened on an aircraft and you begin to understand the scope and value of smart material applications.

The best way to understand the smart material concept is to look at its uses. Smart materials may work completely on their own or as part of a larger smart system. For example, doctors may use shape memory alloy staples used to set broken bones. In this case, the material works as both a sensor and an actuator as the patient's body heat activate the staple to close and thereby clamp the break together. This report deals with the available smart materials, their properties and some of their areas of application and future prospects."

1. Introduction

The development of durable and cost effective high performance construction materials and systems is important for the economic well being of a country mainly because the cost of civil infrastructure constitutes a major portion of the national wealth. To address the problems of deteriorating civil infrastructure, research is very essential on smart materials. This paper highlights the use of smart materials for the optimal performance and safe design of buildings and other infrastructures particularly those under the threat of earthquake and other natural hazards. The peculiar properties of the shape memory alloys for smart structures render a promising area of research in this field.

Everyday materials have physical properties, which cannot be significantly altered; for example if oil is heated it will become a little thinner, whereas a smart material with variable viscosity may turn from a fluid which flows easily to a solid. Varieties of smart materials already exist, and are being researched extensively. These include piezoelectric materials, magneto-rheostatic materials, electro- rheostatic materials, and shape memory alloys. Some everyday items are already incorporating smart materials (coffeepots, cars, the International Space Station, eyeglasses) and the number of applications for them is growing steadily.

Each individual type of smart material has a different property which can be significantly altered, such as viscosity; volume Smart materials have one or more properties that can be dramatically altered. Most and conductivity The property that can be altered influences what types of applications the smart material can be used.

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2. Piezoelectric Materials

Piezoelectric materials have two unique properties which are interrelated. When a piezoelectric material is deformed, it gives off a small but measurable electrical material it experiences a significant increase in size (up to a 4% change in volume)

Piezoelectric materials are most widely used as sensors in different environments. They are often used to measure fluid compositions, fluid density, fluid viscosity, or the force of an impact. An example of a piezoelectric material in everyday life is the airbag sensor in your car. The material senses the force of an impact on the car and sends and electric charge deploying the airbag.

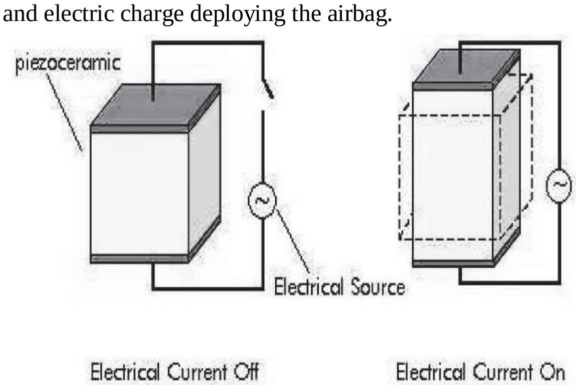

Fig: 1. An illustration of the Piezoelectric Effect

3. Electro-Rheostatic and Magneto-Rheostatic

Electro-rheostat (ER) and magneto-rheostat (MR) materials are fluids, which can experience a dramatic change in their viscosity. These fluids can change from a thick fluid (similar to motor oil) to nearly a solid substance within the span of a millisecond when exposed to a magnetic or electric field; the effect can be completely reversed just as quickly when the field is removed. MR fluids experience a viscosity change when exposed to a magnetic field, while ER fluids experience similar changes in an electric field. The composition of each type of smart fluid varies widely. The most common form of MR fluid consists of tiny iron particles suspended in oil, while ER fluids can be as simple as milk chocolate or cornstarch and oil.

MR fluids are being developed for use in car shocks, damping washing machine vibration, prosthetic limbs, exercise equipment, and surface polishing of machine parts. ER fluids have mainly been developed for use in clutches and valves, as well as engine mounts designed to reduce noise and vibration in vehicles.

