MECHANICAL ENGINEERING SCIENCE

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COMPOSITES

- **A composite is a structural material that consists of two or more combined constituents that are combined at a macroscopic level and are not soluble in each other.**

- One constituent is called the **reinforcing phase** and the one in which it is embedded is called the **matrix**. The reinforcing phase material may be in the form of fibers, particles, or flakes. The matrix phase materials are generally continuous.

- Examples of composite systems include concrete reinforced with steel and epoxy reinforced with graphite fibers, etc.

- Some examples of naturally found composites - **wood**, where the lignin matrix is reinforced with cellulose fibers and **bones** in which the bone-salt plates made of calcium and phosphate ions reinforce soft collagen.

The advantages of using composites over metals -

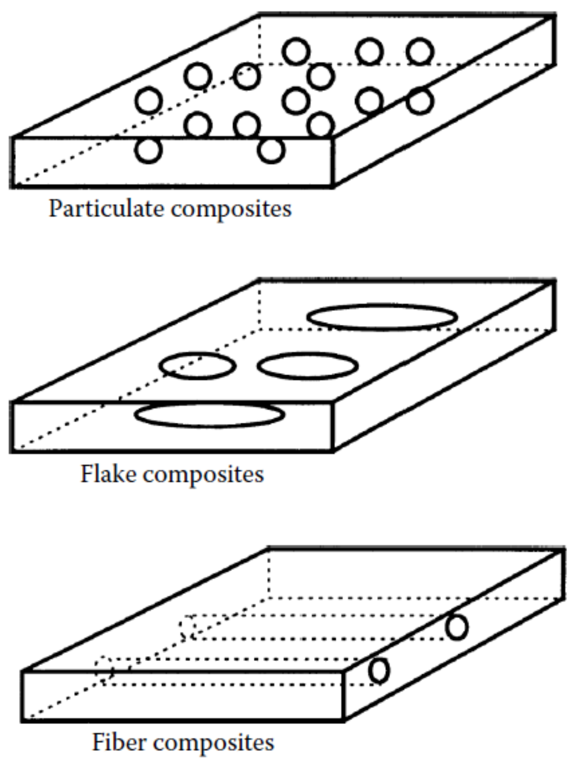
- Monolithic metals and their alloys cannot always meet the demands of today's advanced technologies. Only by combining several materials can one meet the performance requirements.
- For example, trusses and benches used in satellites need to be dimensionally stable in space during temperature changes between –256°F (–160°C) and 200°F (93.3°C). Limitations on coefficient of thermal expansion thus are low and may be of the order of $\pm 1.8\times10^{-7}$ m/m/°C. Monolithic materials cannot meet these requirements; this leaves composites, such as graphite/epoxy, as the only materials to satisfy them.
- In many cases, using composites is more efficient. For example, in the highly competitive airline market, one is continuously looking for ways to lower the overall mass of the aircraft without decreasing the stiffness and strength of its components. This is possible by replacing conventional metal alloys with composite materials.
- Even if the composite material costs may be higher, the reduction in the number of parts in an assembly and the savings in fuel costs make them more profitable. Reducing one lbm (0.453 kg) of mass in a commercial aircraft can save up to 360 gal (1360 l) of fuel per year; fuel expenses are 25% of the total operating costs of a commercial airline.

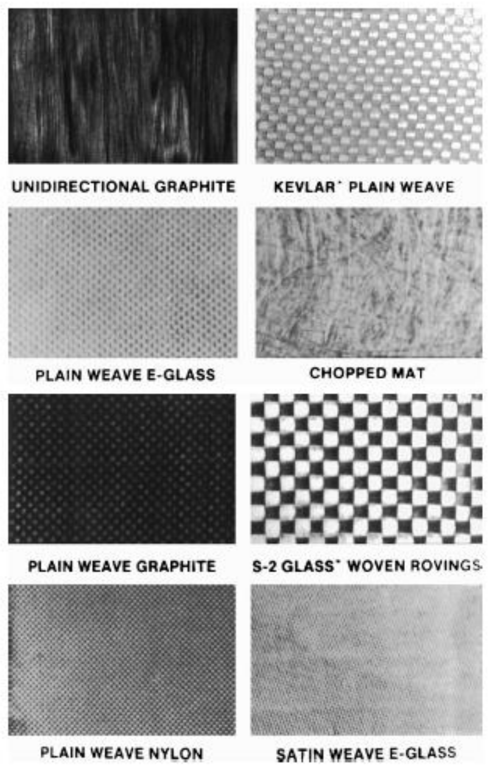
Composites offer several other advantages over conventional materials. These may include

