Composite Materials: Analysis and Design

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Chapter 1:

Introduction to Composite Materials

Chapter 1: Introduction

❑ Outline

- ✓ Definition of Composite Materials
- ✓ FRP Composite Constituent Materials
  - Fibers
  - Matrices
- ✓ Characteristics of FRP Materials
- ✓ Application of FRP Composites
- ✓ Type of Composites

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❑ Definition of Composite Materials?

1 Materials created by

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❑ Definition of composite materials?

2 In the case of advanced composite materials

- **Reinforcing phase:**
- **Matrix phase:**

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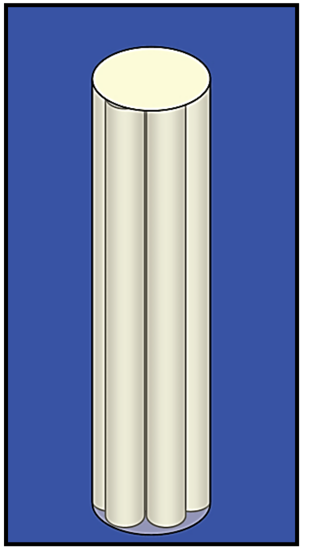
❑ Composite Materials:

Fibers

Improved properties over parent constituent materials are the most desirable characteristic of composites:

- **C**
- **G**
- **A**



Composite

Matrix

Serves to bind the reinforcement together, transfers loads to the reinforcement,

- **P**
  - **thermosets**
  - **thermoplastics**
- **M**
- **C**

❑ Description of Constituent Materials

Composite Constituent	Description
Reinforcement	This is the discontinuous phase, which is strong and/or stiff and typically lightweight
Matrix	This is the continuous phase that transfers the load among reinforcement, provides protection to reinforcement, and is typically lightweight
Interface	This provides bond between reinforcement and matrix and can be strong or weak, depending on application

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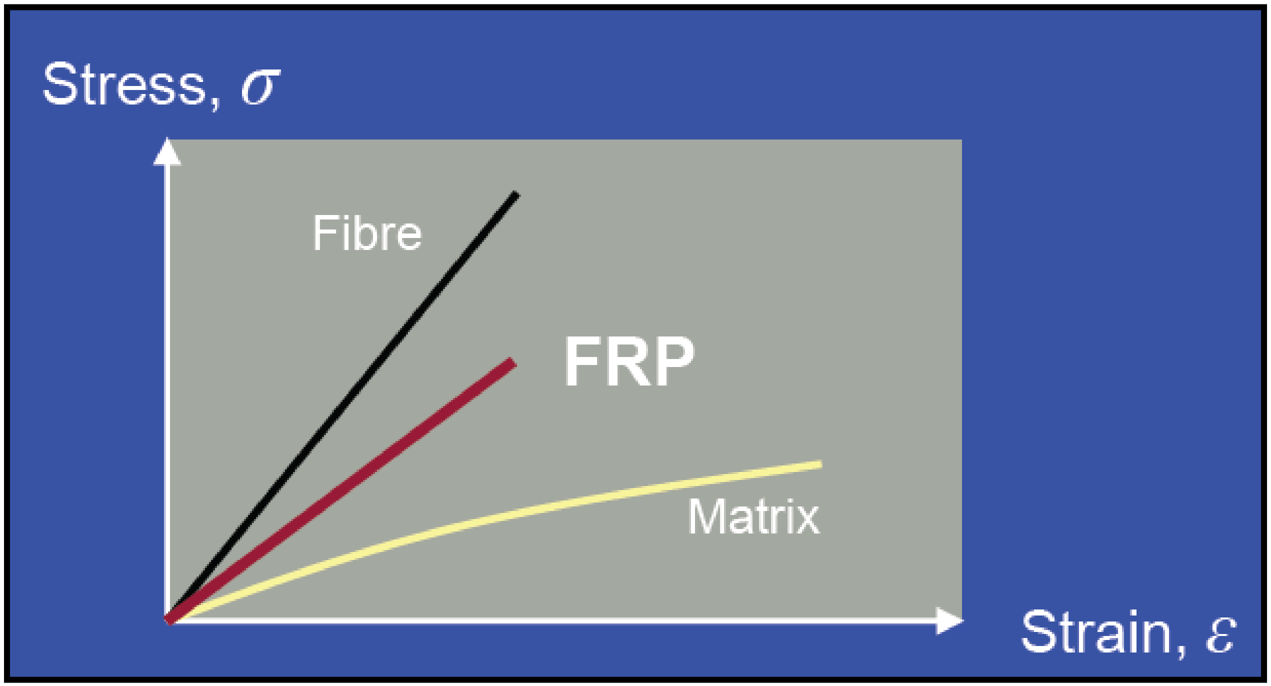
- FRP Materials: Matrix + Fiber= FRP