4. Shape Memory Alloys (SMA)

Shape memory alloys (SMA's) are metals, which exhibit two very unique properties, pseudo-elasticity, and the shape memory effect

The term shape memory refers to the ability of certain alloys (Ni – Ti, Cu – Al – Zn etc.) to undergo large strains, while recovering their initial configuration at the end of the deformation process spontaneously or by heating without any residual deformation .The particular properties of SMA's are strictly associated to a solid-solid phase transformation which can be thermal or stress induced. Currently, SMAs are mainly applied in medical sciences, electrical, aerospace and mechanical engineering and also can open new applications in civil engineering specifically in seismic protection of buildings.

Its properties which enable them for civil engineering application are

1. Repeated absorption of large amounts of strain energy under loading without permanent defor- mation. Possibility to obtain a wide range of cyclic behavior – from supplemental and fully reentering to highly dissipating-by simply varying the number and/or the characteristics of SMA components
2. Usable strain range of 70%
3. Extraordinary fatigue resistance under large strain cycles
4. Their great durability and reliability in the long run.

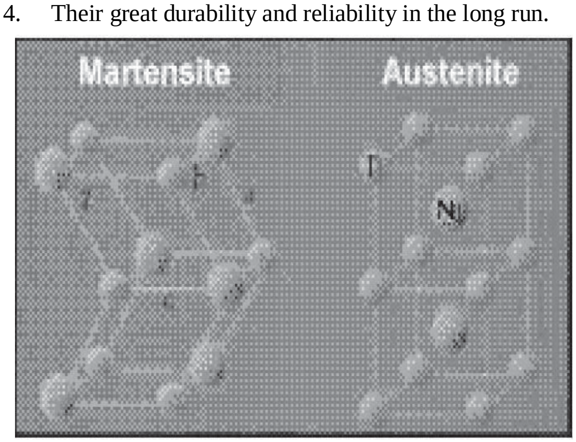

Fig: 2. The Martensite and Austenite phases

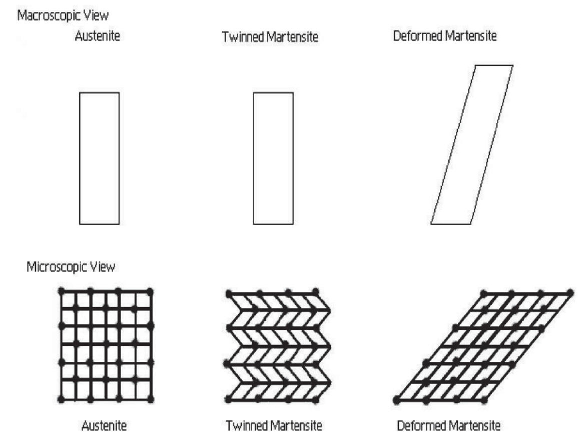

Fig: 3. Microscopic and Macroscopic Views of the Two Phases of Shape Memory Alloys

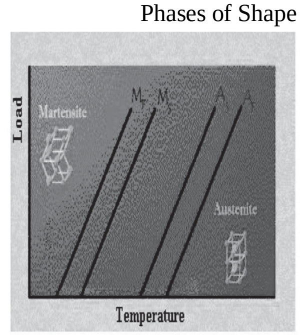

Fig: 4. The Dependency of Phase Change Temperature on Loading

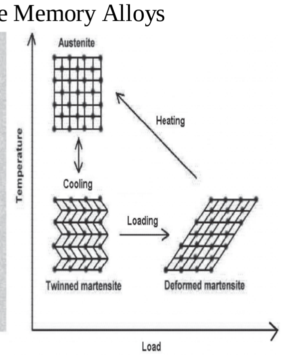

Fig: 5. Microscopic Diagram of the Shape Memory Effect

5. Pseudo-elasticity

Pseudo-elasticity occurs in shape memory alloys when the alloy is completely composed of Austenite (temperature is greater than Af). Unlike the shape memory effect, pseudo-elasticity occurs without a change in temperature. The load on the shape memory alloy is increased until the Austenite becomes transformed into Martensite simply due to the loading; this process is shown in Figure 5. The loading is absorbed by the softer Martensite, but as soon as the loading is decreased the Martensite begins to transform back to Austenite since the temperature of the wire is still above, and the wire springs back to its original shape.

