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A REVIEW ON SMART MATERIALS FOR VARIOUS APPLICATIONS

Divya Ms[*1], Moirangthem Priyobarta Singh[2] & Keerthan G[3]
[*1,2&3]VIII Sem, Mechanical Engineering, KIT, Tiptur.

ABSTRACT

In the field of massive and complex manufacturing we are now in need of materials, with properties, that can be manipulated according to our needs. Smart materials are one among those unique materials, which can change its shape or size simply by adding a little bit of heat, or can change from a liquid to a solid almost instantly when near a magnet. These materials include piezoelectric materials, magneto-rheostatic materials, electro-rheostatic materials, and shape memory alloys (SMA's). Shape memory alloys (SMA's) are metals, which exhibit two very unique properties, pseudo-elasticity (an almost rubber-like flexibility, under-loading), and the shape memory effect (ability to be severely deformed and then return to its original shape simply by heating). The two unique properties described above are made possible through a solid state phase change that is a molecular rearrangement, in which 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.

In this paper we have made a comparative study between SMA's and other generally used materials or alloys, with the help of live examples (aircraft maneuverating, robotic muscles and human bone plates), and could conclude that SMA's are superior to them in strength, biocompatibility and resistance point of view. Finally we have also suggested an idea, how the use of SMA's in the mechanical couplings can make a powerful joint.

I. INTRODUCTION

Nature is full of magic materials, which are to be discovered in forms suitable to our needs. Such magical materials, also known as intelligent or smart materials, can sense, process, stimulate and actuate a response. Smart materials have one or more properties that can be dramatically altered. Most 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. A variety of smart materials already exists, and is being researched extensively. Some everyday items are already incorporating smart materials (coffeepots, cars etc) and the number of applications for them is growing steadily.
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.

II. 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 2. Upon deformation this phase takes on the second form shown in Figure 2, on the right. Austenite, the stronger phase of shape memory alloys, 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.

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Figure 1 Martensite and austenite phases

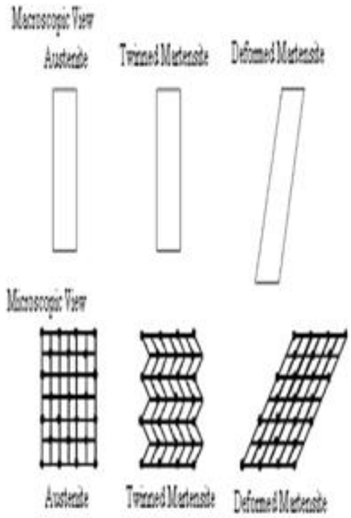

Figure 2 Microscopic and Macroscopic Views of the Two Phases of Shape Memory Alloys

