IJNRD.ORG ISSN : 2456-4184
INTERNATIONAL JOURNAL OF NOVEL RESEARCH AND DEVELOPMENT (IJNRD) | IJNRD.ORG
An International Open Access, Peer-reviewed, Refereed Journal

A Review on Applications of Smart Materials

K. Sreelatha*, C.S. Ananda Kumar[1], P.Srinivasa Sai[2], P. Vijayalakshmi[3], Dr S.V.G.V.A. Prasad[4]

[1] Dept of Physics, SVKP & Dr KS Raju Arts & Science College, Penugonda – 534320, A.P India
[2]Dept of Mathematics, SS & N College, Narsaraopet – 522601, A.P- India
[3]Assistant Professor in Physics, Sir CRR College of Engineering, Eluru – A.P – India
[4]Dept of Physics, Pithapur Rajah's Government College(A)- Kakinada E.G.Dt, A.P - India
[*] Dept of Physics, Ch. S.D St Theresa's College for women (A), Eluru – 534003, A.P- India

***Corresponding author:** **K. Sreelatha**

Abstract: Smart materials belong to the family of advanced materials. These groups of materials have self-accommodation with environment and they are classified according to their responses, such as physical (pressure, temperature, humidity, light, electric field, magnetic field), chemical (pH, CO2, etc.), or biological stimuli. The smart materials can convert the absorbed energy or their characteristics may undergo a change. Smart materials are getting high attentions due to their commercial applications in either actuator or sensor form. In addition, the applications of smart materials are categorized according to the different application areas, such as medical implantation, reducing waste, and nanoengineered systems.

Keywords: Smart materials – Types, Shape Memory Alloys, Various Applications

Introduction: Smart materials are materials that have one or more properties that can be significantly altered in a controlled fashion by external stimuli, such as stress, temperature, moisture, pH, electric or magnetic fields. A variety of smart materials already exist, and are being researched extensively. 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.

Advanced man-made composites such as glass and carbon fibre reinforced plastics can be tailored to suit the requirements of their end application, but only to a single combination of properties. Whereas, the materials and structures involved in natural systems have the capability to sense their environment, process this data, and respond. They are truly 'smart' or intelligent, integrating information technology with structural engineering and actuation or locomotion. "Smartness" of a material is characterized by self-adaptability, self-sensing memory and decision making. Smart materials are the materials that respond with shape or other property change upon application of externally applied driving forces (electrical, magnetic and thermal). In other words, smart materials refer to materials that can undergo controlled transformations through physical interactions and are structured with multi-functionality. They have they are able to respond to slight variation in temperature, moisture, pH, electric or magnetic fields by changing their appearance, state and properties. They are exemplified as boon in tackling the problem of deteriorating civil infrastructure and they had influenced the life cost of these structures by reducing the upfront construction cost as they allow reduced safety factors in initial design.

Types of Smart Materials:

Piezo electric- materials are materials that produce a voltage when stress is applied. Since this effect also applies in the reverse manner, a voltage across the sample will produce stress within the sample. Suitably designed structures made from these materials can therefore be made that bend, expand or contract when a voltage is applied.

Shape memory alloys- and shape memory polymers are Thermo responsive materials where deformation can be induced and recovered through temperature changes.

Magnetic shape memory- alloys are materials that change their shape in response to a significant change in the magnetic field.

pH-sensitive polymers- are materials which swell/collapse when the pH of the surrounding media changes.

Halochromic- materials are commonly materials that change their color as a result of changing acidity. One suggested application is for paints that can change color to indicate corrosion in the metal underneath them.
In chemistry, chromism is a process that induces a reversible change in the colours of compounds. In most cases, chromism is based on a change in the electron states of molecules so this phenomenon is induced by various external stimuli which can alter the electron density of substances.

Chromism

Chromic phenomena are those phenomena, in which colour is produced when light interacts with materials in a variety of ways. These can be categorized under the following five headings:

- Reversible colour change
- The absorption and reflection of light
- The absorption of energy followed by the emission of light
- The absorption of light and energy transfer (or conversion)
- The manipulation of light.