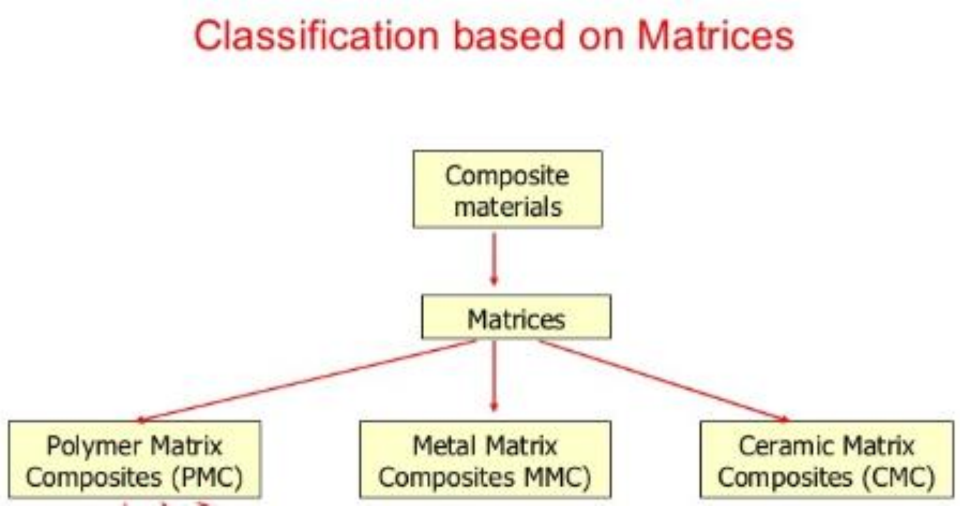
improved strength,
improved stiffness,
improved fatigue and impact resistance,
improved thermal conductivity,
improved corrosion resistance etc.

Classification of composites

➢ Composites are classified by the geometry of the reinforcement — **particulate, flake, and fibers** — or by the type of matrix — **polymer, metal, ceramic, and carbon**.







Particulate composites - aluminum particles in rubber; silicon carbide particles in aluminum; and gravel, sand, and cement to make concrete

Fiber reinforced composites - Fibers are generally anisotropic and examples include carbon and aramids. Examples of matrices are resins such as epoxy, metals such as aluminum, and ceramics such as calcium–alumino silicate.

Polymer matrix composites – It consists of a polymer (e.g., epoxy, polyester, urethane) reinforced by thin diameter fibers (e.g., graphite, aramids, boron).

For example, graphite/ epoxy composites are approximately five times stronger than steel on a weight for weight basis.

Metal matrix composites - Examples of matrices in such composites include aluminum, magnesium, and titanium. Typical fibers include carbon and silicon carbide.

Ceramic matrix composites - Ceramic matrix composites (CMCs) have a ceramic matrix such as alumina calcium alumino silicate reinforced by fibers such as carbon or silicon carbide.

Fiber Reinforced Composites (FRCs)

- **FRCs are** dvanced materials made by embedding strong, stiff **fibers** into a **matrix material** (usually a polymer, metal, or ceramic) to produce a composite with superior mechanical properties.
- These composites are widely used in aerospace, automotive, construction, and sports industries due to their high strength-to-weight ratio and customizable properties.

Components of FRCs

i. Fibers (Reinforcement Phase)

Provide strength and stiffness.