Shape Memory Effect

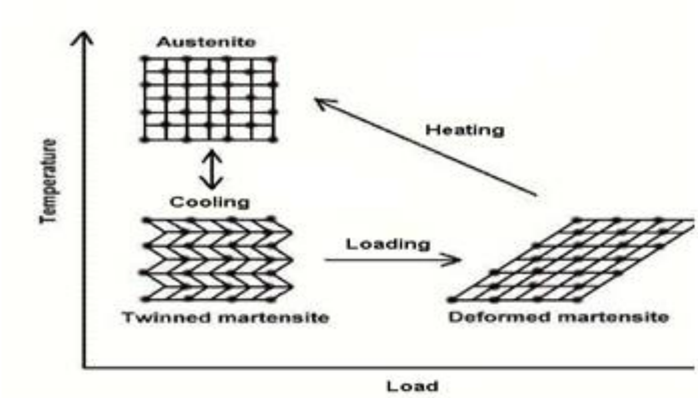

Figure 3: Microscopic Diagram of the Shape Memory Effect

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

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III. PSEUDO-ELASTICITY

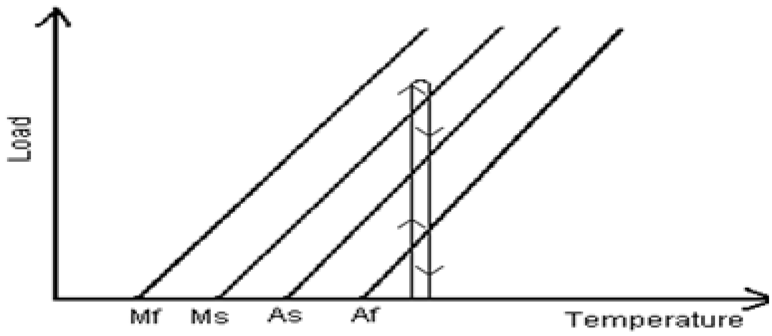

Figure 4: Load Diagram of the pseudo-elastic effect Occurring

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

Applications of Shape Memory Alloys

The unusual properties mentioned above are being applied to a wide variety of applications in a number of different fields.

IV. AIRCAFT MANEUVERABILITY

Aircraft maneuverability depends heavily on the movement of flaps found at the rear or trailing edge of the wings. The efficiency and reliability of operating these flaps is of critical importance.

"Smart" wings, which incorporate shape memory alloys, are typically like the wing shown in Figure 6; this system is much more compact and efficient, in that the shape memory wires only require an electric current for movement

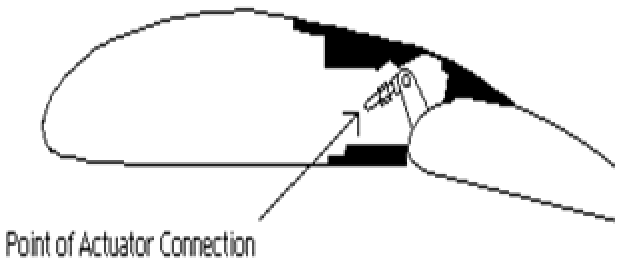

Figure 5: Typical Wing and Flap

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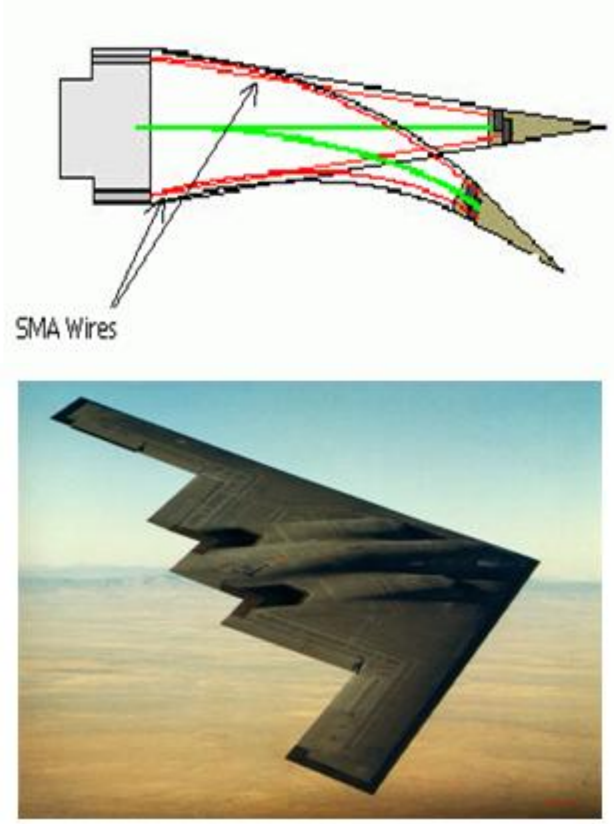
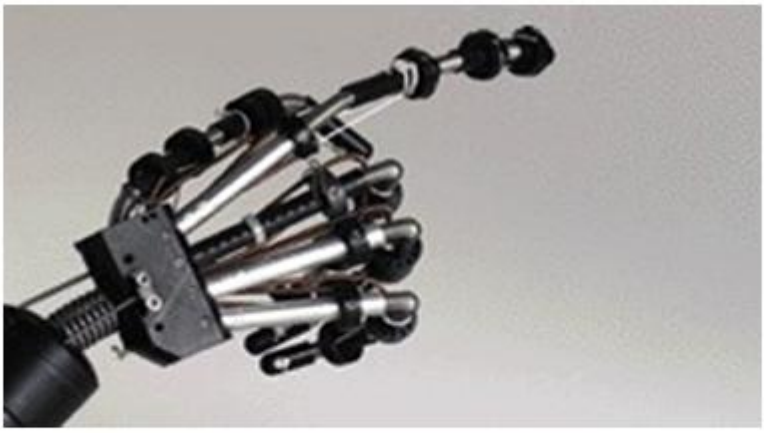


