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Overview On Smart Materials and Their Applications

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Abstract

Smart materials commonly known as intelligent or responsive materials through their unique property to adapt with external parameters like temperature, pressure, light and electric or magnetic field play an industry changing application. This paper explores some of the key smart materials like shape alloys, piezoelectric materials, self-healing materials, magnetostrictive materials, and dielectric elastomers, along with their industrial applications. These materials have played a key role in revolutionizing sectors such as healthcare, aerospace, electronics and construction. Their properties have enhanced the efficiency, durability and cost effectiveness. By the integration of these materials into modern industry, significant advancement can be achieved in innovation. This will help in paving way for future technological breakthroughs.

Relevance

Smart materials also called as responsive or intelligent materials play an important role in today's revolutionary world by their extensive properties and applications. They are capable to modify their internal and external functional parameters like temperature, pressure, light, electric and magnetic fields or chemical environment to cope up with various applications. They provide their applications in various sectors like healthcare, electronics, automobile, aerospace, construction and other sectors. Some of the smart materials with industry valuable properties have been discussed in this paper. Their integration in today's industry can help achieve a difference in various other fields of cost-saving, increased efficiency in work and durability and innovations.

Types of smart materials

They are classified based on their properties which they exhibit and provide necessary applications. Some of the key industry valuable and revolutionary smart materials are:

1. SHAPE MEMORY ALLOYS

shape memory alloys are smart material which are capable to revert and transform back into their original shape and size on heating or cooling.

1.1 Shape memory effect

The shape memory effect occurs due to a temperature induced phase transformation which reverses deformation. The austenite structure is stable at high temperature, and the martensite structure is stable at lower temperatures. When a SMA is heated, it begins to transform from martensite into the austenite phase [1].

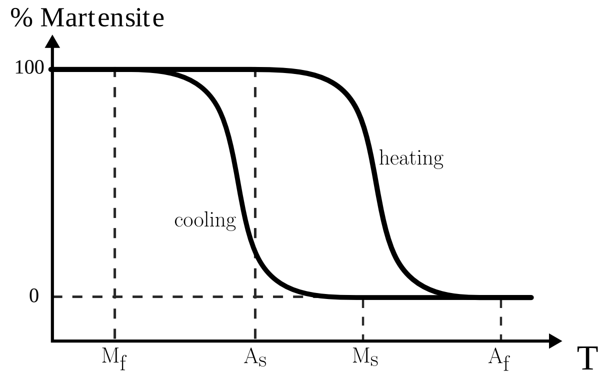

Fig 1- Martensite and Austenite Temperature Phase

1.1.1 MARTENSITE-

It is a hard and brittle microstructure formed through a diffusionless transformation when metal rapidly cools from a high temperature. In shape memory alloys the crystal structure allows them to regain their original shape through twinning.

1.1.2 AUSTENITE-

It is the high temperature phase of metals mostly found in steels and shape memory alloys. It has an FCC (Face centered cube) structure which makes it more ductile and less brittle than martensite. It gets transformed into martensite when it is cooled.

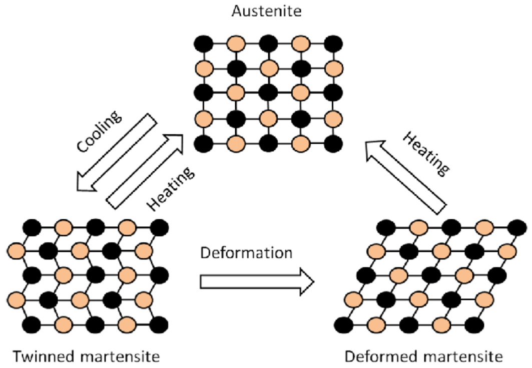

Fig 2- Martensite and Austenite Heating Cooling Transformation

1.2 Types of memory effect:

The mainly considered shape memory characteristics are:

1.2.1 One-way shape memory effect (OWSME):

The one-way SMA (OWSMA) retains a deformed state after the removal of an external force, and then recovers to its original shape upon heating [1].