Common fiber types:

Glass fibers – Economical, good strength
Carbon fibers – High stiffness and strength, lightweight
Aramid fibers (e.g., Kevlar) – Tough and impact-resistant
Natural fibers – Sustainable options like flax, hemp

ii. Matrix (Binding Phase)

Holds fibers in place, transfers loads, and protects them.

Common matrix materials:

Polymers (thermosets like epoxy, or thermoplastics)
Metals (in metal matrix composites)
Ceramics (in ceramic matrix composites)

Types of FRCs

1.Glass Fiber Reinforced Composites (GFRC)
1. Common in construction and automotive parts
2. Affordable and corrosion-resistant

2.Carbon Fiber Reinforced Composites (CFRC)
1. High-performance materials for aerospace and sports
2. Strong, stiff, and lightweight

3.Aramid Fiber Reinforced Composites
1. Excellent toughness and impact resistance
2. Used in body armor, helmets, and aerospace

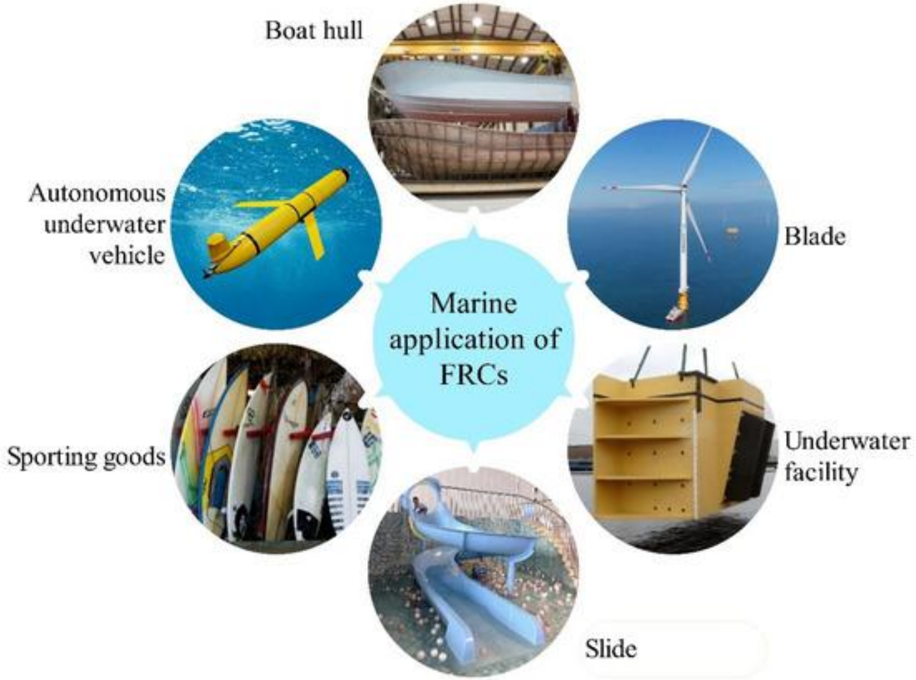
4.Natural Fiber Composites
1. Eco-friendly and renewable
2. Used in automotive interiors and packaging

Applications of FRCs

•**Aerospace** – Aircraft structures, interior panels
•**Automotive** – Body panels, frames, interior parts
•**Construction** – Reinforced concrete, panels, bridges
•**Marine** – Boat hulls, masts
•**Sports Equipment** – Tennis rackets, bicycles, helmets
•**Medical** – Prosthetics, dental materials

Key Properties of FRCs

•High strength-to-weight ratio
•Excellent fatigue and corrosion resistance
•Customizable stiffness and orientation
•Dimensional stability
•Low thermal expansion (especially with carbon fibers)



Source: Journal of Composites Science

Metal Matrix Composites (MMCs)

- **MMCs)** are advanced materials composed of a **metal or alloy matrix** (the base material) reinforced with **ceramic particles, fibers, or whiskers** to improve specific properties.
- They combine the toughness and ductility of metals with the strength, stiffness, and wear resistance of ceramics.

