Smart Material - Shape Memory Alloy

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Abstract— CAN a material possess intelligence? The answer depends on what one means by intelligence. One tends to associate intelligence with what a human brain can do: memory, thinking, problem solving, learning, creativity, etc. A artificial computer can do some of these tasks, but in terms of more sophisticated aspects of intelligence, it is no match even to a modest human brain. The recognition of these ultimate limits has inspired many scientists to study biological system as a model for developing intelligent or smart systems. Several smart systems (or structures) are in various stages of development for civil, military and various biological applications. Air forces require smart planes that can continuously change the wing's shape to achieve supersonic speed and evade radar screen. Diabetics need medical systems to sense sugar levels and deliver insulin. Architects are designing smart buildings with self-adjusting windows and self-cleaning materials we have made a comparative study between shape memory alloy materials and other generally used materials or alloys.

Key words: PTC Resistor Material, Smart PTC Materials

I. INTRODUCTION

The development of durable and cost effective high performance construction materials and systems is important for the economic wellbeing 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.

The difference between an ordinary and a "smart" material can be demonstrated through the following positive temperature coefficient (PTC)-resistance materials. A large group of temperature sensors is based on the temperature dependence of the electrical resistivity of conductors. Platinum, for example, is a widely used metal for PTC sensors. The resistance rises constantly with increasing temperature over a wide range from about 20 to 1,500 K. Temperature sensors based on this material show the advantage to be chemically and mechanically robust and to cover a large temperature range with an almost linear characteristic. The change, however, is less than .03 μΩ·cm/K. Therefore, the material cannot be used for self-regulated heating purposes. An example of smart PTC materials is donor-doped barium titanate ceramics. In this case, there is a temperature range (from ≈350 to 450 K) in which the resistivity rises by almost six orders of magnitude, as shown in Fig. 1.

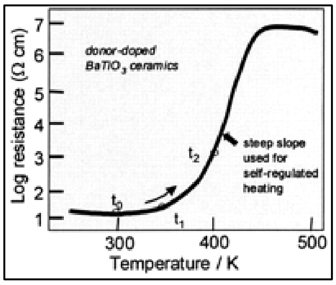

Fig. 1: Temperature dependence of resistivity in smart PTC materials.

Resistive heating elements are usually built with materials of intermediate resistivity level. Applying an electrical voltage to these elements causes a current to flow, which generates Joule's heat in the resistor. If there is a surge of current or a blockage of heat circulation, the resistor frequently overheats and may even cause a fire.

When a smart PTC resistor material is used, it can form a self-protection circuit. The principle can be understood as follows. At the beginning, the PTC heater is at room temperature with low resistance. Closing the switch in the circuit will produce a large current, which causes a fast temperature increase. Because of this rise in temperature, the resistance increases drastically (see Fig. 1); hence, the current will be reduced under a constant voltage source.

Magnetic probe is a good example of a multifunctional composite (1) in which a magnetostrictive material is integrated with a piezoelectric material to produce a large magneto electric effect. The magnetostrictive material will produce shape deformation under a magnetic field, and this shape deformation produces a stress on the piezoelectric material which generates electric charge. The so obtained magneto electric effect could be two orders of magnitude larger than that of Cr_2O_3.

Given below are the types of smart materials. They are piezo-electric materials, magneto & electric-rheostatic materials and shape memory alloys.

A. *Piezo Electric Materials*

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.

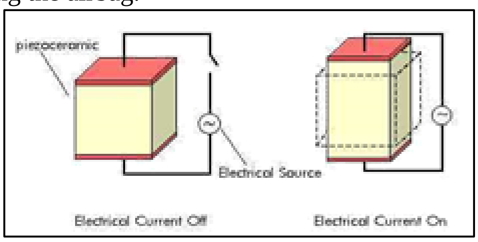

Fig. 2: Piezoelectric Materials

An illustration of the Piezoelectric Effect Piezoelectric materials have two unique properties. These properties are that, when a piezoelectric material is deformed, it gives off a small but measurable electrical discharge. Alternately, when an electrical current is passed through a piezoelectric 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.

Finally, this self-regulation leads to temperature stabilization at the steepest part of the characteristic curve. This established temperature is quite independent of the ambient temperature and the amount of heat extracted from the heating element. Therefore, a smart self-regulating heating circuit is formed.

