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Smart Materials: An Overview of Shape Memory Alloys for the analysis of strength & resistance

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Abstract— World is progressing in all spheres of life be it Science, art or Culture or any other field. The field of manufacturing which is highly monolithic & complicated has directed our need towards the materials that have the properties which can be manipulated as per our requirements. Smart materials are one of them. These materials are unique as they have the property of changing shape & size just by adding a bit of heat or are transformed quickly into solid from liquid when they are placed near a magnet. Smart Materials include wide range of materials like magneto-rheostatic materials, shape memory alloys (SMA's), Electro-rheostatic materials, and piezoelectric materials. Shape memory alloys (SMA's) are those metals which generally portray two extremely unique properties first one is pseudo-elasticity (flexibility just like a rubber & under loading), and the other one being shape memory effect (This is the ability to be deformed drastically and then to regain its original shape by heating.).The above explained two properties can be discovered through the phase changes in solid state. The solid state phase change is an arrangement of molecules very closely so that the substance continues to be in solid. These phases which are generated in shape memory alloys are Marten site & Austenite.

This particular paper is an analysis & study of shape memory Alloys & the materials, Alloys which are used in day to day life. Conclusion have been drawn out by taking the help of examples (like manufacturing of aircraft, human bone system & robotics)That other materials & alloys are far more inferior than shape memory alloys in terms of strength , resistance & compatibility with the surrounding environment. Lastly an idea is also generated about the use of SMA's in mechanical coupling in order to make a powerful joint.

Keyword- Smart Materials, Shape Memory Alloys, manufacturing, mechanical coupling, properties

I. INTRODUCTION

Our surrounding is full of magical materials. These materials are required to bring into existence & form as per our need. These magic materials are well elaborated as smart materials & sometimes intelligent too, as they can sense, function, deflect or stimulate a response. Smart Materials have wonderful property of being altered. Materials which are used in day to day life have physical properties that cannot be altered significantly. This could be understood by an example: When oil is heated it becomes a bit thinner, whereas a smart material with variable viscosity may turn to a solid easily from liquid phase. A large range of smart materials already exist in the surrounding and are being researched extensively. Smart Materials are already being incorporated in the products which are used in day to day life. (Tea pots, Vehicles etc). Their use is also being dispersed in wide area

A. What Are Shape Memory Alloys?

Shape memory alloys (SMA's) are those metals which generally portray two extremely unique properties first one is pseudo-elasticity (flexibility just like a rubber & under loading), and the other one being shape memory effect (This is the ability to be deformed drastically and then to regain its original shape by heating.). NiTi (Nickel - Titanium), CuZnAl, and CuAlNi are extensively used shape memory alloys.

B. Working

The above two properties of SMA'S are well explained & Made possible through a solid state phase change i.e. rearrangement of molecules of SMA'S. The solid state phase change is an arrangement of molecules very closely so that the substance continues to be in solid. These phases which are generated in shape memory alloys are Marten site & Austenite.

Marten site is comparatively softer & easily deformed phase of SMA that exists at low 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.

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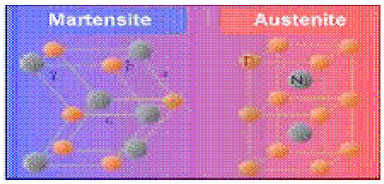

Figure 1. Martensite and austenite phases

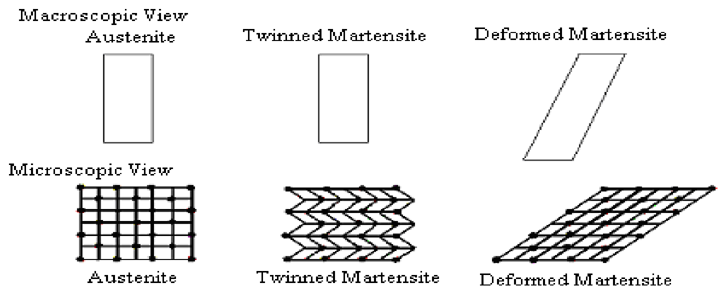

Figure 2: Microscopic and Macroscopic Views of the Two Phases of Shape Memory Alloys