Components of MMCs

Matrix (Metal)

Common metals: **Aluminum, Magnesium, Titanium, Copper, Nickel**

Provides toughness, ductility, and thermal/electrical conductivity

Reinforcement (Non-metallic)

Forms: **Particles, fibers, whiskers**

Materials: **Silicon carbide (SiC), alumina (Al_2O_3), carbon fibers, boron fibers**

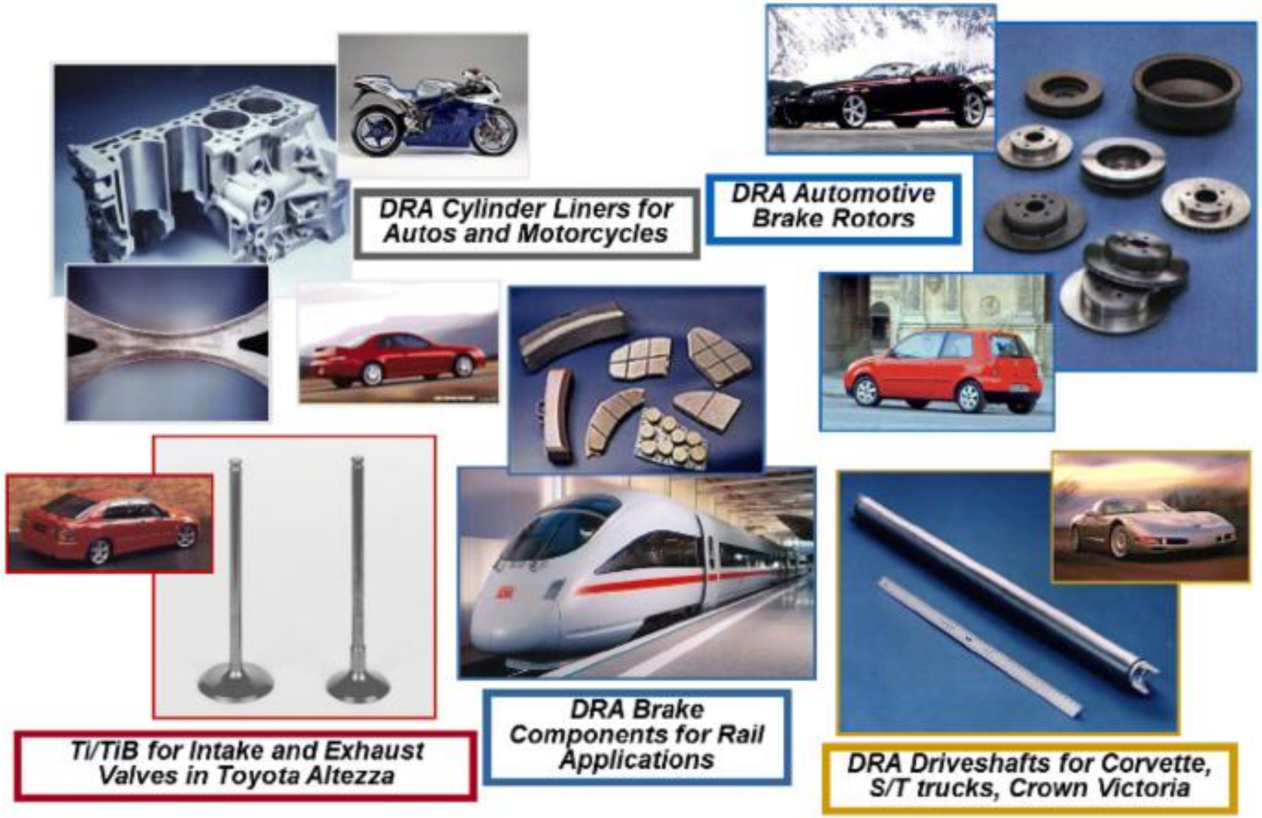
Adds strength, stiffness, wear and thermal resistance