B. Electro-Rheostatic and Magneto-Rheostatic

Electro-rheostatic (ER) and magneto-rheostatic (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.

Fig. 3: Electro-rheostatic (ER) and magneto-rheostatic (MR)

C. What are Shape Memory Alloys?

Shape memory alloys (SMA's) are metals, which exhibit two very unique properties, pseudo-elasticity (An almost rubber-like flexibility demonstrated by shape memory alloys), and the shape memory effect (The unique ability of shape memory alloys to be severely deformed and then returned to their original shape simply by heating them). The most effective and widely used alloys include Ni, Ti (Nickel - Titanium), Cu, Zn, Al, and Cu, Al, Ni.

Its properties which enable them for civil engineering application are

- Repeated absorption of large amounts of strain energy under loading without permanent deformation. 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.
- Usable strain range of 70%
- Extraordinary fatigue resistance under large strain cycles
- Their great durability and reliability in the long run.

D. Working of Shape Memory Alloys

The two unique properties described above are made possible through a solid-state phase change that is a molecular rearrangement, which occurs in the shape memory alloy. A solid-state phase change is similar in that a molecular rearrangement is occurring, but the molecules remain closely packed so that the substance remains a solid.

The two phases, which occur in shape memory alloys, are Martensite, and Austenite. Martensite is the relatively soft and easily deformed phase of shape memory alloys, which exists at lower temperatures.

The molecular structure in this phase is twinned as shown Figure 4. Upon deformation this phase takes on the second form shown in Figure 4, on the right. Austenite, the stronger phase of shape memory alloys.

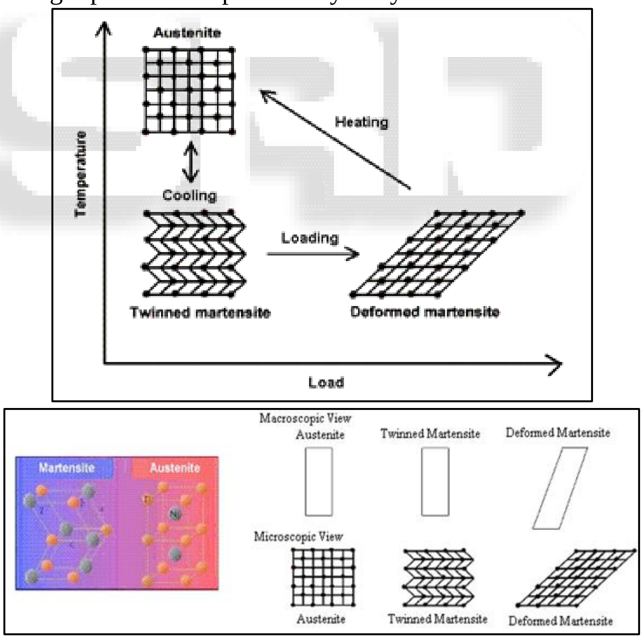

Fig. 4: Microscopic Diagram of the Shape Memory Effect occurs at higher temperatures. The shape of the Austenite structure is cubic. The un-deformed Marten site phase is the same size and shape as the cubic Austenite phase on a macroscopic scale.

E. Structural Uses

1) Active control of structures

The concept of adaptive behavior has been an underlying theme of active control of structures which are subjected to earthquake and other environmental type of loads. The structure adapts its dynamic characteristics to meet the performance objectives at any instant. A futuristic smart bridge system (An artist rendition) is shown below: Fig.1 (3)

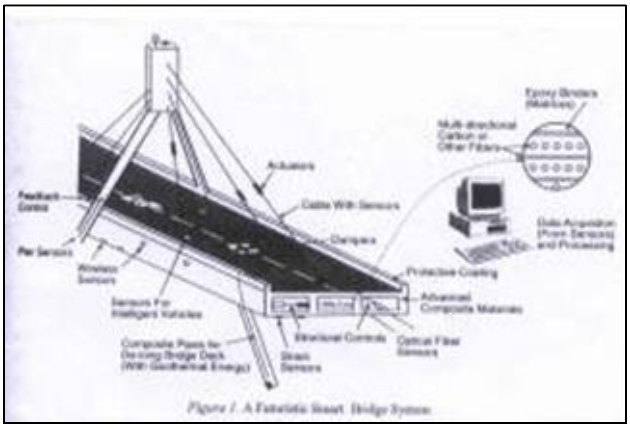

Fig. 5: Active control of structures

2) Passive control of structures

Two families of passive seismic control devices exploiting the peculiar properties of SMA kernel components have been implemented and tested within the MANSIDE project (Memory Alloys for New Seismic Isolation and Energy Dissipation Devices). They are Special braces for framed structures and isolation devices for buildings and bridges. Fig.2.shows the arrangement of SMA brace in the scaled frame model and the reduced scale isolation system.