Absorption of light and energy transfer (or conversion) involves collared molecules that can transfer electromagnetic energy, usually from a laser light source, to other molecules in another form of energy, such as thermal or electrical. These materials can provide invisibility to the soldiers in the battle field.

ChromogenicSystems

They change color in response to electrical, optical or thermal changes. These include electro chromic materials, which change their color or opacity on the application of a voltage (e.g. liquid crystal displays), thermo chromic materials change in color depending on their temperature, and photochromic materials, which change color in response to light - for example, light sensitive sunglasses that darken when exposed to bright sunlight.
The development of durable and cost effective high performance construction materials is important for the economic wellbeing of a country. Assorted developments are being made these days to increase the strength and durability of these structures and make them accustomed to various natural changes.
The technology now addresses the growing needs for strengthening aging structures, rehabilitating damaged structures and designing new structures to more severe requirements and for longer service life. Innovations are being made in structural materials and to develop superior products that have positive impact on our cost-effective competitiveness, national security and quality of life. In order to achieve the above requirements evaluation of structure is essential.
Engineers have to use three main criteria to select materials: desired properties, availability of manufacturing technology, economic feasibility. One of the latest developments in this context is the development of smart material.

Table. Classification of chromic materials and their stimuli

Chromic group	**Stimuli type**
Photochromic	Absorbing Electromagnetic light
Thermochromic	Changing of temperature
Electrochromic	Appling electric Field
Magnetochromic	Appling magnetic field
Piezochromic	Mechanical Loading
Solvatechromic	Contact with some liquid
Carsolchromic	Bombarding with electron beam

SHAPE MEMORY ALLOYS (SMA):

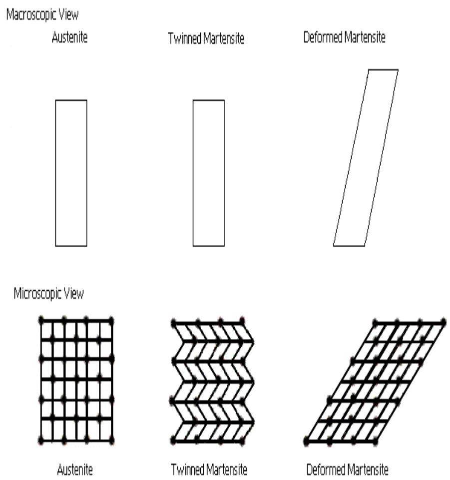
- A shape memory alloy is an alloy that "remembers" its original, cold, forged shape, and which returns to that shape after being deformed by applying heat.
- This material is a lightweight, solid-state alternative to conventional actuators such as hydraulic, pneumatic, and motor-based systems.
- The three main types of shape memory alloys are the **copper-zinc-aluminium-nickel**, **copper-aluminium-nickel**, and **nickel-titanium (NiTi)** alloys but SMA's can also be used by alloying zinc, copper, gold, and iron.
- Ni Ti alloys are generally more expensive and change from austenite to martensite upon cooling.
- The transition from the martensite phase to the austenite phase is only dependent on temperature and stress.
- It is the reversible diffusion less transition between these two phases that allow the special properties to arise.
- While martensite can be formed from austenite by rapidly cooling carbon-steel, this process is non-reversible.
- The term shape memory refers to the ability of certain alloys to undergo large strains, while recovering their original configuration at the end of the deformation process impulsively or by heating without any residual deformation.
- They are known as shape memory alloys as they remember their original shape when deformed from their original crystallographic configuration.
- Shape memory alloys (SMA's) are metals, which exhibit two very unique properties, pseudo-elasticity, and the shape memory effect.
- The most effective and widely used alloys include NiTi (Nickel - Titanium), CuZnAl, and CuAlNi and CuZnAl

Manufacture:

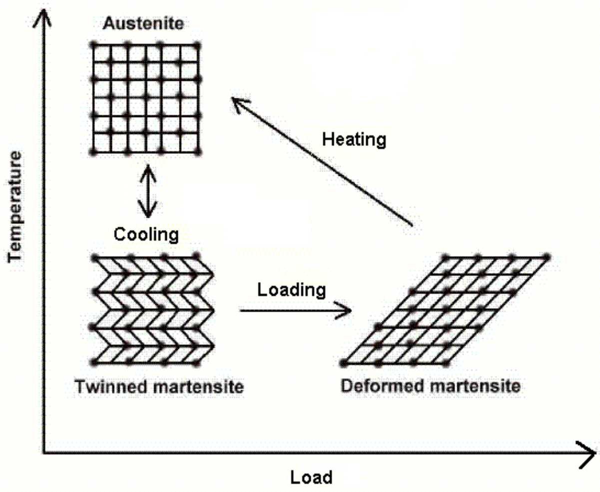
- The way in which the alloys are made depends on the properties wanted. They are heated to between 400 °C and 500 °C for 1-5 minutes.
- Typical variables: 500 °C and for more than 5 minutes.
- They are then shaped while hot and are cooled rapidly by quenching in water or by cooling with air.

Repeated use of the shape memory effect may lead to a shift of the characteristic transformation temperatures (this effect is known as functional fatigue, as it is closely related with a change of microstructural and functional properties of the material).Aircraft manoeuvrability depends heavily on the movement of flaps found at the rear or trailing edge of the wings. Most aircraft in the air today operate these flaps using extensive hydraulic systems. A more promising alternative is the **shape memory wire** used to manipulate a flexible wing surface. The wire on the bottom of the wing is shortened through the shape memory effect, while the top wire is stretched bending the edge downwards, the opposite occurs when bending upwards. The shape memory effect is induced in the wires simply by heating them with an electric current, resulting in weight loss.

Microscopic and Macroscopic Views of the Two Phases of Shape Memory Alloys



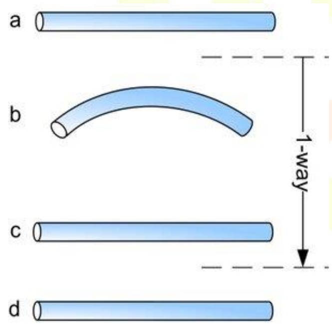
Shape Memory Effect

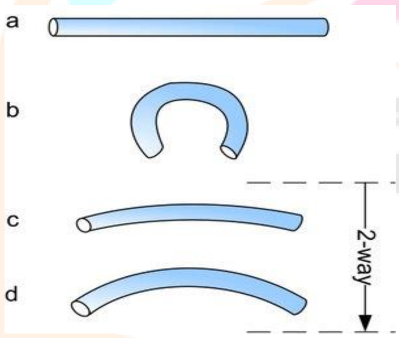


Shape Memory Effect:

Shape memory effect is observed when temperature of a piece of SMA below the temperature Mf. At this stage alloy is completely composed of Martensite which can be easily deformed. The distorted shape can be recovered by heating the wire above temperature Af. Thus the deformed Martensite is now transformed to cubic Austensite phase.

