# Biomedical application of smart materials- An Overview

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***Abstract:*** **Response to stimulus is a basic process of living system. Based on the lesson from the nature, scientists have been designing useful materials that respond to external stimuli such as temperature, pH, light, electrical field, magnetic field and chemical's ionic strength. These responses are manifestated as a changes in one or more of the following: shape, surface characteristics, solubility, formation of an intricate molecular self assembly, a sol-to-gel transition and so on. Such structurs are called smart structures and such materials are referred to as smart materials. Recent advantages in the design of stimuli responsive have created opportunities for novel biomedical applications. Stimuli-responsive changes enable several novel applications in the delivery of therapeutics, tissue engineering, biomemitic actuators and thermoresponsive surfaces. The scope of this paper is limited to the brief overview of the technology, material requirements, smart materials classification and its application. The insight gained by gathering data on smart materials found a large number of application in biomedical and biotechnological field.**

***Keywords -*** **Smart materials and its types, biomedical, biotechnological and biomemitic application of smart materials.**

## I. INTRODUCTION

Many applied scientists or engineer, whether mechanical, civil, chemical, or electrical, will one time or another be exposed to a design problem involving materials. Material scientists and engineers are specialists who are totally involved in the investigation and design of materials. Many times, a materials problem is one of selecting the right material from the thousands of materials available. In fact, early civilizations have been designated by the level of their materials development (Stone age, Bronze age, Iron age). We can't specify the present age. Because, the present age is the choice of flexibility of the materials.

Smart (or intelligent) materials are a new group of materials and state of the art materials now being developed that will have a significant influence on many technologies. The adjective "Smart" implies that these materials are able to sense changes in their environments and then respond to these changes in the predetermined manners-traits that are also found in living organisms[1]. Components of smart materials are

1. Sensor(detects an input signal)
2. Actuator(that performs adaptive functions)

Four types of materials commonly used for actuators are: shape memory alloy, piezoelectric ceramics, magnetostrictive materails, and electrorheological/magnetorheological fluids.

## II. SHAPE MEMORY ALLOYS

### *2.1. Basics about shape memory alloys*

In 1932, Chang and Read observed a reversible phase transformation in gold-cadmium (AuCd), which is the first record of shape memory transformatio. It was after 1962, when Buechler and co-researchers discovered shape memory effect in nickel-titanium at Naval Ordnance Laboratory (they named the material Nitinol after their workplace), that both in-depth research and practical application of shape memory alloys emerged. Up to date many shape memory alloys have been discovered. Among them Nitinol possesses superior thermomechanical and thermoelectrical properties and is the mostly used shape memory alloy[2]. Generally, smart materials exists in two phases at different temperatures such as[5]:

1. Austenite phase, which exists at high temperatures, and
2. Martensite phase, which exists at low temperature.

These two phases differ in their crystal structure. The austenite has a BCC structure, while the martensite has the parellelogram structure (which is asymmetric structure), having upto 24 variations.

### *2.2. Shape memory effect and superelasticity*

Due to change in either temperature or loading conditions, the smart material exhibits many unique properties during the transformations between these two phases, such as shape memory effect and superelasticity effect. The shape memory effect refers to the phenomenon that shape memory alloys returned back to their predetermined shapes upon heating. The superelasticity refers to the phenomenon that shape memory alloys can undergo a large amount of inelastic deformations and recover the shapes after unloading[4]. These unique properties are the result of reversible phase transormations of shape memory alloys. When shape memory alloys in martensite are subjected to external stress, they deform through a so called detwinning mechanism, which transforms different martensite variations to the particular one variation that can accommodate the maximum elongation. Due to its parellelogram structure, the martensite phase is weak and can be easily deformed. On the contrary, the austenite phase has only one possible orientation and shows relatively strong resistance to external stress[4].which is represented in the given diagram Fig. 1.

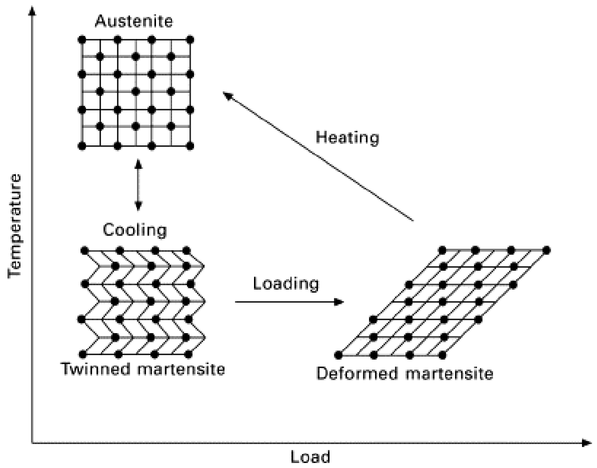


Fig. 1. Shape memory effect

*2.3. Phase transformations associated with SMA*

The composition of shape memory alloy deponds on the internal energy level. For a given temperature, the crystal structure is required to accommodate the minimum energy state. Driven by the external force, the two crystal phases can be transformed: the martensitic transformation and its inverse transformation. The driving force for the phase transformation is the difference in their Gibb's free energy between two phases that will be provided by either heat energy or external loading[7]. Hence, there are two types of two types of martensitic formation: the temperature induced transformation and stress induced transformation. Both transformations are responsible for specific functions

1. temperature induced transformation results in shape memory effect.
2. while stress induced transformation results in superelasticity.