Figure 6: Hinge less shape memory alloy Flap & SMA Based Aircraft Picture

The shape memory wire is 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 the wing must be bent upwards. The shape memory effect is induced in the wires simply by heating them with an electric current, which is easily supplied through electrical wiring, eliminating the need for large hydraulic lines. By removing the hydraulic system, aircraft weight, maintenance costs, and repair time are all reduced.

V. ROBOTIC MUSCLES



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SMA Based Robotic Gripper

There have been many attempts made to re-create human anatomy through mechanical means. The human body however, is so complex that it is very difficult to duplicate even simple functions. Robotics and electronics are making great strides in this field, of particular interest are limbs such hands, arms, and legs.

In order to reproduce human extremities there are a number of aspects that must be considered:

- The gripping force required to manipulate different objects (eggs, pens, tools)
- The motion capabilities of each joint of the hand
- The ability to feel or touch objects (tactile senses)
- The method of controlling movement within the limb
- Emulating real human movement (smoothness, and speed of response).

Creating human motion using SMA wires is a complex task but a simple explanation is detailed here. For example to create a single direction of movement (like the middle knuckle of your fingers) the setup shown in Figure 1 could be used. The bias spring shown in the upper portion of the finger would hold the finger straight, stretching the SMA wire, then the SMA wire on the bottom portion of the finger can be heated which will cause it to shorten bending the joint downwards (as in Figure 7).