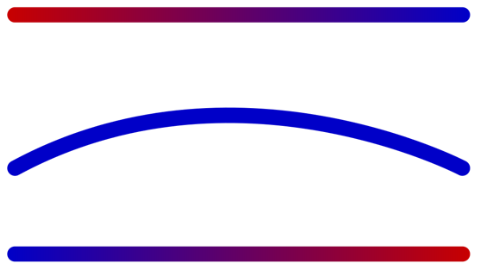

Fig 3- One Way Shape Memory Effect

1.2.2 Two-way shape memory effect (TWSME):

In addition to the one-way effect, a two-way SMA (TWSMA) can remember its shape at both high and low temperatures [1]. The one way shape memory material provides better industrial application than the two way shape memory as it produces only half the recovery strain in comparison to OWSMA. The difference in produced recovery strain hinders the reliability and the economic viability.

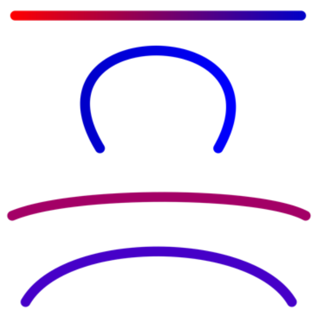

Fig 4- Two Way Shape Memory Effect

1.2.3 Pseudoelasticity(PE) or Superelasticity(SE):

The shape memory alloy reverts to its original shape after applying mechanical loading at temperatures between Austenite finish temperature and Martensite Desist temperature without the need for any thermal activation.

1.3 Applications of SMA:

The serve variety of application in sector like:

HEALTHCARE SECTOR:

1.3.1 Coronary stents:

The most commonly used shape memory alloy is Nitinol (Nickel and Titanium). Nitinol allow the stent to be compressed into very small size for delivery through the balloon catheter into our body and self-expand once it reaches the target location inside the artery due to the body warmth.

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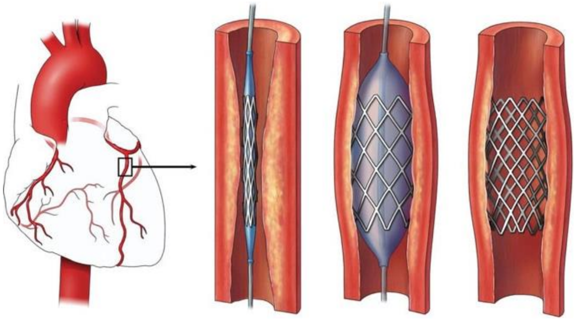

Fig 5- SMA used as Coronary Stent

1.3.2 Orthodontic wires:

Nitinol wires are used in teeth braces due to their shape memory material which provide superelasticity, ductility, resistance to corrosion and biocompatibility.

Fig 6- SMA used in Orthodontic Wires

AEROSPACE INDUTRY:

1.3.3 F-14 fighter jets:

The traditional fighter jets used to have fixed wings but the F-14 fighter jets introduced the usage of shape memory alloys. When the jets had to land on airplane carrier it had to be provided with great stability at supersonic speed. This need was fulfilled by using smart material which helped in changing the shape of the wing and clinching it inward to the jet. This provided superior supersonic speed stability.

Fig 7- F-14 Fighter Jet

Fig 8- SMA in Jets and Planes

1.3.4 Rover Tyres developed by NASA:

The NASA have introduced the usage of smart material alloy based spring tyres to be used in Martian stimulated surfaces for testing. The tyres will later on be used in rovers sent to Mars for expeditions to tackle with the variations in the rock surfaces.