Shape Memory Effect

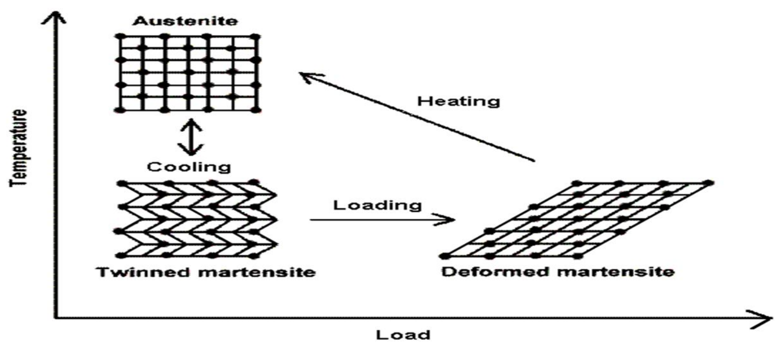

Figure 3: Microscopic Diagram of the Shape Memory Effect

The shape memory effect can be experienced when the temperature of a piece of shape memory alloy is cooled to below the temperature Mf. At this particular stage the alloy is completely composed of Marten site, 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 Martensite 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: teapots, space shuttle & thermostat.

C. Applications

These different & unusual properties mentioned above are being applied & practiced on a wide variety of applications in a large number of different fields.

D. Maneuverability in Aircraft

The maneuverability in aircraft largely depends upon the movement of flaps found at the rear or trailing edge of the wings.

The efficiency and reliability of operating these flaps is of Prime concern & importance. Today almost each and every aircraft in the air operate these flaps using hydraulic system extensively. These hydraulic systems utilize large centralized pumps to maintain pressure, and hydraulic lines to distribute the pressure to the flap actuators. In order to maintain reliability of operation, multiple hydraulic lines must be run to each set of flaps. This complex system of pumps and lines is often relatively difficult and costly to maintain.

Many alternatives to the hydraulic systems are being explored by the aerospace industry. Among the most promising alternatives are piezoelectric fibers, electrostrictive ceramics, and **shape memory alloys**.

"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.

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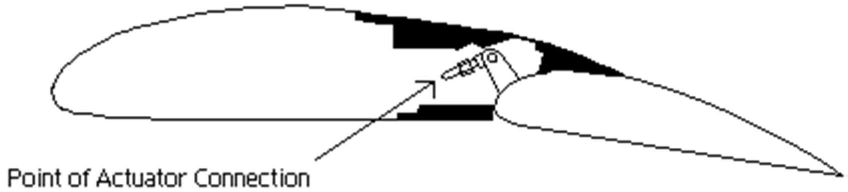

Figure 5: Typical Wing and Flap

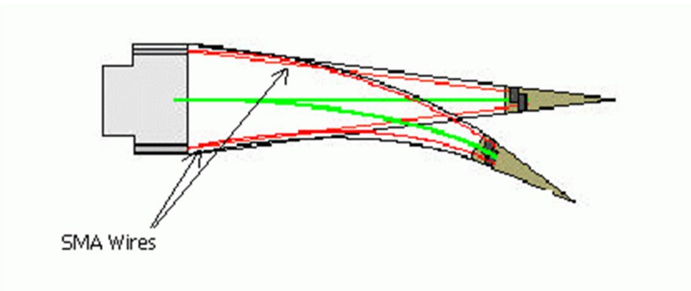

Figure 6: Hinge less shape memory alloy Flap SMA Based Aircraft Picture

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.

E. Robotic Muscles

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:

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

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Many different solutions have been proposed for this problem, some include using "muscles" controlled by air pressure, piezoelectric materials, or shape memory alloys.

Shape memory alloys mimic human muscles and tendons very well. SMA's are strong and compact so that large groups of them can be used for robotic applications, and the motion with which they contract and expand are very smooth creating a life-like movement unavailable in other systems. 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).

The heating takes place by running an electric current through the wire; the timing and magnitude of this current can be controlled through a computer interface used to manipulate the joint.