✓ **Combing fibers and matrix gives a composite material with superior properties**

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- Fiber Choice for Different Matrix Materials

Matrix	Fiber Choice
Polymer	Glass, carbon, aramid (Kevlar, etc.)
Metal	Silicon carbide, boron, alumina (large diameter)
Ceramic	Silicon carbide, alumina, and sapphire

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❑ Fiber Components:

3 fibers commonly used in infrastructure applications

❑ Factors influencing fiber suitability:

- S
- C
- En
- S
- A

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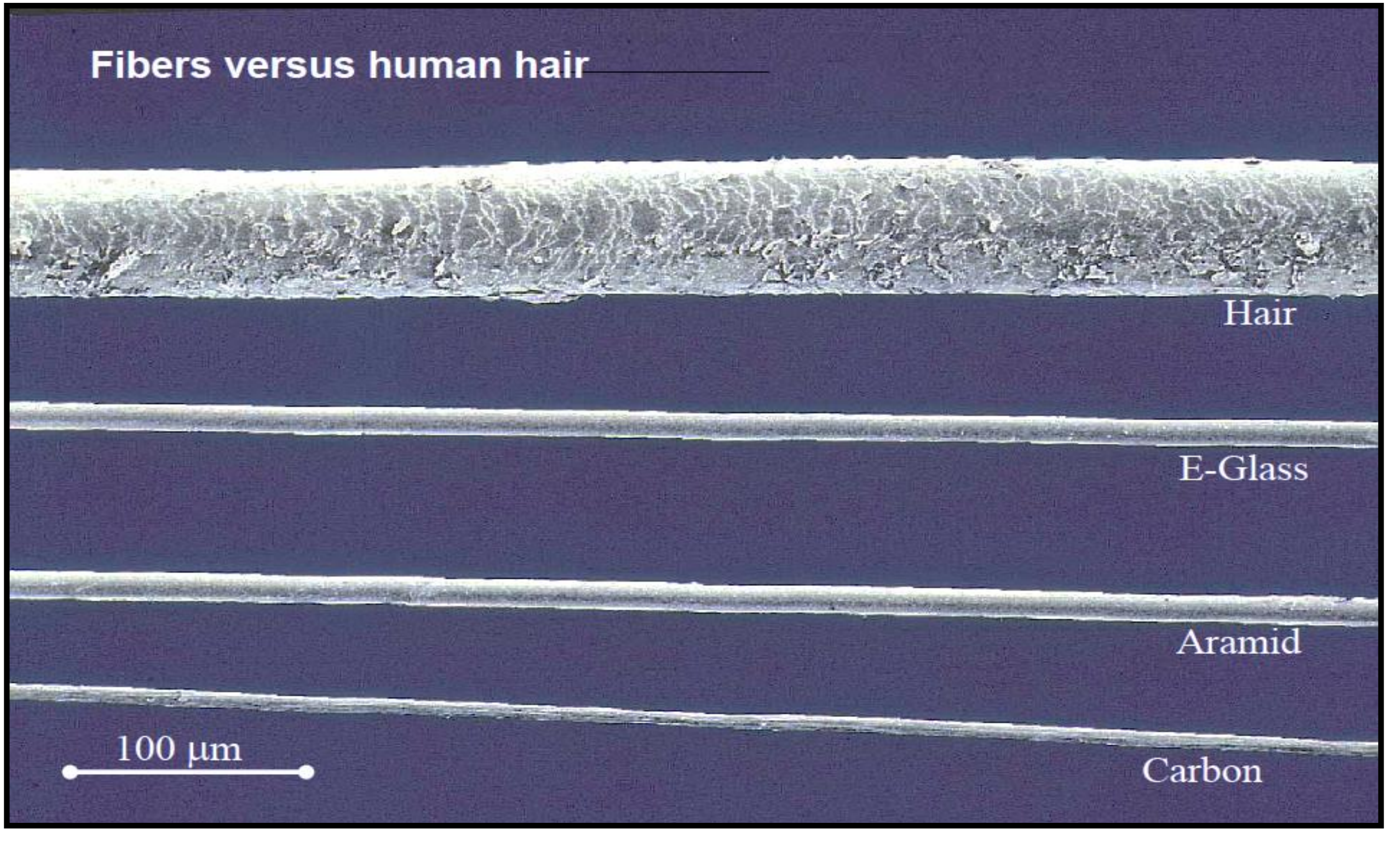
- Fibers VS. Human Hair:



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❑ Glass Fibers :

- Inexpensive
- Most commonly used
- Several grades available:

- High strength, moderate modulus, medium density
- Used in non weight/modulus critical applications.

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- **Typical Composition of Different Types of Glass Fibers:**

	% Weight			
Material	**A-Glass**	**C-Glass**	**E-Glass**	**S-Glass**
Silicon oxide (SiO_2)	64	65	54	64
Aluminum oxide (Al_2O_3)	1	4	15	25
Zirconium oxide (ZrO_2)	13	—	—	—
Calcium oxide (CaO)	5	14	17	—
Magnesium oxide (MgO)	—	3	5	10
Sodium oxide (Na_2O)	14	8	0.6	0.3
Boron oxide (B_2O_3)	—	5	8	—
Titanium oxide (TiO_2)	3	—	—	0.2

❑ Typical Properties of Glass Fibers :

Properties	E-Glass	A-Glass	S-Glass	C-Glass	R-Glass	D-Glass	High Modulus
Density, ρ (g/cm^3)	2.54	2.45	2.49	2.45	2.58	2.14	2.89
Tensile strength, σ_{ult} (GPa)[a]	3.45	3.30	4.58	3.31	4.40	2.50	3.40
Elastic modulus, E (GPa)	72.4	69.0	85.5	69.0	84.8	55.0	110.4
Diameter, d (μm)	3–20	—	8–13	—	—	—	—
Thermal expansion, α (10^{-6}/°C)	5.0	—	2.9	6.3	—	3.1	—
Max operation temp. (°C)	550	—	650	600	—	477	—

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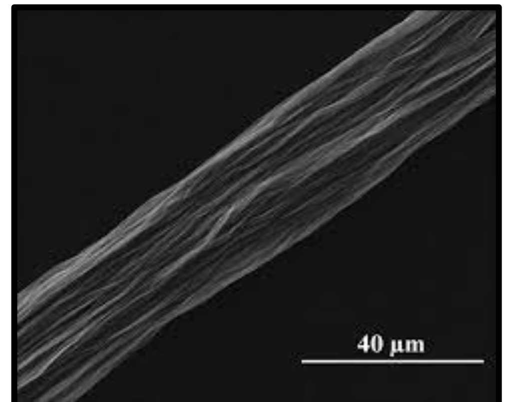
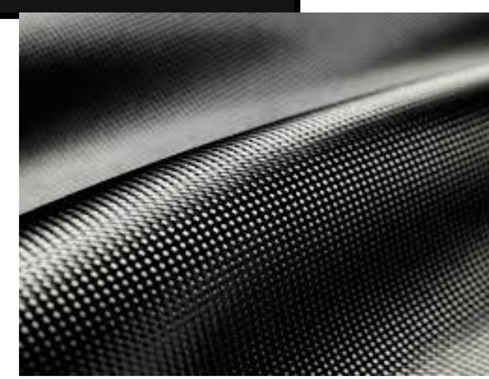
❑ Carbon Fibers :



- Significantly higher cost than glass
- Several grades available:
  - •Standard modulus → GPa
  - •Intermediate → GPa
  - •High → GPa
  - •Ultra-high → GPa



- High strength, high modulus, low density
- Superior durability and fatigue characteristics
- Used in weight/modulus critical applications.

