Materials Technology

Composite

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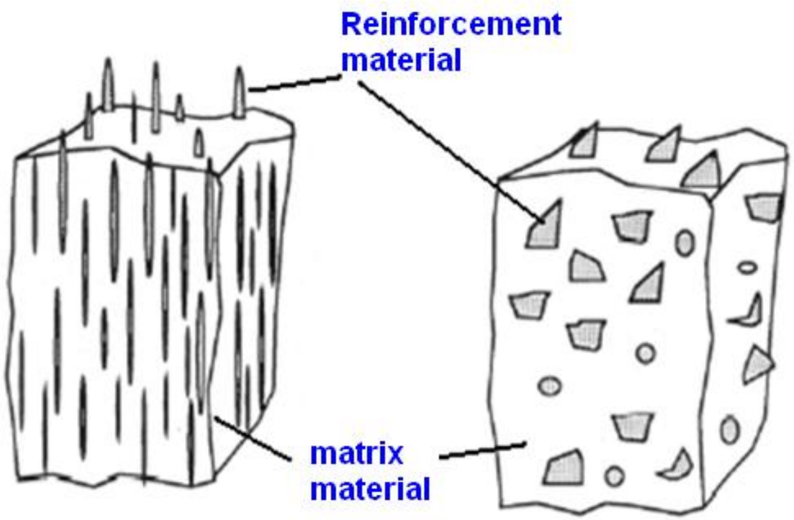
INTRODUCTION

Composite is a mixture or combination of at least two materials that differ in form, composition, properties (physical and Mechanical) and do not form a solution.

Multiphase material that is artificially made.

Consist of matrix (continuous phase) and reinforcement (discontinuous phase) and surrounded by matrix



Matrix material:

- Can be a metallic, polymeric, or ceramic
- Protects the fibers from mechanical damage
- Transfer stress to dispersed phase

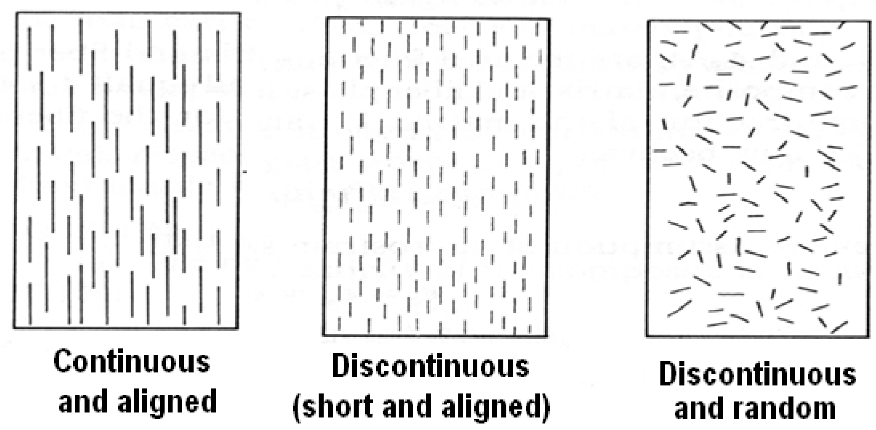
Reinforcement material (RM):

- Hard and brittle ; SiC, Al_2O_3, glass, graphite, B.
- In the form of Fibre, short fiber or particle
- Min. 5 vol. %

COMPOSITE CLASSIFICATION

-- Types: MMC, CMC, PMC

metal ceramic polymer



- Dispersed RM phase:

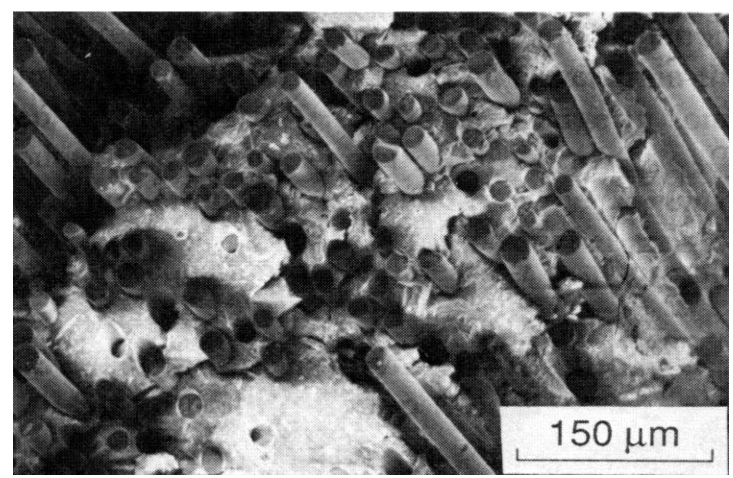
  -- Purpose:

  MMC: increase σ_y, *TS*, creep resist.