Fig 9- NASA Rover Tyres

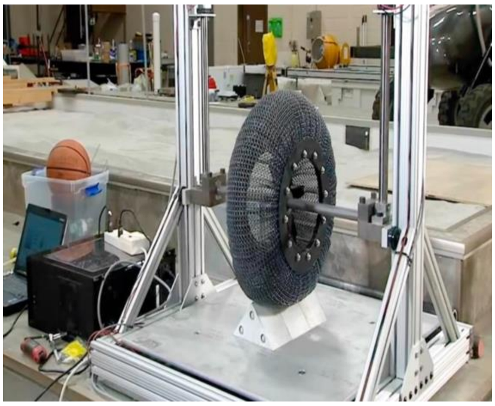

Fig 10- Rover tyres made using SMA

ROBOTICS

1.3.5 SMA used in Robotic Hand

A clever use of muscle wire (Made from SMA) and a micro-controller circuit is a robotic hand. A robotic hand has 'stretched muscle wires' attached to the base of each finger. When current is applied to the muscle wire it contracts to its ‘natural' length by pulling on the ordinary wire. The micro-controller is programmed to give five of the outputs with switch on and off options. This makes the fingers of the hand move.

B) Robotic Arm :-

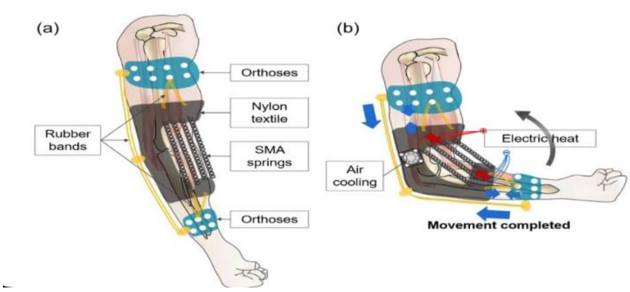

Fig 11- SMA used in robotic arm

2. PIEZOELECTRIC MATERIAL

Piezoelectric materials convert mechanical energy from pressure, vibrations or force into electricity. They are capable of generating electrical charge when a mechanical load is applied on them [2].

Environmental excitation energy ⇨ Mechanical vibration energy ⇨ Electrical energy output

Fig 12- Piezoelectric flowchart

2.1 Piezoelectric effect

When pressure is applied the atomic structure shifts, creating an imbalance which generates voltage. This is called as direct piezoelectric effect. Vice versa when electric field is applied, altering atomic positions in turn causing mechanical deformation is known as inverse piezoelectric effect. This phenomenon enable applications like sensor and actuators

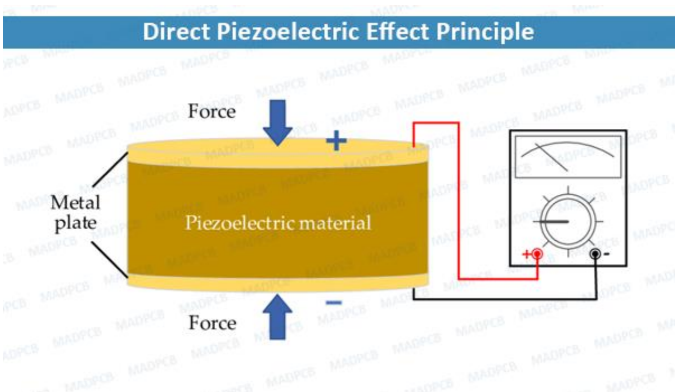

Fig 13- Piezoelectric effect principle

2.2 Applications of piezoelectric materials

2.2.1 Stethoscope:

Polyvinylidene fluoride is used I the form of thin film placed on chest piece to convert mechanical vibration from the patient's body into electrical signals that can be amplified and heard through the earpiece. It's exactly located between the transducer housing and steel plate.

Fig 14- Stethoscope

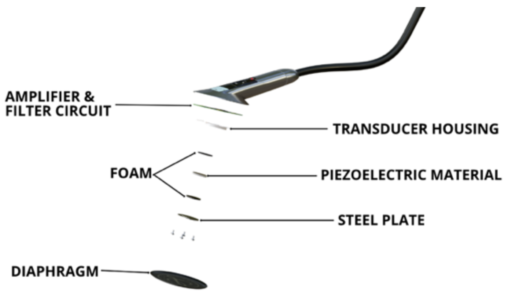

Fig 15- Stethoscope

2.2.2 Ultrasonic imagining:

Piezoelectric Transducers are often used in medical Ultrasound Equipment. Advances in equipment over the decades have enabled improved monitoring of pregnancies and facilitated minimally invasive surgical procedures[3].