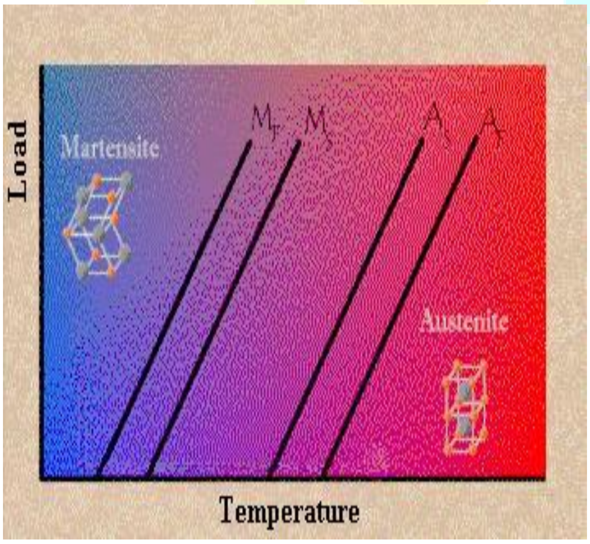
One-way vs. two-way Shape Memory

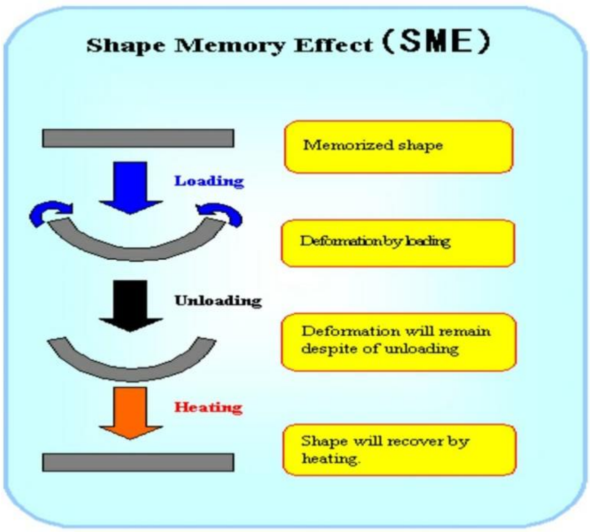




One way shape memory Two way shape memory

How Shape Memory Alloys Work? The two unique properties of SMA's (Pseudo-elasticity and shape memory effect) are strictly associated to a solid-solid phase transformation which can be thermal or stress induced i.e. a molecular rearrangement occurs in these SMA's. The two phase transformations which occur in SMA are Martensite and Austensite. Martensite is relatively soft and easily deformed phase of shape memory alloys, which exists at lower temperatures. Austensite the stronger phase.





Applications of Smart Materials

There are many possibilities for such materials and structures in the manmade world. Engineering assemblies could operate at the very limit of their performance envelopes and to their structural limits without fear of exceeding either. Smart materials and structures will solve engineering problems with hitherto unachievable efficiency, and provide an opportunity for new wealth creating products.

Smart Materials in Aerospace

Some materials and structures can be termed 'sensual' devices. These are structures that can sense their environment and generate data for use in health and usage monitoring systems (HUMS). To date the most well established application of HUMS are in the field of aerospace, in areas such as aircraft checking. An aircraft constructed from a 'sensual structure' could self-monitor its performance and provide ground crews with enhanced health and usage monitoring. Potential applications of such adaptive materials range from the ability to control the aero-elastic form of an aircraft wing, thus minimising drag and improving operational efficiency, to vibration control of lightweight structures such as satellites, and power pick-up pantographs on trains.

Smart Materials in Defence Applications

- **Ballistic protection** — New polymers with improved tensile properties that can increase ballistic protection and reduce weight over current individual protection systems.
- **Integrated protective helmet** — New and improved polymers for fibre-reinforced plastics and resins to provide increased ballistic protection and lighter weight, besides new materials for energy absorption and improved lightweight, integrated communications devices.
- **Modular personnel protection system** — A modular personnel protective system that can be tailored to protect areas of the body not currently protected by standard armour vests and plates from threats.
- **Chemical and biological protection** — Novel materials and concepts that could provide protection against highly toxic compounds, including toxic industrial chemicals and military offensive chemical agents.
- **Counter-surveillance** — Enhancement of textile systems that cloak soldiers' uniforms, equipment and skin-camouflage paints from infrared and other sensors used in enemy surveillance.
- **Materials nanotechnology** — Materials incorporating nanotechnology include personnel armour, clothing, airdrop systems, and load carriage systems, packaging materials, textile-integrated electronic systems, chemical/biological

Civil Engineering Properties:

- Usable strain range of 70%.
- Repeated absorption of large amount of strain energy under loading without deformation.
- Fatigue resistance under large strain cycles.
- Great durability and reliability.
- Corrosion resistance.
- Low stiffness.
- As a shape memory coupling for piping.
- Dental braces
- An SMA of titanium is used to make eyeglass frames.