  CMC: increase K_{Ic}

  PMC: increase *E*, σ_y, *TS*, creep resist.

Final Mechanical Properties will depend on the type and volume fraction of RM



Fracture surface of glass- SiC composite

Reinforcement Phase

Whiskers - thin single crystals - large length to diameter ratios

- **high crystal perfection – extremely strong, strongest known**
- **very expensive and difficult to disperse**

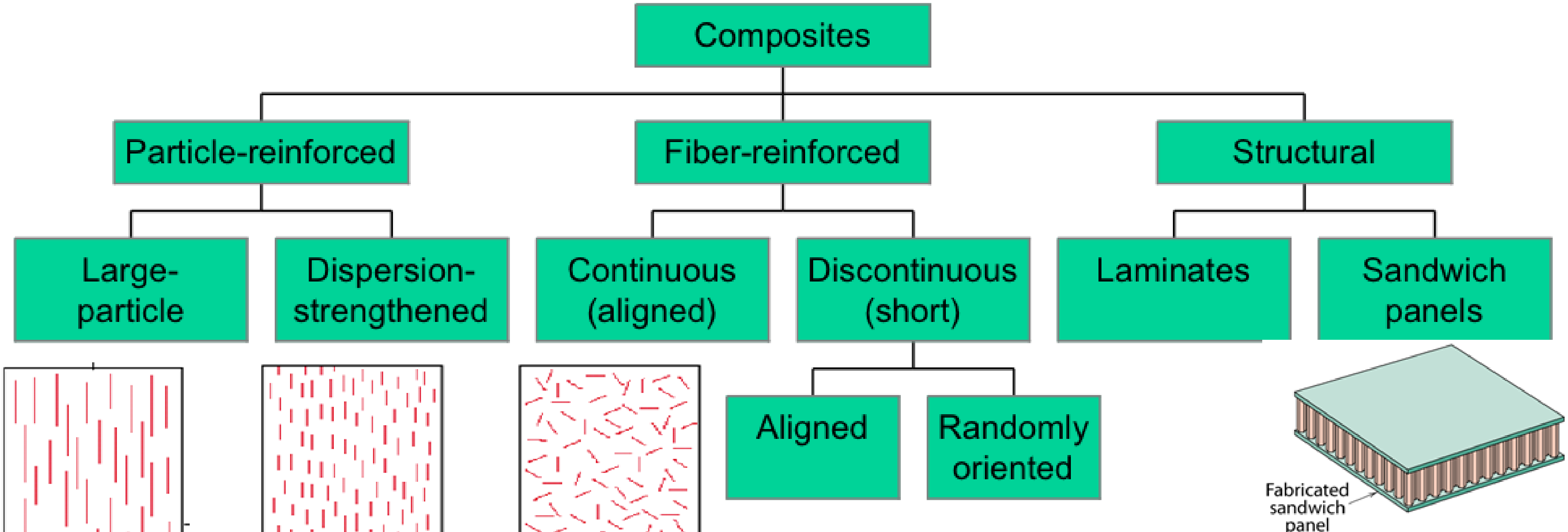
Fibers

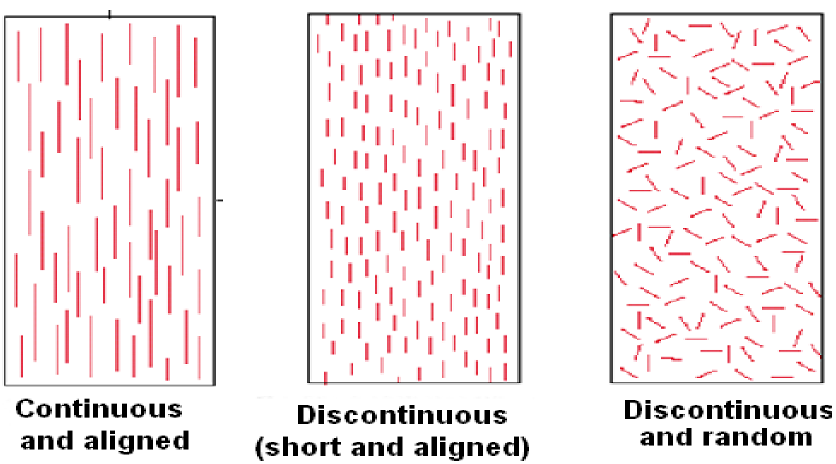
- **polycrystalline or amorphous**
- **generally polymers or ceramics**
- **Ex: alumina, aramid, E-glass, boron, UHMWPE**