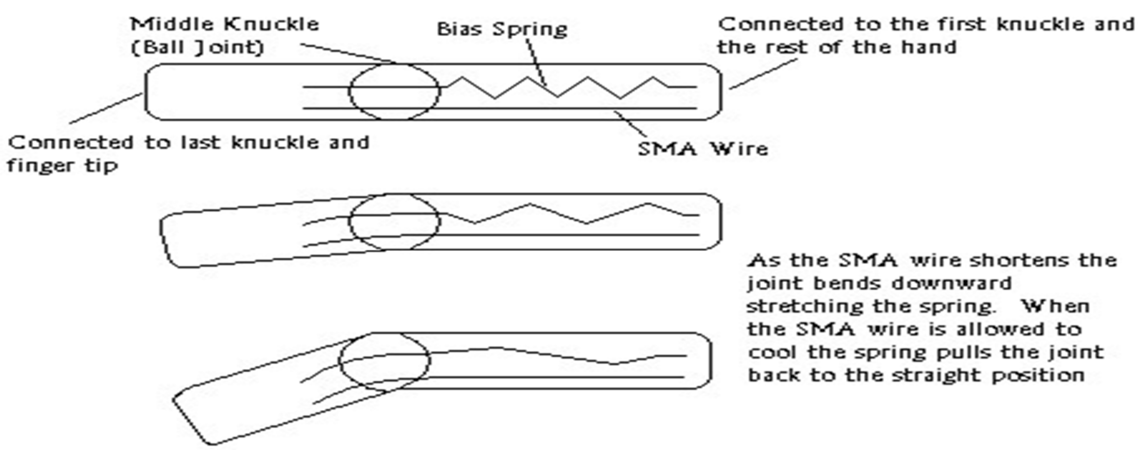
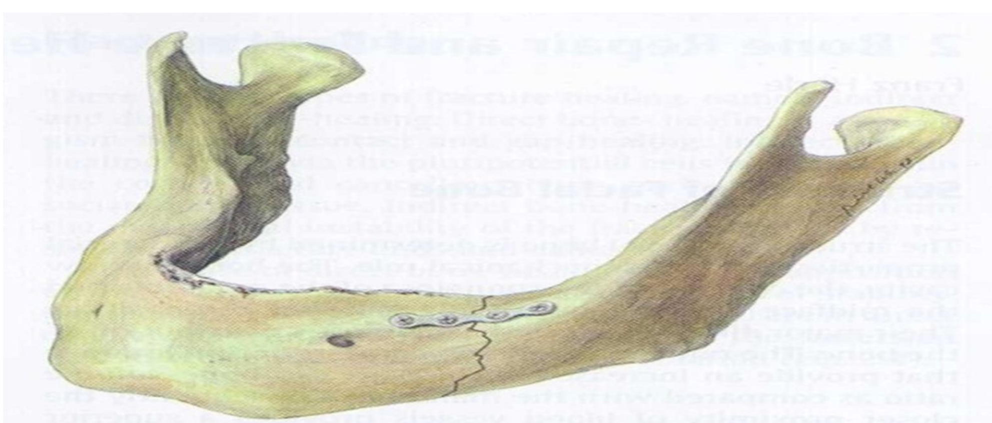


Figure 7

Bone Plates



Conventional bone plate used to repair jaw fracture

Bone plates are surgical tools, which are used to assist in the healing of broken and fractured bones. The breaks are first set and

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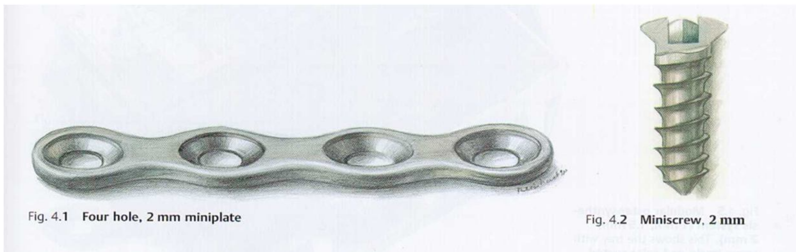
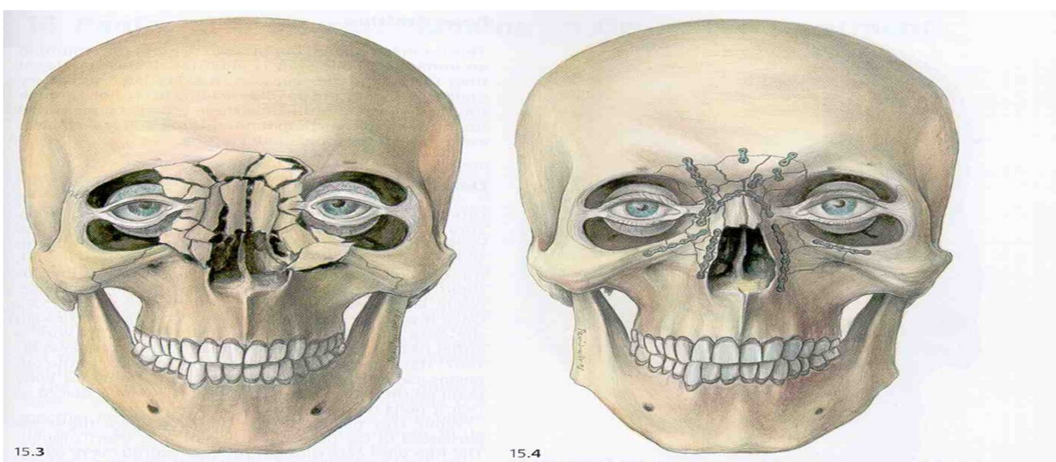
then held in place using bone plates in situations where casts cannot be applied to the injured area. Bone plates are often applied to fractures occurring to facial areas such the nose, jaw or eye sockets. Repairs like this fall into an area of medicine known as Oteosynthesis. Currently osteotemy equipment 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.