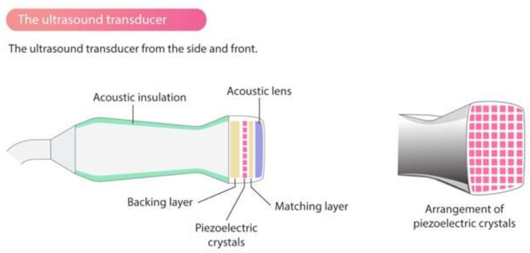

Fig 16- Ultrasonic Transducer

2.2.3 Tennis Racket:

A somewhat unusual application for piezoelectricity integrates piezoelectric fibres into the throat of a tennis racquet along with a microcontroller in the handle. When the tennis player strikes the ball, the racquet frame deflects and generates an electric output that is boosted, reversed, and fed back into the fibres [3].

3. SELF HEALING MATERIAL

Self-healing materials are no more an illusion and we are not far away from the days when manmade materials can restore their structural integrity in case of a failure. Self-healing can be defined as the ability of a material to heal (recover/repair) damages automatically and autonomously, that is, without any external intervention. Many common terms such as self-repairing, autonomic-healing, and autonomic-repairing are used to define such a property in materials [4].

3.1 Applications of self-healing material

3.1.1 Self-healing concrete:

Concrete elements loaded In bending or in tension easily crack. For this reason reinforcement is installed. Passive reinforcement is activated as soon as the concrete cracks. Various healing agents have been proposed in the studies that have been undertaken on the self-healing of concrete. The main healing materials that have been proposed to date are epoxy resins, cyanoacrylates, alkali–silica solutions and bacterial-concrete. It is obvious that the effectiveness of the healing process is not only dependent on the capillary forces that are dictated by the crack width[4].

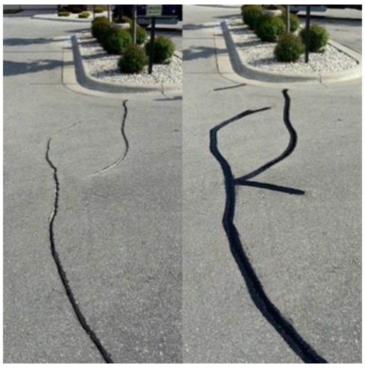

Fig 17- Crack repairing using Self-Healing material

3.1.2 Hydrogel adhesive for tissue adhesion:

Injectable and biocompatible hydrogel adhesives are developed via catalyst. The hydrogels demonstrate rapid and firm adhesion to various tissues. The hydrogel adhesives show controlled degradation profiles of 6 to 22 weeks. In liver and blood vessel injury, the hydrogels effectively seal the incisions and rapidly stop bleeding [5].

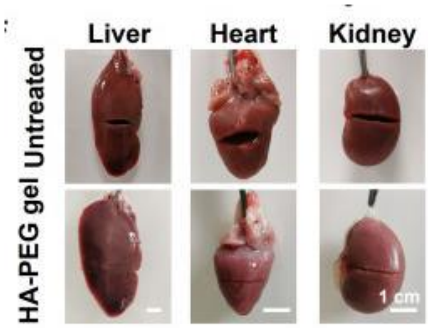

Fig 18- Human Body parts untreated and with usage of Hydrogel Adhesives

4. MAGNETOSTRICTIVE MATERIAL

Magnetostriction is an property of magnetic materials that causes them to change their shape or size during the process of magnetization.

4.1 Magnetostrictive effect:

Magnetostriction is the reversible deformation of a ferromagnetic material when it's placed in an external magnetic field. This effect is caused by the rotation of the material's internal magnetic fields[6].