Wires

- **metals – steel, molybdenum, tungsten**

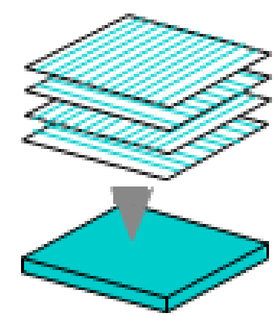
- **The ability to strengthen a composite using a fiber reinforcement depends on :**
  - **Fiber Properties**
  - **Fiber Geometry**
  - **Interfacial bonding with matrix**





Sandwich panels

Honeycomb core between two facing sheets



Laminates -

Stacked and bonded fiber- reinforced sheets

Stacking sequence: e.g., 0º/90º

Continuous fibers - Estimate fiber-reinforced composite modulus of elasticity for continuous fibers

- Longitudinal deformation

$$\sigma_c = \sigma_m V_m + \sigma_f V_f \quad \text{and} \quad \varepsilon_c = \varepsilon_m = \varepsilon_f$$

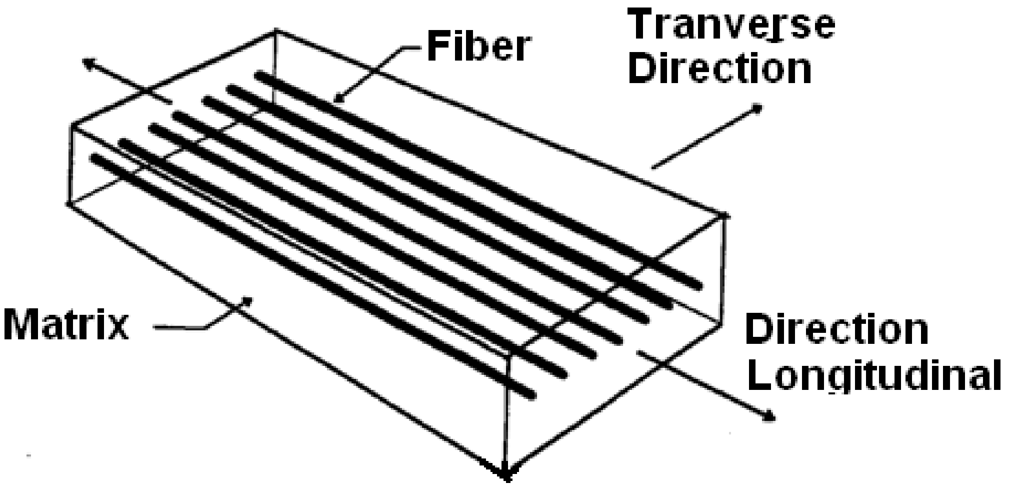
volume fraction

isostrain

$$\therefore \quad E_{cl} = E_m V_m + E_f V_f$$

E_{cl} = longitudinal modulus

c = *composite*
f = fiber
m = matrix



- In **transverse loading** the fibers carry less of the load

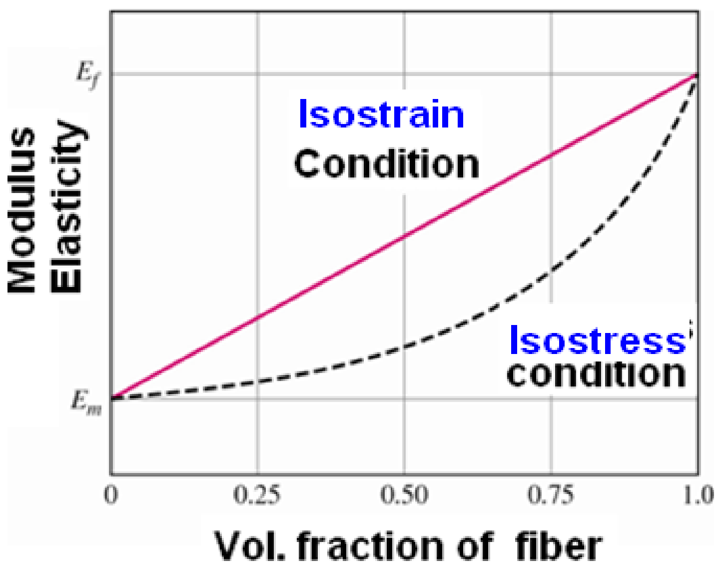
$\varepsilon_c = \varepsilon_m V_m + \varepsilon_f V_f$ and $\sigma_c = \sigma_m = \sigma_f = \sigma$

isostress

$$\therefore \boxed{\frac{1}{E_{ct}} = \frac{V_m}{E_m} + \frac{V_f}{E_f}} \qquad E_{ct} = \frac{E_m E_f}{V_m E_f + V_f E_m}$$

E_{ct} = transverse modulus

c = *composite*
f = fiber
m = matrix



Higher modulus values are obtained with isostrain loading for equal volume of fibers

$\rho_c = \rho_f V_f + \rho_m V_m$
$\sigma_c = \sigma_f V_f + \sigma_m V_m$ (σ = TS)

- Since σ = Eε and $\varepsilon_f = \varepsilon_m$

$$\frac{P_f}{P_m} = \frac{\sigma_f A_f}{\sigma_m A_m} = \frac{E_f \varepsilon_f A_f}{E_m \varepsilon_m A_m} = \frac{E_f A_f}{E_m A_m} = \frac{E_f V_f}{E_m V_m}$$

$P_c = P_f + P_m$

- From above two equations, load on each of fiber and matrix regions can be determined if values of E_f, E_m, V_f, V_m and P_c are known.