3) Smart Material Tag

This smart material tag can be used in composite structures. These tags can be monitored externally throughout the life of the structure to relate the internal material condition. Such measurements as stress, moisture, voids, cracks and discontinuities may be interpreted via a remote sensor (6).

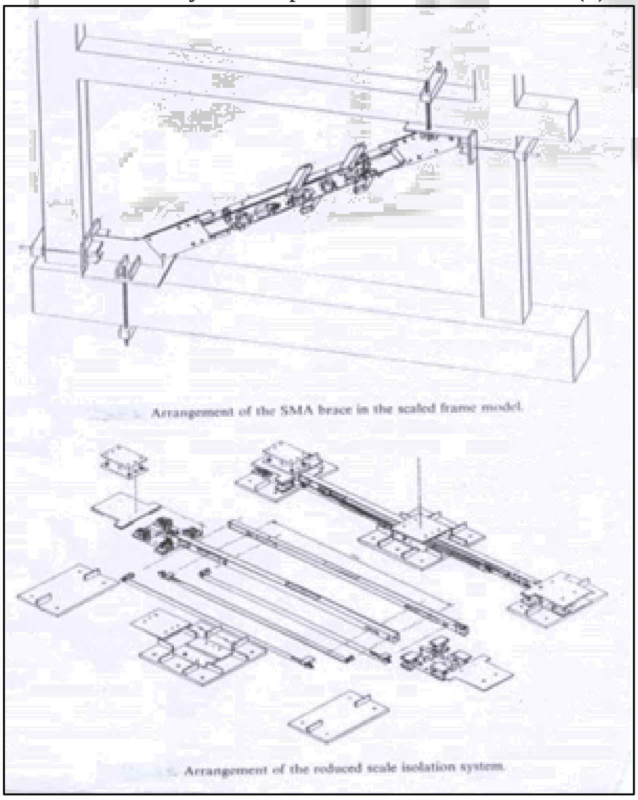

Fig. 6: Smart Material Tag

4) Retrofitting

SMAs can use as self-stressing fibres and thus they can be applied for retrofitting. Self-stressing fibres are the ones in which reinforcement is placed into the composite in a non-stressed state. A prestressing force is introduced into the system without the use of large mechanical actuators, by providing SMAs. These materials do not need specialized electric equipments nor do they create safety problems in the field. Treatment can be applied at any time after hardening of the matrix instead of during its curing and hardening. Long or short term prestressing is introduced by triggering the change in SMAs shape using temperature or electricity.

F. Shape Memory Effect

The shape memory effect is observed when the temperature of a piece of shape memory alloy is cooled to below the temperature Mf. At this stage the alloy is completely composed of Martensite, which can be easily deformed. . After distorting the SMA the original shape can be recovered simply by heating the wire above the temperature AF. The deformed Marten site is now transformed to the cubic Austenite phase, which is configured in the original shape of the wire. The Shape memory effect is currently being implemented in:

- Coffeepots
- The space shuttle
- Thermostats
- Pseudo-elasticity

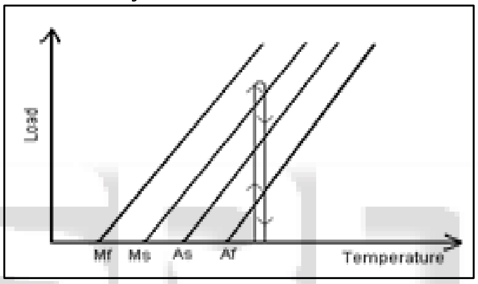

Fig. 7: Load Diagram of the pseudo-elastic effect Occurring

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 4. 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 AF, and the wire springs back to its original shape.