Properties of MMCs

- High strength-to-weight ratio
- Improved wear and creep resistance
- Good thermal conductivity
- Better dimensional stability at high temperatures
- Tailorable properties depending on reinforcement type and volume

Applications of MMCs

- **Aerospace** – Structural components, engine parts
- **Automotive** – Brake rotors, driveshafts, pistons
- **Electronics** – Heat sinks, circuit substrates
- **Defense** – Armor materials, missile components
- **Sports Equipment** – Bicycle frames, golf clubs



Source: International Journal of Metalcasting

Applications –

Aircraft - Use of composites is limited to secondary structures such as rudders and elevators made of graphite/epoxy for the Boeing 767 and landing gear doors made of Kevlar–graphite/epoxy. Composites are also used in panels and floorings of airplanes.

Sporting goods - Graphite/epoxy is replacing metals in golf club shafts mainly to decrease the weight and use the saved weight in the head. Tennis and racquetball rackets with graphite/epoxy frames are now commonplace.

Medical devices - Applications here include the use of glass–Kevlar/epoxy lightweight face masks for epileptic patients. Artificial portable lungs are made of graphite–glass/epoxy so that a patient can be mobile.

Automobile - The fiberglass body of the Corvette comes to mind when considering automotive applications of composites. In addition, the Corvette has glass/epoxy composite leaf springs with a fatigue life of more than five times that of steel.

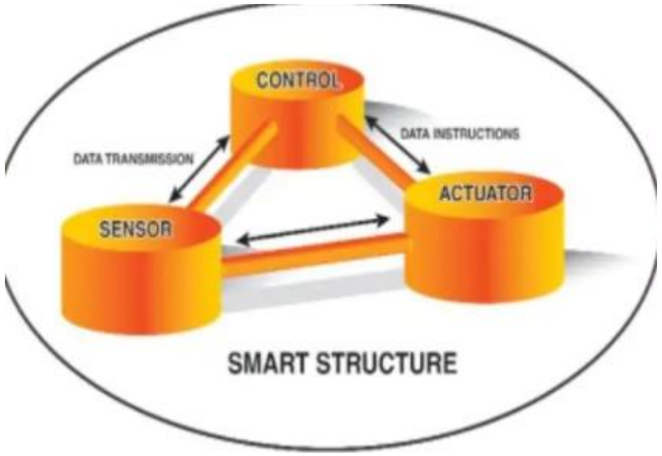
SMART MATERIALS

- Smart materials are materials that have to respond to stimuli and environmental changes and to activate their functions according to these changes.

- The stimuli like temperature, pressure, electric flow, magnetic flow, light, mechanical etc. can originate internally or externally.

- A smart system/ structure involves actuators and sensors, one or microprocessors that analyse the responses from the sensors and use integrated control theory to command the actuators to apply localised action to alter system response.

- Key elements of smart system/structure-
  Sensor
  Actuator
  Control System
  Power and Signal Conditioning Electronics
  Computer



Types of SMART MATERIALS

- Piezoelectric Materials
- Shape Memory Alloys
- Rheological Fluids
- Electrostrictive Materials
- Magnetostrictive Materials
- Thermoresponsive Materials
- Electrochromic Materials etc.

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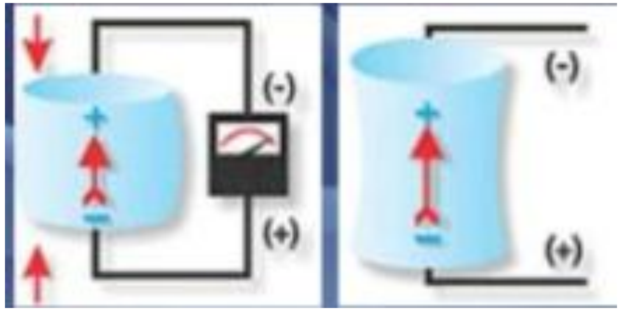
PIEZOELECTRIC MATERIALS

- Piezoelectricity is a phenomenon that occurs in certain class of anisotropic crystals subjected to change in mechanical deformation.