The volume fraction of fibers (V_f) in a composite is defined as:

$$V_f = \frac{v_f}{v_c} = \frac{\text{Fiber Volume}}{\text{Composite Volume}}$$

The weight fraction of fibers (W_f) in a composite is defined as:

$$W_f = \frac{w_f}{w_c} = \frac{\rho_f v_f}{\rho_c v_c} = \frac{\rho_f}{\rho_c} V_f$$

Example:

A continuous reinforced composite is to be produced with 60 vol % of fiber by using the following materials :

	Density (lb/in^3)	TS (Psi)	Elastic Modulus (Psi)
Epoxy	0.043	8400	550 000
Carbon	0.065	305 000	58 000 000

Calculate :

i. Density of the composite ($0.0562\ lb/in^3$)

ii. Weight percentage of fiber (0.694)

iii. Tensile strength of the composite (186,360 Psi)

iv. Elastic modulus of the composite (35 020 000 Psi)

POLYMER MATRIX COMPOSITE

The easiest composites to form given the low temperatures needed to process the matrix

Glass and Carbon polymer reinforced composites

*** Glass reinforced polymer composites are more common in marine, automobiles and other industrial applications**

*** Raw materials, cheap, relatively easy to make**

Polyester and epoxy resins are the two important matrix materials.

Polyester resins: Cheaper

*** Applications: Boat hulls, auto and aircraft applications.**

Epoxy resins: Good strength, low shrinkage.

*** Commonly used matrix materials for carbon and aramid-fiber composite.**

Example of PMC

Fiberglass-reinforced polyester resins:
* Higher the wt% of glass, stronger the reinforced plastic is.

Carbon fiber reinforced epoxy resins:
* Carbon fiber contributes to rigidity and strength while epoxy matrix contributes to impact strength..

Glass fiber reinforced plastic composite materials have high strength-weight ratio, good dimensional stability, good temperature and corrosion resistance and low cost.