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

- Eyeglass Frames
- Cellular Phone Antennae
- Orthodontic Arches

G. Smart Materials in Civil Engineering Applications

However, ‘sensual structures’ need not be restricted to hi-tech applications such as aircraft. They could be used in the monitoring of civil engineering structures to assess durability. Monitoring of the current and long term behavior of a bridge would lead to enhanced safety during its life since it would provide early warning of structural problems at a stage where minor repairs would enhance durability, and when used in conjunction with structural rehabilitation could be used to safety monitor the structure beyond its original design life. This would influence the life costs of such structures by reducing upfront construction costs (since smart structures would allow reduced safety factors in initial design), and by extending the safe life of the structure. 'Sensual' materials and structures also have a wide range of potential domestic applications, as in food packaging for monitoring safe storage and cooking.

Potential applications of such adaptive materials and structures range from the ability to control the aero elastic form of an aircraft wing, thus minimizing drag and improving operational efficiency, to vibration control of lightweight structures such as satellites, and power pick-up pantographs on trains. The domestic environment is also a potential market for such materials and structures, with the possibility of touch sensitive materials for seating, domestic appliances, and other products. These concepts may seem 'blue sky', but some may be nearing commercial readiness as we read this.

H. Active Railway Track Support

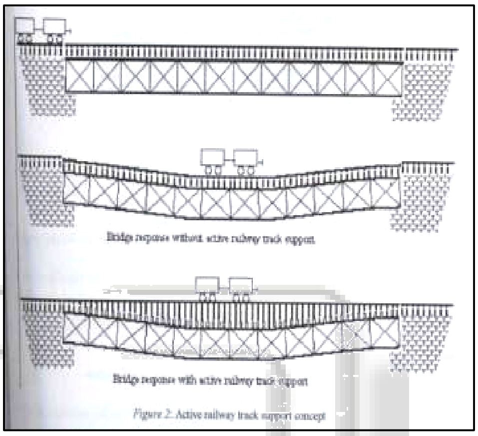

Fig. 8: Active railway track control system

To achieve speed improvements on existing bridges and to maintain the track in a straight and non-deformed configuration as the train passes with the help of optimal control methodology the train will pass the bridge with reduced track deflections and vibrations and thus velocity could be safely increased. Fig shows various positions of the train with and without active railway track support.

I. Commercial Applications

1) Antiscaled Devices

Basically an extension which fits between the shower head and the water pipe, containing a Ti-based SMA element which expands if water becomes too hot, choking off the flow. A very cheap, easy and effective alternative to more expensive technologies.

2) Connecting Rings

Rings and cylinders of SMA which are austenite at ambient temperature can provide significant constraining force around their inner circumference, ensuring a strong joint which can be released by cooling couplings.

3) Fastening Functions

Shape Memory Effect Elements (SMEE), in a variety of shapes can be used for fastening and coupling purposes, e.g. building engineering, aeronautics and in assembly operations. By expanding or shrinking at preset temperatures, SMEE can perform high forces and assure tight fastening, either permanent or temporary. In temporary fastening, the fixation can be released by means of the two-way-memory effect.

J. Advantages and Disadvantages of Shape Memory Alloys

Some of the main advantages of shape memory alloys include:

- Biocompatibility
- Good Mechanical Properties (strong, corrosion resistant).
- Diverse Fields of Application.

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.

1) Smart Structures

Smart structures are an integration of sensors, actuators, and a control system. Apart from the use of better functional materials as sensors and actuators, an important part of a "smarter" structure is to develop an optimized control algorithm that could guide the actuators to perform required functions after sensing changes.

A smart structure is a system containing multifunctional parts that can perform sensing, control, and actuation; it is a primitive analogue of a biological body. Smart materials are used to construct these smart structures, which can perform both sensing and actuation functions.

2) Device: Geophone

A geophone is a device which converts ground movement (displacement) into voltage, which may be recorded at a recording station.

K. Linear Variable Differential Transformer

Linear variable differential transformer (LVDT) is a type of electrical transformer used for measuring linear displacement.