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

F. Suggestions

A hydraulic coupling used for power transmission from driver to driven requires a complex and expensive arrangement. This complexity can be eliminated by applying shape memory effect,resulting a strong but removable coupling between the sleeve and metal tube, of the driver and driven shafts respectively. This makes the joint superior to other joining processes by having flexibility to be detached.

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G. Advantages and Disadvantages of Shape Memory Alloys

Some of the main advantages of shape memory alloys include:

1) Biocompatibility.
2) Diverse Fields of Application.
3) Good Mechanical Properties (strong, corrosion resistant).

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.

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. 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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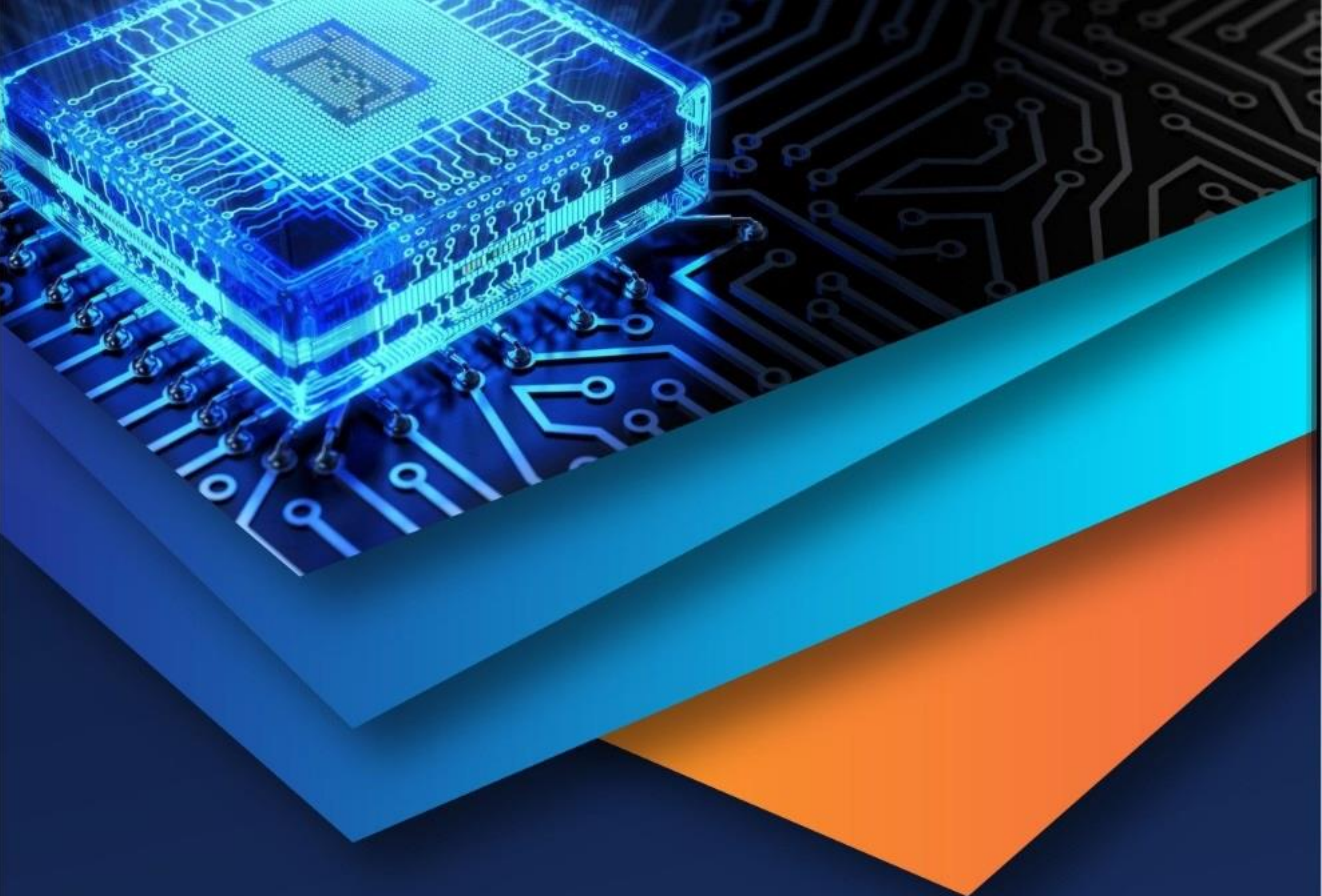

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