Boron fiber reinforced plastic
golf-club shaft, tennis racket, fishing rods, sailboards

S-glass fiber-epoxy resin : Helicopter blade

Glass- epoxy : composite Ladders (do not conduct electticity) (Al)

UHMWPE fiber in TS matrix : Military helmet –. (Mg-steel)

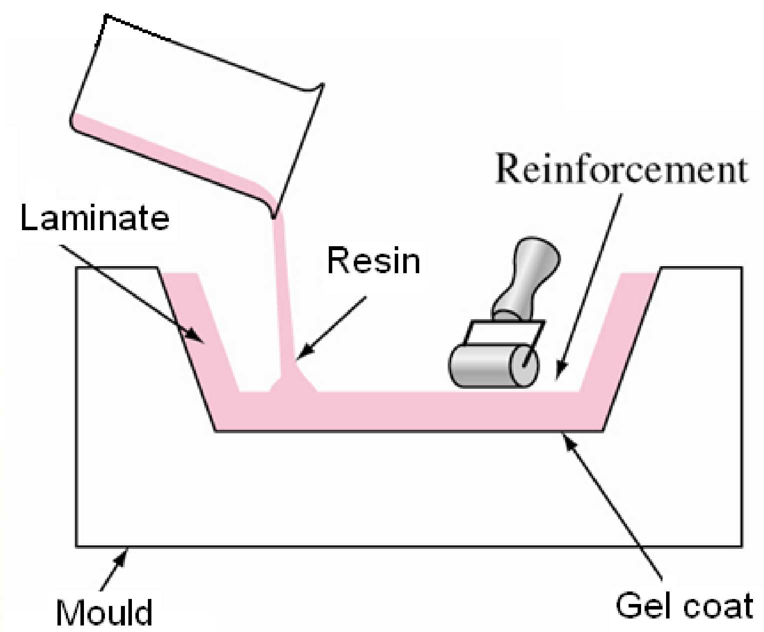
Example of PMC fabrication metdhods

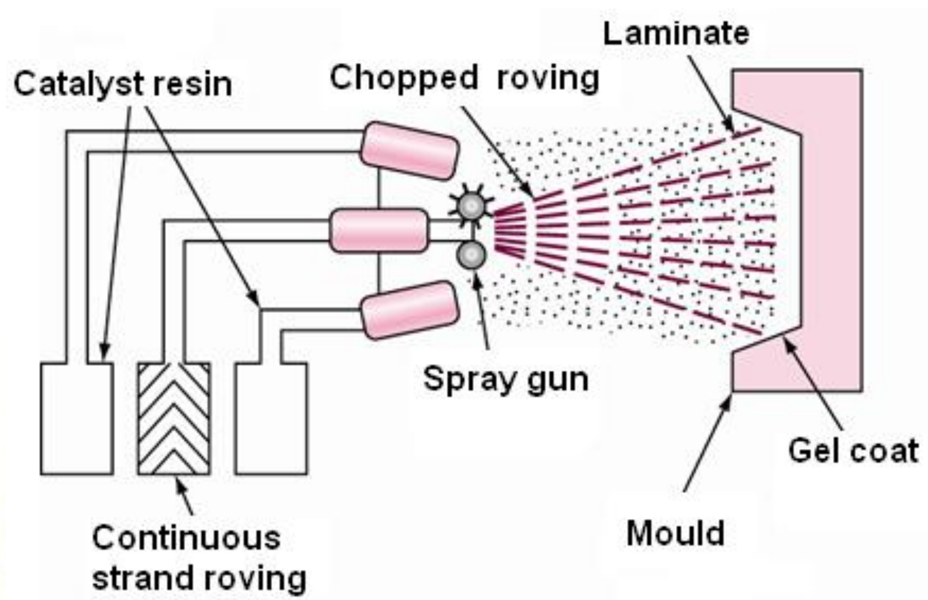
Hand lay-up process:

* Gel coat is applied to open mold.
* Fiberglass reinforcement is placed in the mold.
* Base resin mixed with catalysts is applied by pouring brushing or spraying..

Spray-up process:

Continuous strand roving is fed by chopper and spray gun and chopped roving and catalyst resin is deposited in the mold





METAL MATRIX COMPOSITE (MMC)

Metal as a matrix material

Matrices: Al, Cu, Mg and Ti, low temp fluidity

Reinforcements : Carbon, SiC, B, Al_2O_3...no glass

Advantages:

- Higher specific modulus & strength
- Better properties at elevated temp
- Better creep resistance
- Lower CTE
- Better wear resistance

Example of application

Rangka basikal lumba lasak, golf club, engine block

Aerospace application :

- Cu- C combustion chamber
- Cu-SiC nozzle (rocket, space shuttle)
- Al-SiC housings (pump, satellite)
- Al-C : wings, blades,