Advantages

- Bio-compatibility
- Diverse Fields of Application
- Good Mechanical Properties (strong, corrosion resistant)
- Boeing, General Electric Aircraft Engines, Goodrich Corporation, NASA, and All Nippon Airways developed the Variable Geometry Chevron using shape memory alloy that reduces aircraft's engine noise. Boeing's upcoming aircraft, the 787 and the 747-8 will be equipped with this new technology.

Disadvantages

- Energy inefficiency
- Slow response times
- High manufacturing cost
- Reactive materials and tactical optics.

Structural Applications:

Self-healing material

Self-healing materials are a class of smart materials that have the structurally incorporated ability to repair damage caused by mechanical usage over time. A material (polymers, ceramics, etc.) that can correct damage caused by normal usage could lower production costs, reduce inefficiency, as well as prevent costs incurred by material failure.

Dissipation of Energy in Structures:

Owing to the super-elastic plateau, SMA's have the ability to act as force limiting devices. In case of reinforcement using steel bars, the force transmitted to masonry structures are higher due to stiffness of steel bars. But these SMA's during unloading do not return all energy accumulated upon loading and can dissipate certain amount of energy when subjected to large cyclic deformations and are able to increase energy dissipation capacity of masonry itself (by friction in masonry joints and fractures), due to better distribution of damage in structure, when damage cannot be avoided and thus helps in avoiding localized damage.

Earthquake Resistant Structures:

Super-elastic behavior of SMA i.e., the ability to recover from large deformation during loading-unloading cycles is used for construction of earth-quake resistant structure. This is due to the flexibility, thermo mechanical and damping property of these material which makes them to hold the building together and absorb shocks 50%more than old masonry made structure.
In case of bridges, SMA's restrainer are being used which are able to limit the relative hinge displacements and maximum hinge displacement being about half of steel restrainers. And even after repeated cycling of loads, there is little degradation of properties and they reach their yield level whereas the steel restrainers fail.

Innovative Columns:

These days innovative columns (using thermo mechanical property of SMA) are being made having more strength than those built with steel reinforcement. Nitinol shape memory alloy is generally being used. These innovative columns can be used as retrofit, in seismic structure and in new construction that exhibits performance which is superior to existing.

Bullet Proof Structure:

When a projectile touches a material it causes a shock wave, propagating through the material. When the shock wave arrives at the other end of the material, it can damage the material. The damaging starts with a small crack at the back side. These shock wave propagates back to the front due to their reflection and causes further penetration of projectile. In order to make a structure bullet proof, CU-ZN-AL PROTEUS having high specific damping capacity is generally being used.

Reversible Self-Healing Polymers

Reversible systems are polymeric systems that can revert to the initial state whether it is monomeric, oligomeric, or non-cross-linked. Since the polymer is stable under normal condition, the reversible process usually requires an external stimulus for it to occur. For a reversible self-healing polymer, if the material is damaged by means such as heating and reverted to its constituents, it can be repaired or "healed" to its polymer form by applying the original condition used to polymerize it.

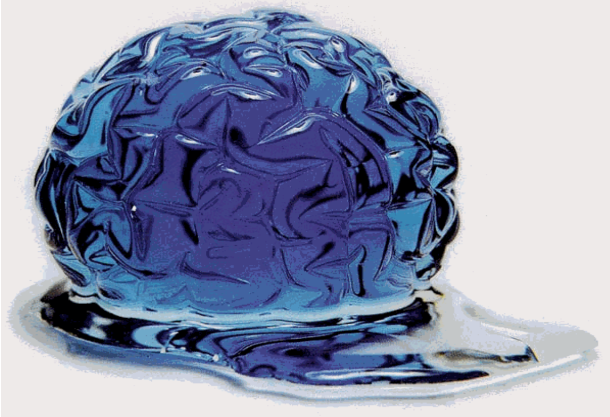
Autonomic Polymer Healing

The first report of a completely autonomous man-made self-healing material was an epoxy system containing microcapsules. These microcapsules were filled with a (liquid) monomer. If a microcrack occurs in this system, the microcapsule will rupture and the monomer will fill the crack. This model system of a self-healing particle proved to work very well in pure polymers and polymer coatings.