Typical Properties of Carbon Fibers:

	PAN			
Properties	Type I	Type II	Pitch	Rayon
Density, ρ (g/cm^3)	1.95	1.75	2.0	1.7
Tensile strength, σ_{ult} (GPa)[a]	2.4–2.7	3.4–4.5	1.55	2.50
Long. elastic modulus, E_L (GPa)	380	230	380	500
Trans. elastic modulus, E_T (GPa)	12	20	—	—
Diameter, d (μm)	7–10	8–9	10–11	6.5
Long. thermal expansion, α_L (10^{-6}/°C)	–0.5	–0.5	–1.0	–0.9
Trans. thermal expansion, α_T (10^{-6}/°C)	7–12	7–12	8	7.8

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❑ Aramid (Organic) Fibers

Kevlar is the most commercially recognized brand:

- Moderate to high cost
- Verity grades available:
  K29, K49, K149
- High
- Low
- Some durability concerns:
  - •Potential
  - •Potential

❑ Typical Properties of Aramid Fibers :

Properties	K29	K49	K68	K119	K129	K149
Density, ρ (g/cm^3)	1.44	1.44	1.44	1.44	1.45	1.47
Tensile strength, σ_{ult} (GPa)	2.9	3.0	2.8	3.0	3.4	2.4
Long. elastic modulus, E_L (GPa)	70.5	112.4	101	55	100	147
Diameter, d (μm)	12	12	12	12	12	12
Long. thermal expansion, α_L (10^{-6}/°C)	–4.0	–4.9	—	—	—	—

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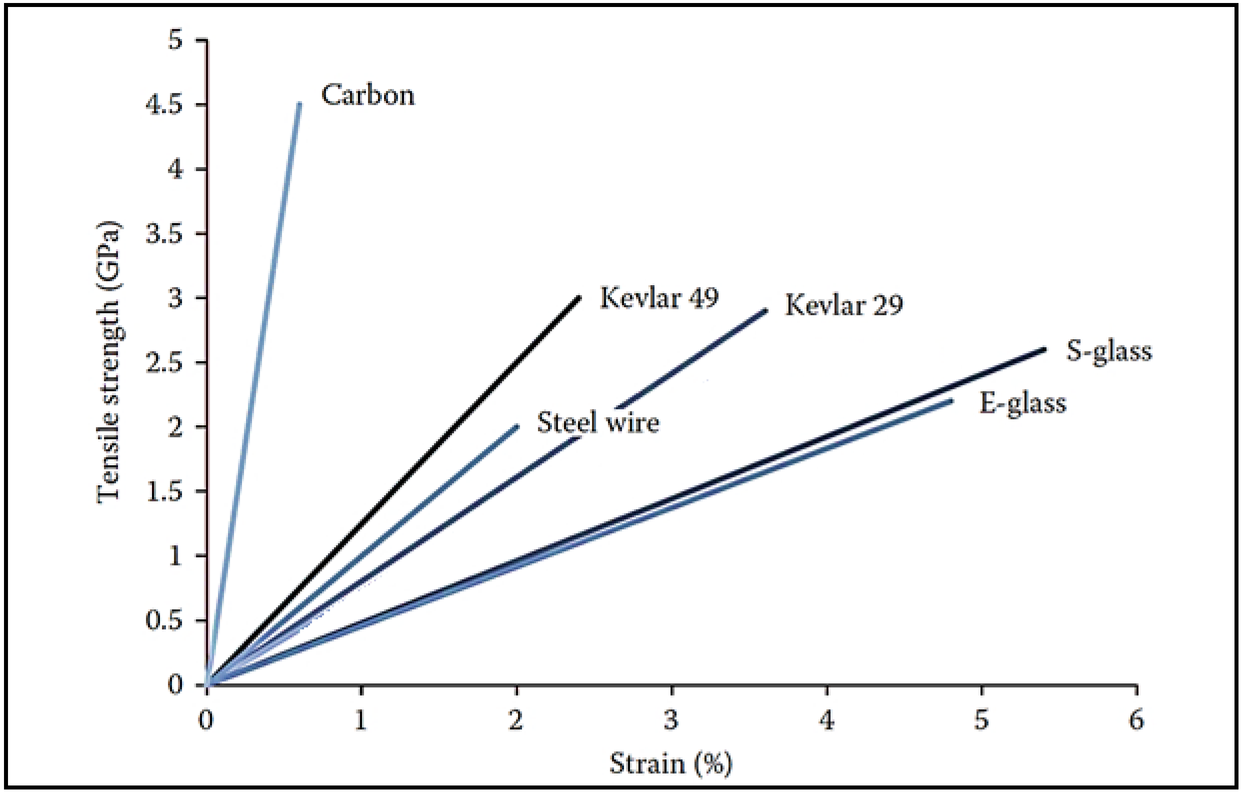
❑ Thermal Stability of Fibers:

Fiber	Kevlar	E-Glass	C-Glass	S-Glass	Carbon
T_{max} (°C)	250	500	600	650	2000

Steel melting point $\approx$ 1000 °C

❑ Stress–strain behavior of various fibers:



❑ Fibrous Reinforcement:

- The theoretical longitudinal strength of a fiber is approximately:
- The typical measured strength of a fiber is approximately:

where *E* is a fiber’s longitudinal modulus of elasticity.

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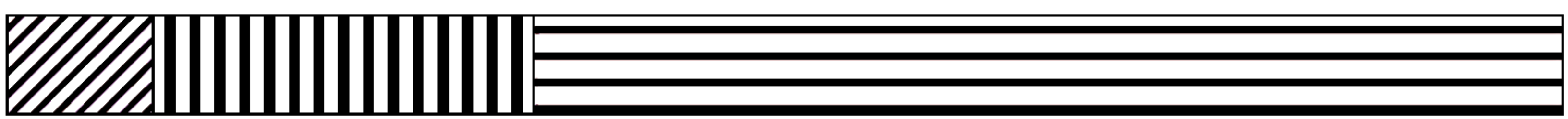
❑ Matrix Constituents:

The selection of matrix material is often influenced by the required **temperature** performance of the composite.

- Polymers ➡
- Metals ➡
- Ceramics ➡



Temperature range for different matrix materials.

Matrix Constituents:

Metal and **ceramic** matrices have not been used in civil infrastructure applications because of cost. **Polymers** are the most commonly used form of matrix in civil infrastructure applications.

- **Advantages of polymer matrices :**

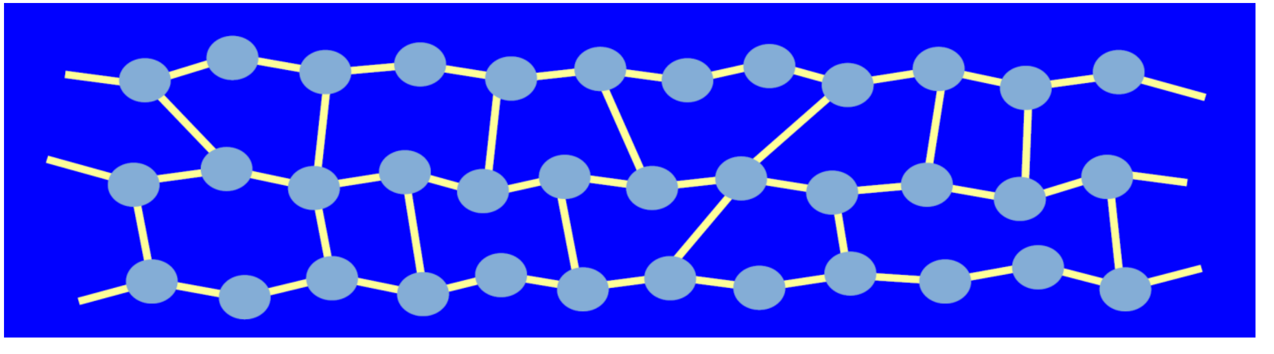
❑ Polymers:

Polymer matrices are classified into **thermosets** and **thermoplastics**:

- **Thermosets**

➢ Thermosets are

➢ Typical



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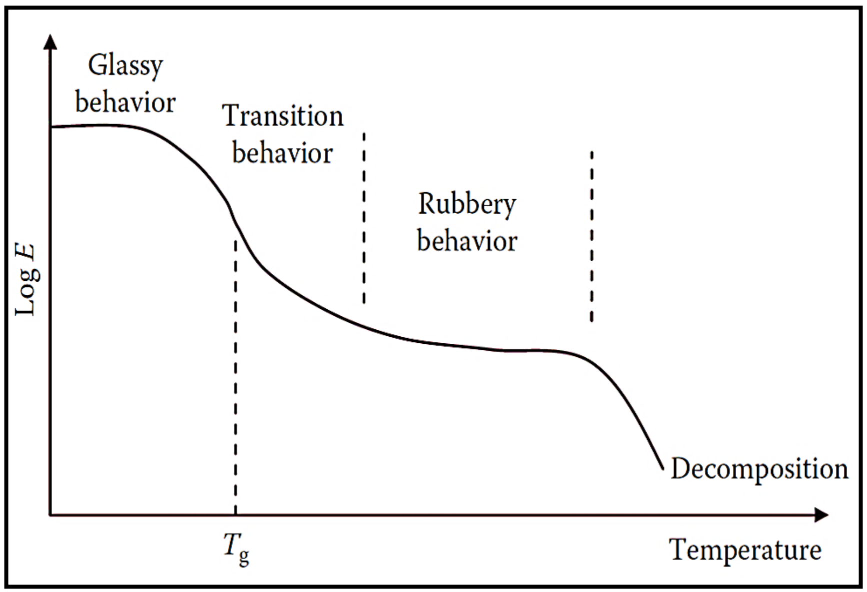
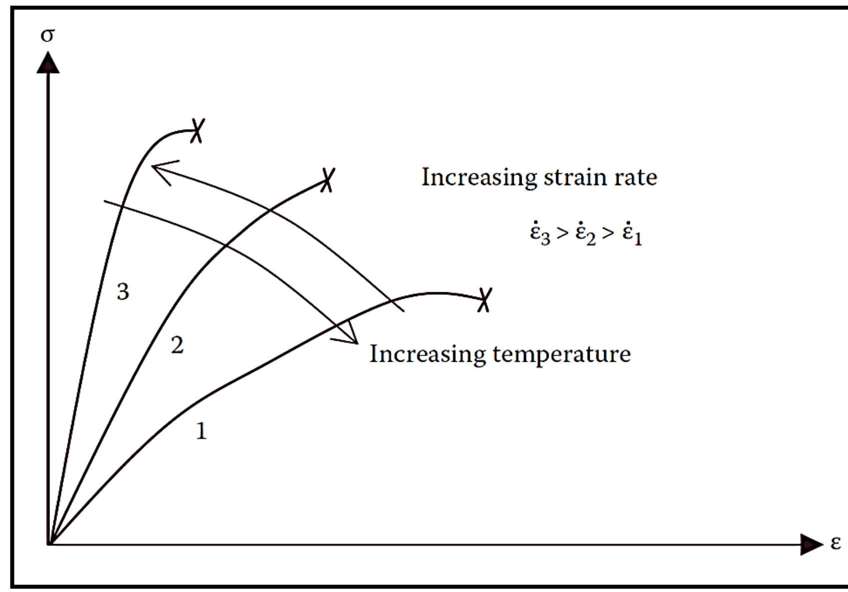
- **Thermosets:**

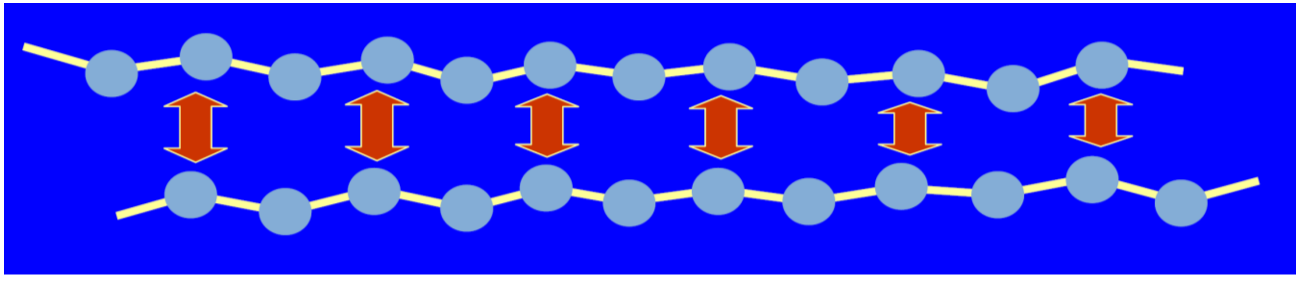




❑ Thermoplastics:

Thermoplastics are

✓ Typical thermoplastics include



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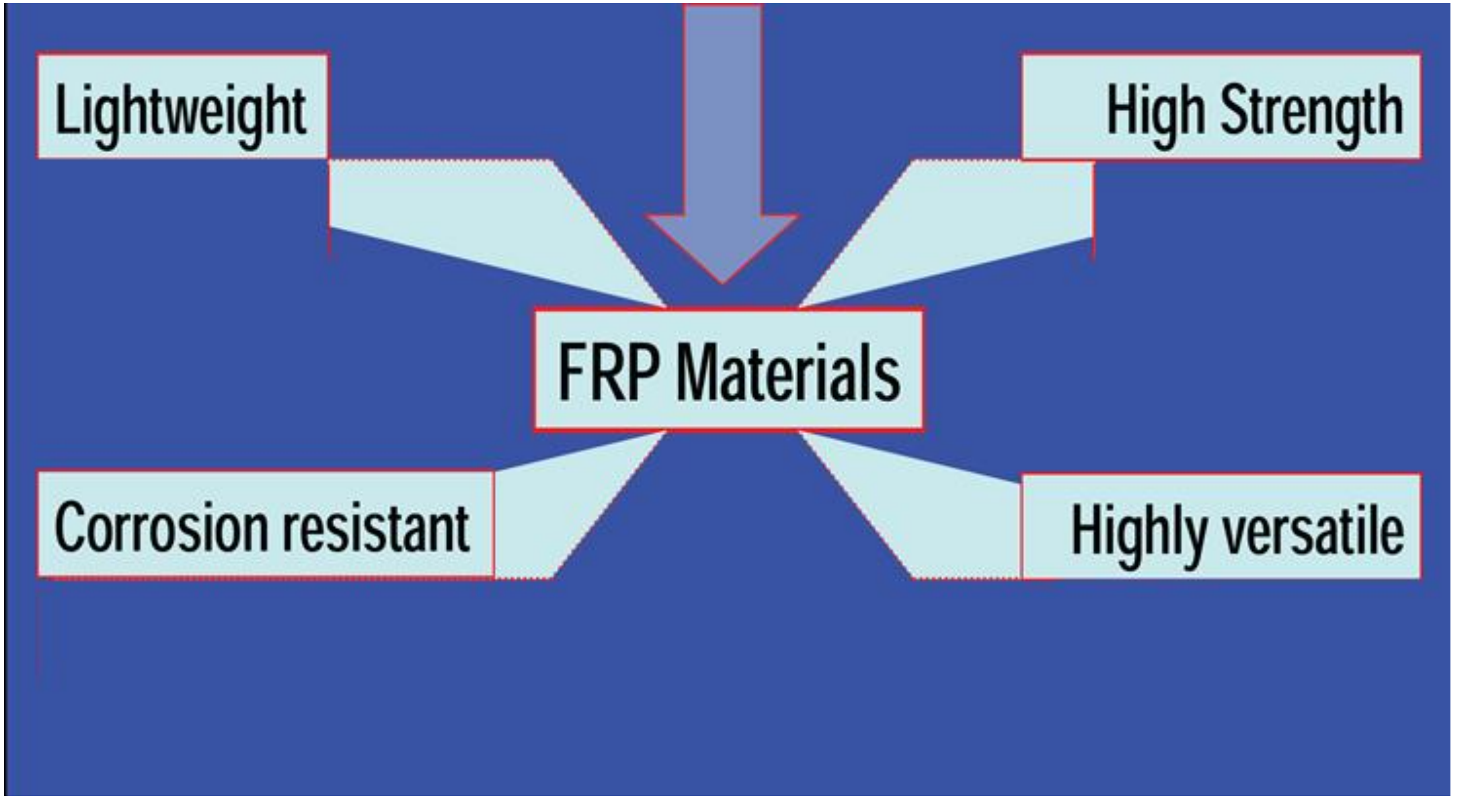
- Characteristics of FRP Materials?



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❑ Fatigue

- Fatigue:
- Carbon FRPs:
- Glass FRPs:
- Aramid FRPs:

❑ Creep and Creep-Rupture

- Creep:
- Fibers:
- Matrix:
- For Unidirectional FRPs

  Creep not a

  Glass

  Aramid

  Carbon

Temperature

- **Other temperature effects:**

Temperature = Creep

Temperature = Moisture or chemical ingress

Potential for development of thermal stresses due to differential thermal expansion

Potential for damage due to thermal cycling

❑ Fire

- All polymers soften at elevated temperatures
- Potential concerns during fire:
- Research is ongoing in this area...