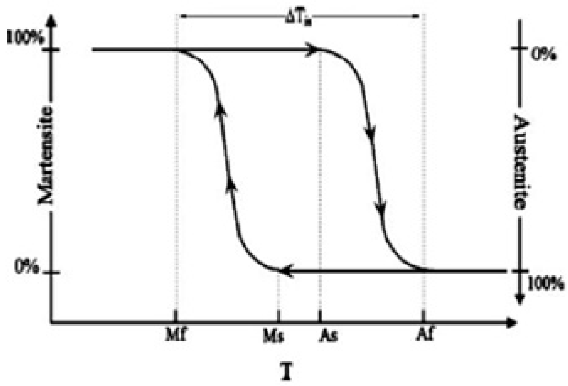


Fig.2. Stress- free martensite phase transformation.

Fig.2 stress free temperature induced transformation and its inverse transformation under a temperature excitation cycle. Four temperatures characterize the the transformation loop: martensite finish temperature($M_f$ ), martensite start temperature *($M_s$)*, austenite start temperature *($A_s$)*, austenite finish temperature *($A_f$)*. It is noticeble that the temperature-deformation loop is hysteretic due to internal phase friction.

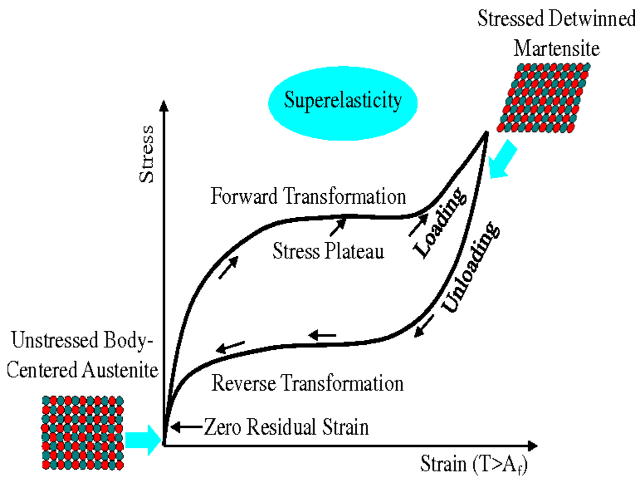


Fig.3 Isothermal stress induced martensite phase transformation

Fig.3 represents a typical stress induced martensite formation. ($T$ <$M_f$). when the martensite is subjected to tension, the elastic deformation is followe by a large increase of strain corresponding to an almost constant stress. This yeilding is due to the hysteresis mobility of the twinned variation interfaces. If the deformation exceeds the maximum value which martensite can sustain through the martensite reorientation mechanism, the permanent plastic deformation takes place. Hence, for practical use, the applied stress should not exceed this maximum value to avoid a plastic permanent deformation[4].

## . III. PIEZOELECTRIC MATERIALS

When the stress is applied across the material, some amount of voltage will be developed. Such, materials are called piezoelectric materials. When the electric potential is applied across the material, stress will be developed. This effect is the converse of piezoelectric effect[7]. The both effect are due to the lattice distortion of the piezoelectric material. This effect is shown in the Fig.4 .

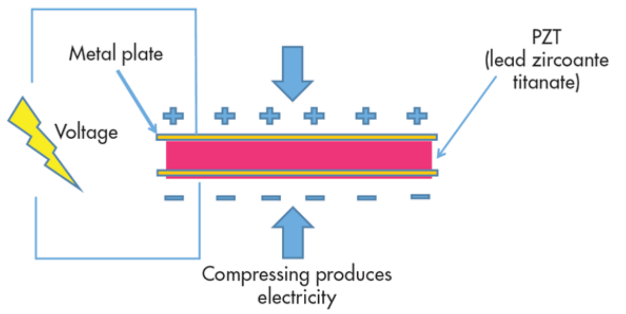


Fig.4. Piezoelectric effect

## IV. MAGNETOSTRICTIVE MATERIALS

It is similiar to the piezoelectric effect, that the dimension of the ferromagnetic materials can be changed by the application of magnetic field. Also, electrorheological and magnetorheological fluids are the liquids that experience the dramatic change in their viscosities when the electric and the magnetic fields are applied.

## V. BIOMEDICAL APPLICATION OF SMART MATERIALS

The different forms and unique properties of shape memory effect and superelasticity finds its wide applicaton in the field of biomedical. The shape memory alloy is shape memorized at the range of human body temperature and it is deformed. When the deformed structure is placed in the human body, it gains the predetermined structure and it will take much more time to get deformed in comparison with other materials. Shape memory alloy based biomedical application can dilate, constricts and enable difficult problematic tasks in surgery.