- By applying mechanical deformations to these crystals, electric dipoles are generated and potential difference develops that is contingent upon the changing deformations – **Direct effect**

- By applying potential difference across the crystal, mechanical deformations are also generated – **converse effect**.

- Commercially available industrial piezoelectric materials are piezoceramics such as **Lead Zirconate Titanate (PZT)** ad piezopolymers such as **polyvinylidene fluoride**

- Applications – Voltage and power sources, sensors, actuators, piezoelectric motors, active vibration control, surgery etc.

SHAPE MEMORY ALLOYS

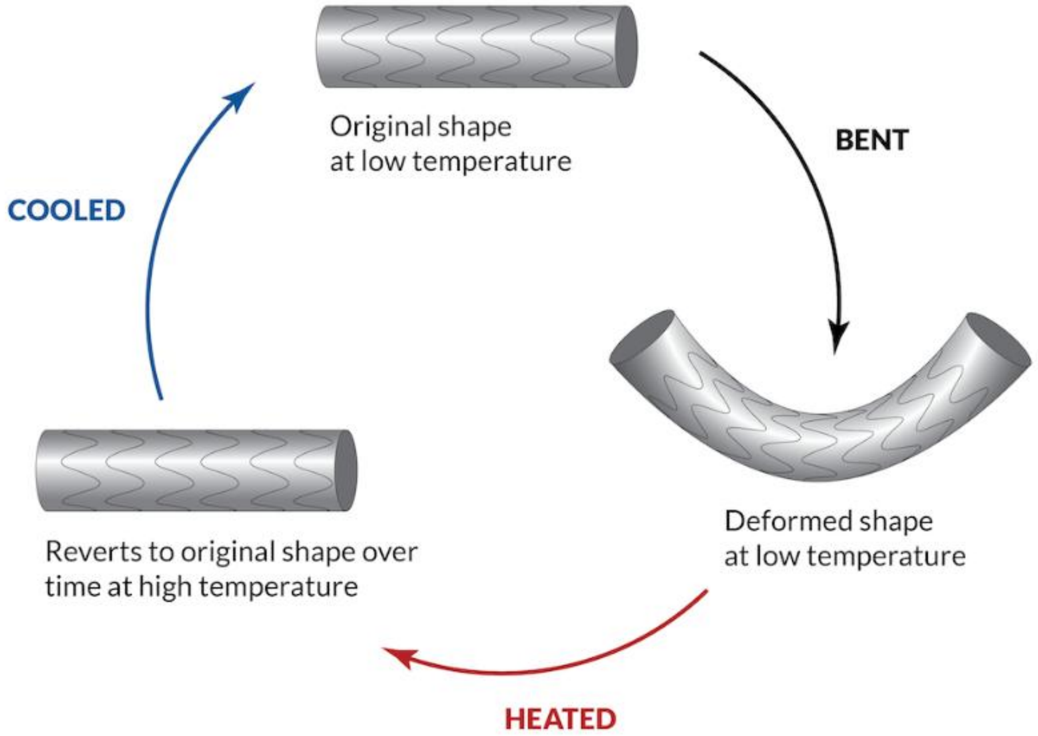
- A shape memory alloy is a material that undergoes a phase transformation when it experiences a mechanical stress or temperature change. When the conditions return to normal, the SMA “remembers” its original shape and reverts to it.