MMC FABRICATION METHODS

Two types

i. Solid state processing method

ii. Liquid state processing method

Main problems between matrix and RM :

i. Chemical reaction

ii. Wettability

Solving methods :

i. Control temperature
ii. Use high wt% Si for Al alloy

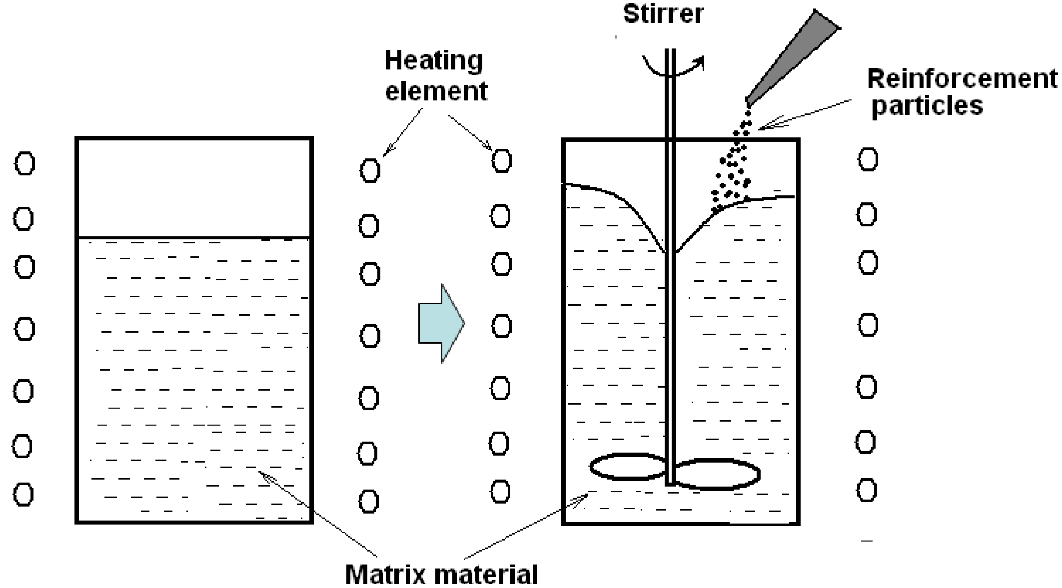
Solving methods:

i. Wetting agent eg Mg
ii. Coating of RM with metal
iii. Heat treatment (RM)

Example of MMC fabrication methods

1. STIR CASTING

Suitable for discontinuous RM



Method :

i. Melting matrix materials

ii. Stir - Vortex

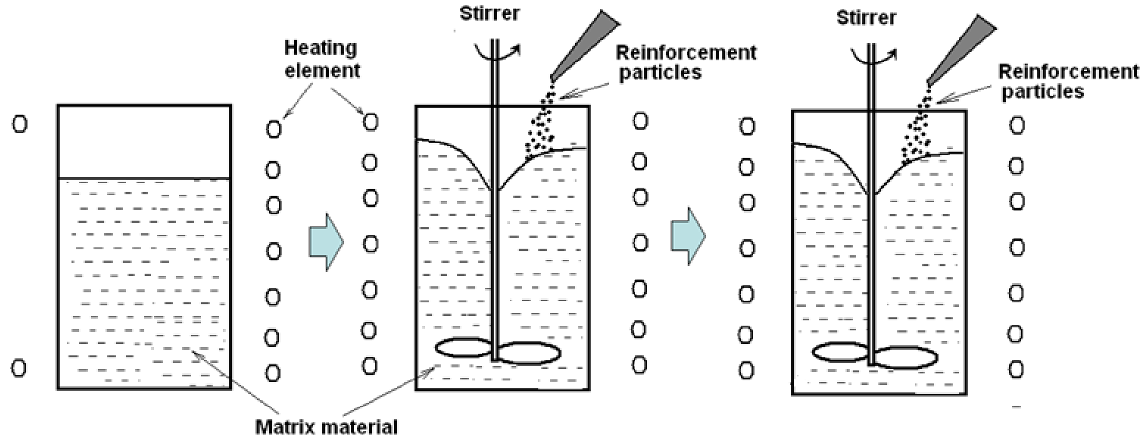
iii. Incorporation of RM, slowly. Eg 5g/min

iv. Stirring – continuously

v. Pouring into a mould

2. RHEO CASTING

Suitable for discontinuous RM



(a) Melting process
(b) Addition of RM in a semi solid liquid matrix material
(c) Increase temperature to fully liquid, before pour into mould