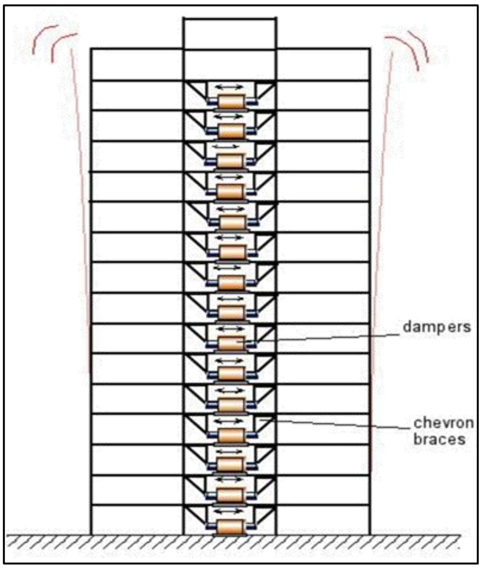

Fig. 8: Smart Structure Technology

1) Ground Penetrating Radar

- Mining and Quarrying
- Geotechnical and Environment
- Forensics and Archaeology
- Buried Utilities

- Concrete and Pavement Assessment
- Military and Security
- Agriculture and Forestry
- Ice and Snow

2) Magneto rheological fluid

Magnetorhelogoical (MR) fluid is a liquid that changes to a near-solid when exposed to a magnetic force, and then back to liquid once the magnetic force is removed. It can be used as a fluid in massive dampers that control large buildings during earthquakes and strong winds.

3) Optical Fibres

Electronic sensing technologies for design validation, process optimization and condition monitoring. Smart Fibers have been pioneering the development of Optical fiber sensing can deliver numerous, key advantages over conventional, such systems based on fiber Bragg gratings since 1995.

4) Piezoelectric Material

Piezoelectric material can generate an electric potential in response to applied mechanical stress, or vice-versa.

5) Stereo Lithography

Stereo lithography, also known as 3D printing, enables to create solid objects from CAD drawing in a fraction of time that would be possible by using traditional modeling methods.

- Materials: Steel, Concrete, Prestresed Concrete, Masonry, Timber, Composites
- Components: Abutment, anchor rod, pier, bearing, cable, cross frame, expansion joint, pile and pile group, stiffener
- Miscellaneous: Software, drawing, inspection, low energy buildings, sustainable design, non-destructive evaluation, painting, structural health monitoring, surveying,

L. How Smart Structures Work

A smart structure can be an earthquake-proof skyscraper, a mile-long bridge, a multi-million dollar aircraft, or a shape conforming $2 foam pillow, and many objects in-between.

Computer technology, allied with structural engineering research, has fuelled the growth of smart structures, and they increasingly impact our lives by allowing better, safer, and more reliable products to be built.

Most of us, when we think of smart structures, envisage earthquake-proof skyscrapers and bridges, large structures that can now withstand quite strong earthquakes. Not too long ago, huge structures like these used to be built as rigidly as possible with massive cross-beams.

The problem is that rigid structures crack, and, inside a rigid building during an earthquake, the non-rigid contents, including humans, go flying all over the place. Not too long ago, dampers were introduced in this type of structure, massive ball-bearings or other devices that allowed a building to "roll with the punch."

During an earthquake, sensors signal the computer to send an electrical charge through the damper, and the earthquake vibration causes the MR fluid to change from liquid to solid thousands of times per second. In a large building, there can be hundreds of dampers, and each damper will help reduce the shaking. With computer control, a building can be left to sway gently and safely during minor quakes, insulating people and equipment inside, or it can be frozen solid during severe quakes, protecting the building from major damage.

Smart structures and structural components have unusual abilities: they can sense temperature and pressure changes; they can identify strain; they can diagnose a problem; initiate an action to preserve structural integrity and continue to perform their intended functions.

They can also store processes in memory and learn to repeat actions taken. The design, development, and deployment of smart structures are at the cutting edge of engineering research.

II. Conclusion

It is clear from the foregoing, that this alterable property of the SMA's will have a major say in the field of precision engineering and surgical operations in years to come. The biocompatibility, strength and corrosion resistance stands them ahead in tough competition with other materials used in Eyeglass Frames, Medical Tools, Cellular Phone Antennae, Orthodontic Arches, Robotics, the Space shuttle and thermostats. The sensing and responding property of these materials make them analogous to human brain and muscular system and also we can avoid most of the train accidents. By overcoming few of its setbacks we can make these magical materials unarguably the best alternative in the field of manufacturing.

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