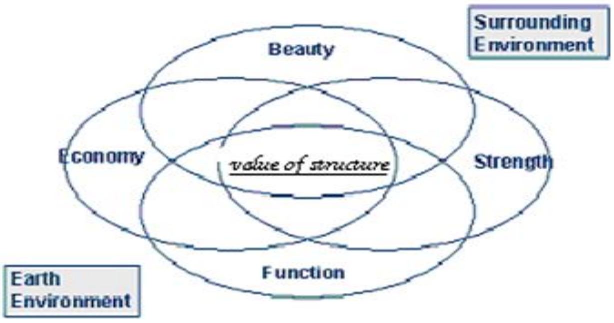
Ferro fluids

A Ferro fluid is liquid which becomes strongly polarised in the presence of a magnetic field. Ferro fluids are colloidal mixtures composed of nano scale ferromagnetic mixtures composed of ferromagnetic, or ferrimagnetic, particles suspended in a carrier fluid, usually an organic solvent or water. The ferromagnetic nanoparticles are coated with a surfactant to prevent their agglomeration. Ferro fluids do not display ferromagnetism, since they do not retain magnetization in the absence of an externally applied field. In fact, ferrofluids display paramagnetism, and are often described as "superparamagnetic" due to their large magnetic susceptibility. Permanently magnetized fluids are difficult to create at present.

Description: Ferrofluids are composed of nanoscale particles of magnetite or hematite. Ferrofluids are tiny iron particles covered with a liquid coating, also surfactant that are then added to water or oil, which gives them their liquid properties. They are colloidal suspensions - materials with properties of more than one state of matter. In this case, the two states of matter are the solid metal and liquid it is in.



A smart fluid developed in labs at the Michigan Institute of Technology



Evaluation components of structure

This ability to change phases with the application of a magnetic field allows them to be used as seals and lubricants. These surfactants prevent the nanoparticles from clumping together, ensuring that the particles do not form aggregates that become too heavy to be held in suspension by Brownian motion.
The United States Air Force introduced a Radar Absorbent Material (RAM) paint made from both ferro fluidic and non-magnetic substances. By reducing the reflection of electromagnetic waves, this material helps to reduce the Radar Cross Section of aircraft. NASA has experimented using ferrofluids in a closed loop as the basis for a spacecraft's attitude control system. A magnetic field is applied to a loop of ferro fluid to change the angular momentum and influence the rotation of the spacecraft.

Conclusion: The main focus on the use of these materials is to develop cost effective, durable & efficient structure. The various properties of smart materials like self - health monitoring, shape memory effect, electrical resistance etc. had led to development of smart structures in which health and performance is monitored throughout the lifetime of structure and had made structure earthquake resistance. So,it can be accomplished that if these materials are used in proficient manner it can lead to increase in strength and durability of structure and may have a positive impact on our cost-effective competitiveness, national security, and quality of life which can help in the development of a country.

REFERENCES:

- Kumar Dr. Rakesh and Kumar Dr. Ram: ICI journal; pp. 15-18; April- June 2005.
- http://dbtindia.nic.in
- http://www.cs.ualberta.ca
- http://www.answers .com
- http://structure.nuae.nagoya-u.ac.jp
- Thakur, S., Shape Memory Polymers for Smart Textile Applications, in Textiles for Advanced Applications. 2020, In Tech.
- Rock, M., Temperature responsive smart textile. 2021, Google Patents.
- Mishra, A.K., Smart materials for waste water applications. 2016: John Wiley & Sons. Miyazaki, S. and R. Sachdeva, Shape memory effect and super elasticity in Ti—Ni alloys, in Shape memory alloys for biomedical applications. 2009, Elsevier. p. 3-19
- Akrar. J 2005, "Eurofly A330-200 interiors", Airliners, viewed 13th September 2007 Amin, A and Newnham, RE 1999, Smart systems: Microphones, fish farming, and beyond, American Chemical Society,
- 'Material science and manufacturing" M Moallem 1997
- "Material science and engineering" K M Gupta Umesh Publications
- Elements of material science and engineering Van Vlack/ Adison Wesley