- The recovery of strains imparted to the material at a lower temperature, as a result of heating, is called the **Shape Memory Effect (SME).**

Shape Memory Effect

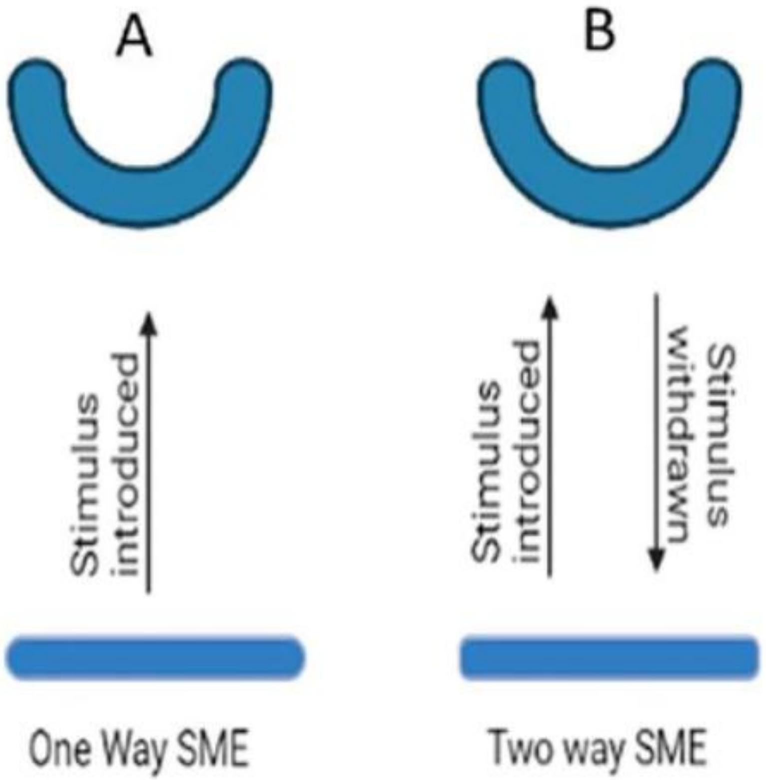
One way Shape Memory Effect | **Two way Shape Memory Effect**

SHAPE MEMORY ALLOYS



- Shape Memory Effect
  - One way Shape Memory Effect
  - Two way Shape Memory Effect

SHAPE MEMORY ALLOYS

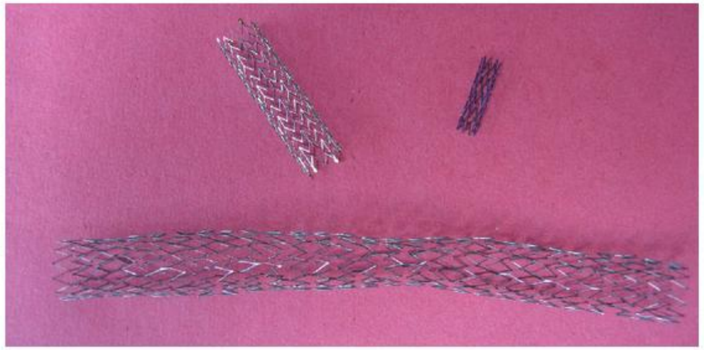


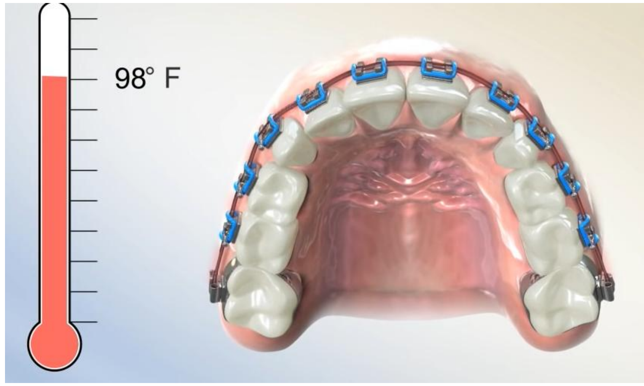
- A material which exhibits shape memory effect only upon heating is known as one-way shape memory.
- The material "remembers" its original (high-temperature) shape.
- When deformed at a low temperature, it returns to that original shape upon heating above a certain temperature (called the transformation or Austenite finish temperature).
- It only recovers shape when heated. On cooling, it stays in the deformed shape.
- A material which shows a shape memory effect during both heating and cooling is called two-way shape memory.
- The material "remembers" two shapes: one at a low temperature (Martensite phase) and one at a high temperature (Austenite phase).
- It automatically changes shape on heating and cooling without needing external force.
- Shape changes both on heating and cooling — no manual deformation needed every cycle.