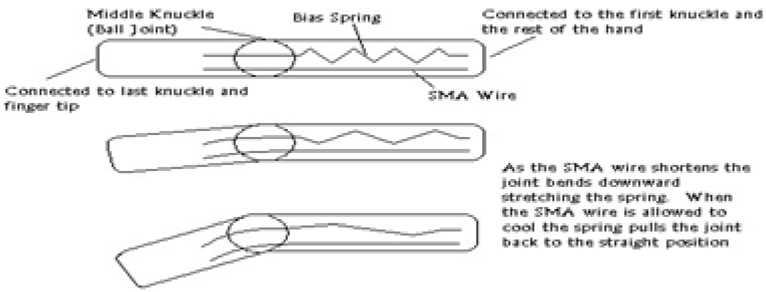

Figure 7

VI. BONE PLATES

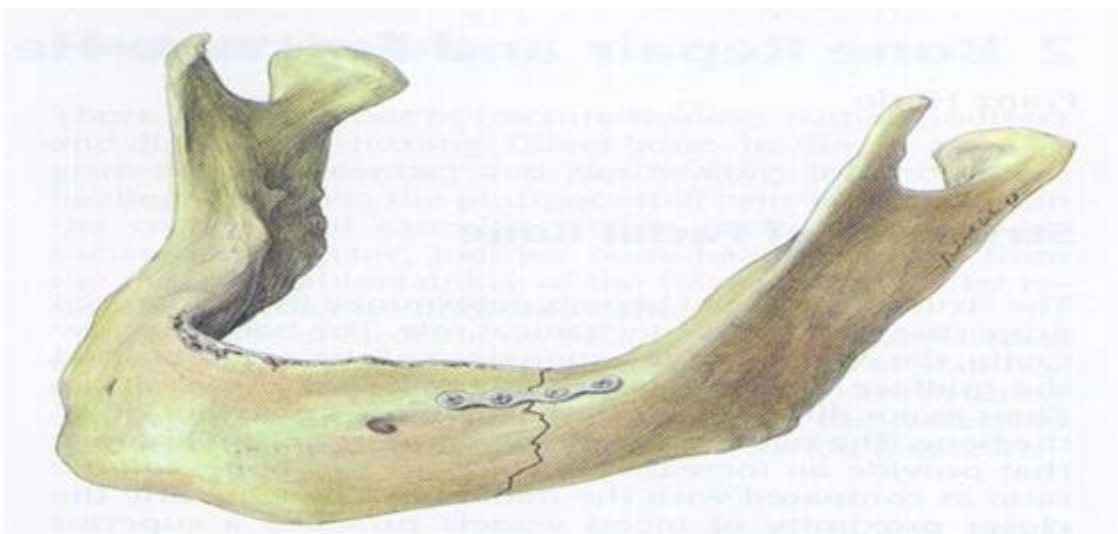

FIG: Conventional bone plate used to repair jaw fracture

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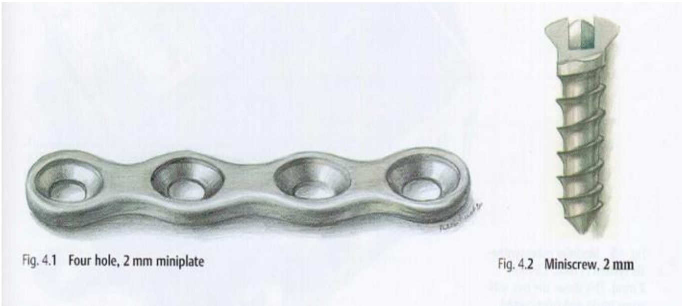
Bone plates are surgical tools, which are used to assist in the healing of broken and fractured bones. The breaks are first set and then held in place using bone plates in situations where casts cannot be applied to the injured area.

Currently osteotemy equipment is made primarily of titanium and stainless steel. The broken bones are first surgically reset into their proper position. Then a plate is screwed onto the broken bones to hold them in place, while the bone heals back together. This method has been proven both successful and useful in treating all manner of breaks; however there are still some drawbacks. After initially placing the plate on the break or fracture the bones are compressed together and held under some slight pressure, which helps to speed up the healing process of the bone. Unfortunately, after only a couple of days the tension provided by the steel plate are lost and the break or fracture is no longer under compression, slowing the healing process.



Typical Osteosynthesis tools

Bone plates can also be fabricated using shape memory alloys, in particular nickel titanium. Using a bone plate made out of NiTi, which has a transformation temperature of around AF much greater than 15 °C surgeons follow the same procedure as is used with conventional bone plates. The NiTi plates are first cooled to well below their transformation temperature, and then they are placed on the set break just like titanium plates. However, when the body heats the plate up to body temperature the NiTi attempts to contract applying sustained pressure on the break or fracture for far longer than stainless steel or titanium. This steady pressure assists the healing process and reduces recovery time.

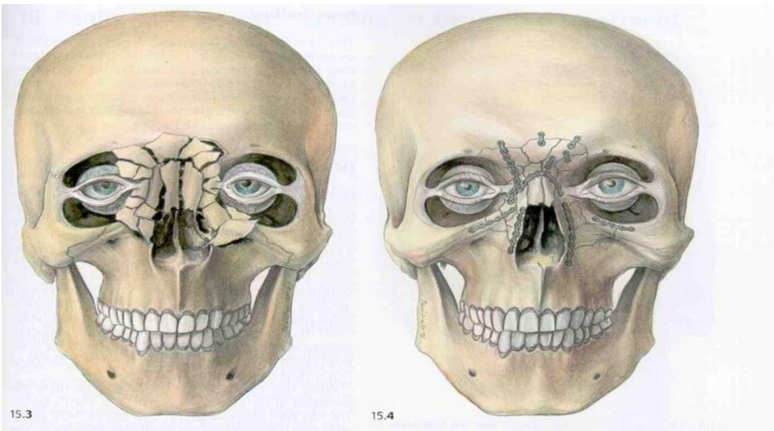


Fig:Example of how even a badly fractured face can be reconstructed using bone plates

VII. ADVANTAGES AND DISADVANTAGES OF SHAPE MEMORY ALLOYS

Some of the main advantages of shape memory alloys include:

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

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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.

VIII. 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. 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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