4.2 Applications of Magnetostrictive material:

4.2.1 Sonar transducer:

The need of low-frequency high-power active sonars for the Navy was fulfilled by magnetostrictive sonar transducer. The discovery of a giant magnetostrictive material, commercially known as Terfenol-D helped the discovery[6].

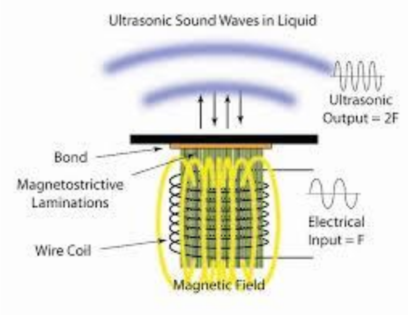

Fig 19- Magnetostrictive Material Sonar Transducer

4.2.2 Actuator and Sensors

Converts the magnetic energy into mechanical energy(Actuators) and vice versa (sensors). They are used for precise position sensing and vibration control

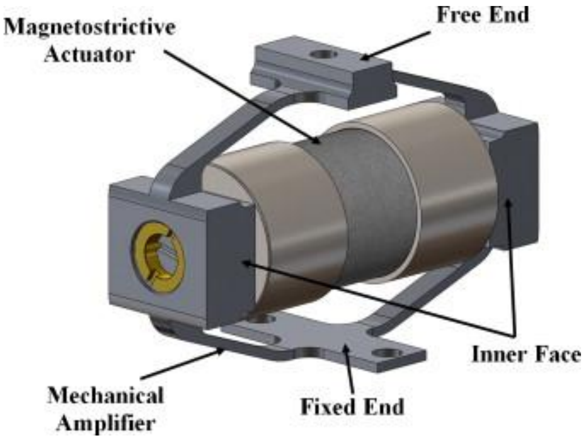

Fig 20- Magnetostrictive Actuator

5. DIEELECTRIC ELASTOMERS

Electro-active polymer (EAP) is a kind of intelligent multifunctional material. When subjected to an external electric field, EAP reduces its thickness and expands its area[7].

5.1 Dielectric elastomer effect:

When subjected to electric field, DE can produce large deformation. What's more, it possesses the advantages of high elastic energy density, super-short response time, high electromechanical conversion rate, excellent flexibility, light weight[7].

5.2 Applications of Dielectric elastomers

5.2.1 Artificial muscles

Artificial muscle technologies enable low-power mobile actuators, robots that mimic efficient and natural forms of motion, autonomous robots and sensors, and lightweight wearable technologies.

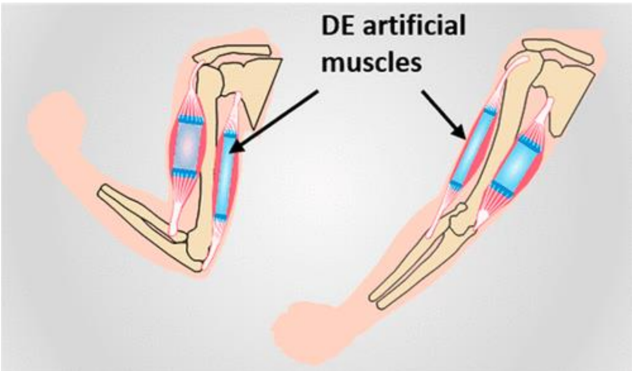

Fig 21- Artificial muscle using Dielectric Elastomers

Conclusion

Smart materials have revolutionised and changed the industry through their properties and ability to alter their properties. Smart materials like Shape memory alloys, piezoelectrical material, self-healing material and magnetostrictive material have found groundbreaking use case in healthcare, aerospace, construction and other sectors. Their properties enhance efficiency, durability and cost effectiveness wherever necessary. From coronary stents and orthodontic wires to aerospace components and self-repairing concrete, these materials contribute significantly to modern engineering. As the research will continue more and more applications of smart materials will be discovered.

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