SHAPE MEMORY ALLOYS

Materials exhibiting shape memory effect –
NiTiNOL (**Ni**ckel **Ti**tanium alloy developed at the **N**aval **O**rdinance **L**ab)
Cu-Al-Ni, Cu-Zn-Al, Au-Cd, Mn-Cu and Ni-Mn-Ga

Applications –
Medical field – braces, stents etc.
Actuation systems – Aerospace (Actuation systems in jet engines, variable geometry chevron)
Automotive (Chevrolette Corvett SMA actuator)





RHEOLOGICAL FLUIDS

- A special class of fluids exists that change their rheological properties on the application of an electric or a magnetic field.

- These controllable fluids can in general be grouped under one of two categories: **electrorheological (ER) fluids and magnetorheological (MR) fluids.**

- An electric field causes a change in the viscosity of ER fluids, and a magnetic field causes a similar change in MR fluids. The change in viscosity can be used in a variety of applications.
- **Composition** - Both ER and MR fluids consist of a colloidal suspension of particles in a carrier fluid.
- In the case of ER fluids, the particles are micron-sized dielectric particles, and could be corn starch or some alumino-silicate compound. The carrier fluid is electrically non-conducting, and could be mineral oil, silicone oil or paraffin oil.
- In the case of MR fluids, the properties of the carrier fluid are similar to those of ER fluids. However, the particles must be some ferromagnetic material.

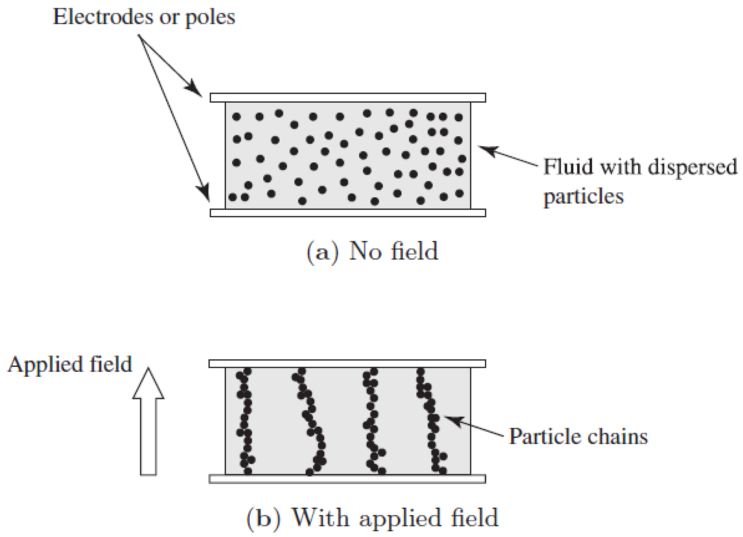
RHEOLOGICAL FLUIDS

- In the case of an ER/MR fluid, when an electric/magnetic field is applied, the particles become polarized and attract each other. As a result, chains of particles form in the fluid between the electrodes.

- In the absence of a field, the fluid can freely flow across the electrodes in response to an applied pressure gradient, or can be sheared by a relative motion of the electrodes.

- On the application of the field, the fluid flow across the electrodes is impeded by the particle chains. A larger pressure gradient is required to break the chains and maintain the flow of the fluid. As a result, a larger force is required on the electrodes to produce a relative motion between them.

- The forming and breaking of the chains results in a significant change in the viscosity of the fluid.



RHEOLOGICAL FLUIDS

Applications –
controllable dampers,
clutches,
suspension shock absorbers,
valves,
brakes,
prosthetic devices,
traversing mechanisms,
torque transfer devices,
engine mounts and robotic arms.

THANK YOU

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