### *5.1. Stent application*

Thermally induced elasticity is the main principle behind this stent application of smart materials[10]. Stent is a tiny device that is inserted into the lumen of an anatomic vessel to widen the blood vessel. Corony artery disease, one of the leading diseases that causes major death around the world. It is because of the fat deposits that restricts blood flow to the heart. Initially plastic or metal is used. A problem is associated with these stents called restenosis[8],[9]. But the shape memory alloy has achieved a significant place in the stent preparation. The stent is made using Nitinol at the appropriate diameter, the shape memory is at the human body temperature range and is deformed. Then, the deformed stent made of smart material is then inserted inside the human body. This nitinol wire is highly sensitive[11],[12]. As it reaches the human body temperature, it regains its predetermined shape. Then, the stent dilate and it lasts for the longer duration of time[2].

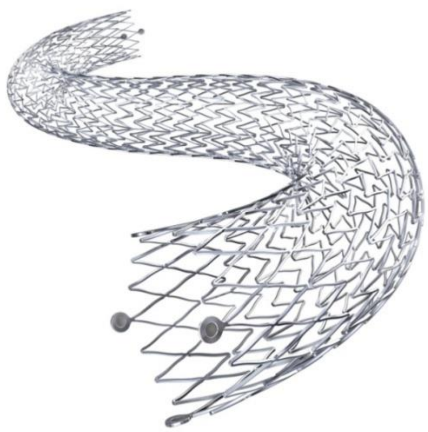

Fig.5. Stent made of Nitinol

### *5.2. Vena cava filters*

Superelasticity is the principle behind the vena cava filters. The part of circulatory system that collects deoxygenated blood to the heart is called vena cava. There are two types of vena cava:

1. Inferior vena cava- collects blood from lower half of the body.
2. Superior vena cava- collects blood from the upper half of the body.

Vena cava filters are used to prevent the blood clot entering into the pulmonary system and life threatening pulmonary embolism. The shape memory alloys act as the best vena cava filter as it has the superelasticy. Usually, the diameter ranges between 2-2.5m[2].

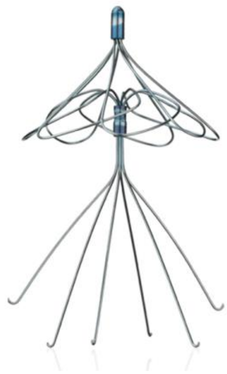

Fig.6. Nitinol vena cava filter

### *5.3. Dental and orthodontic application*

Superelasticity and shape memory effect are the properties required in the dental application. In orthodontics, the braces are used to align and straighten the teeth. Intially, stainless steel is used for the brace material. The limited stretch and tensile properties of these stainless steel led to re-tensioning of braces after 3-4 weeks. Using, the nitinol material for braces has paved the way for the previous problem and the shape of the braces has the better durability. Incase of nitinol wire, it require monitering after 3-4 years.

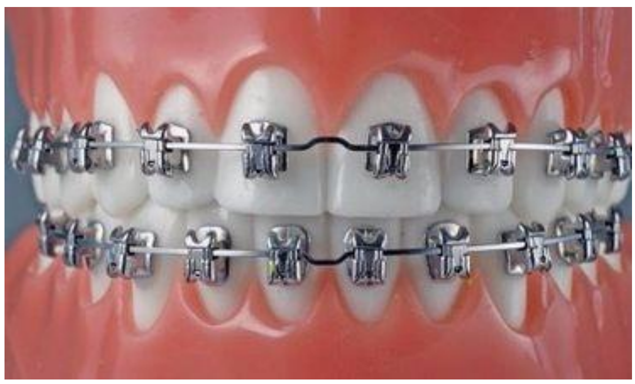

 

Fig.7. Nitinol braces*5.4. Bone application*

early stages, stainless steel along with titanium is used as the bone plate. The bone plates are fixed near the fractured surface and it results in the slight increase in the pressure. This pressure results in the healing of the fractured surface. As the time progress, the material loses its strength and the pressure will be reduced. Incase of stainless steel and titanium, Nitinol can be used[13]. Nitinol plates are cooled to well below the transformation temperature and are set. It can withstand the problems metioned and showed a better performance. So that, in shorter period of time healing can be achieved[2].

Fig.7. Nitinol clavicular hook plate

## VI. FUTURE SCOPE OF BIOMEDICAL APPLICATION OF SMART MATERIALS

Because of the sensing and actuating properties of smart materials find its application in the various fields. In biomedical field the design should be extracted from the biological materials and it can be easily done with the help of the smart materials. Smart T-shirts,Smart bandages etc. can be developed by using smart materials.

## VII. CONCLUSIONS

Based on the brief review of this paper, it is concluded that:

1. Smart materials are not only useful but also cost efficient.
2. Smart materials give promise of optimum responses to highly complex problems.
3. Smart materials can also find the best applications in biomedical, bitechnological fields

Thus, understanding the behaviour of smart material is the ultimate objective in smart field technology.

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