Some examples of applications in which pseudo-elasticity is used are:

- Eyeglass Frames
- Medical Tools
- Cellular Phone Antennae Orthodontic Arches

Advantages and Disadvantages of Sma's

Some of the main advantages of shape memory alloys include:

- Bio-compatibility
- Diverse Fields of Application
- Good Mechanical Properties (strong, corrosion resistant)

There are still some difficulties with shape memory alloys that must be overcome before they can live up to their full potential. These alloys are still relatively expensive to manufacture and machine compared to other materials such as steel and aluminum. Most SMA's have poor fatigue properties; this means that while under the same loading conditions (i.e. twisting, bending, compressing) a steel component may survive for more than one hundred times more cycles than an SMA element.

6. Applications

6.1 Substitute for steel

It is reported that (4) the fatigue behavior of CuZnAl-SMA's is comparable with steel. If larger diameter rods can be manufactured. It has a potential for use in civil engineering applications. Use of fiber reinforced plastics with SMA reinforcements requires future experimental investigations.

6.2 Carbon fiber reinforced concrete

Its ability to conduct electricity and most importantly, capacity to change its conductivity with mechanical stress makes a promising material for smart structures .It is evolved as a part of DRC technology (Densified Reinforced Composites).The high density coupled with a choice of fibers ranging from stainless steel to chopped carbon and Kevlar, applied under high pressure gives the product with outstanding qualities as per DRC technology. This technology makes it possible to produce surfaces with strength and durability superior to metals and plastics.

6.3 Smart concrete

A mere addition of 0.5%specially treated carbon fibers enables the increase of electrical conductivity of concrete. Putting a load on this concrete reduces the effectiveness of the contact between each fiber and the surrounding matrix and thus slightly reduces its conductivity. On removing the load the concrete regains its original conductivity. Because of this peculiar property the product is called "Smart Concrete". The concrete could serve both as a structural material as well as a sensor.

The smart concrete could function as a traffic-sensing recorder when used as road pavements. It has got higher potential and could be exploited to make concrete reflective to radio waves and thus suitable for use in electromagnetic shielding. The smart concrete can be used to lay smart highways to guide self steering cars which at present follow tracks of buried magnets. The strain sensitive concrete might even be used to detect earthquakes.

6.4 Active structural control against wind

Aerodynamic control devices to mitigate the bi-directional wind induced vibrations in tall buildings are energy efficient, since the energy in the flow is used to produce the desired control forces. Aerodynamic flap system (AFS) is an active system driven by a feedback control algorithm based on information obtained from the vibration sensors. The area of flaps and angular amplitude of rotation are the principal design parameters.

7. Future

The development of true smart materials at the atomic scale is still some way off, although the enabling technologies are under development. These require novel aspects of nanotechnology (technologies associated with materials and processes at the nanometer scale, 10-9m and the newly developing science of shape chemistry.

Worldwide, considerable effort is being deployed to develop smart materials and structures. The technological benefits of such systems have begun to be identified and, demonstrators are under construction for a wide range of applications from space and aerospace, to civil engineering and domestic products. In many of these applications, the cost benefit analyses of such systems have yet to be fully demonstrated.

The concept of engineering materials and structures which respond to their environment, including their human owners, is a somewhat alien concept. It is therefore not only important that the technological and financial implications of these materials and structures are addressed, but also issues associated with public understanding and acceptance

8. Conclusion

The technologies using smart materials are useful for both new and existing constructions. Of the many emerging technologies available the few described here need further research to evolve the design guidelines of systems. Codes, standards and practices are of crucial importance for the further development.

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