Method :

i. Melting matrix materials

ii. Stirring - Vortex

iii. Control temperature to semi-solid state

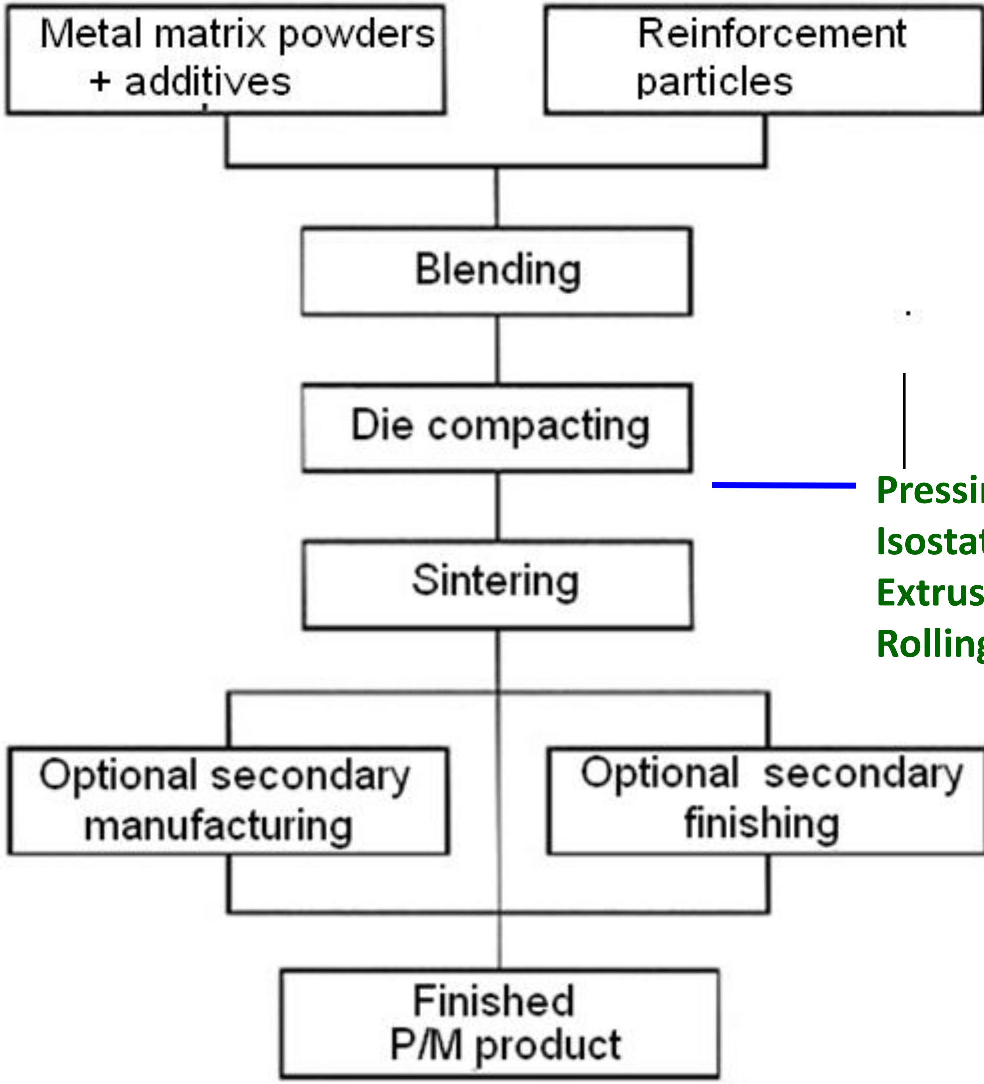
iv. Incorporation of RM, slowly. Eg 5g/min

v. Increase temperature to fully liquid state

vi. Stirring – continuously

vii. Pouring into a mould

3. POWDER METALLURGY



Lubricants :
- to reduce the particle-die friction

Binders :
- to achieve enough strength before sintering

Die compacting:

- Pressing
- Isostatic pressing (CIP or HIP)
- Extrusion
- Rolling

Optional secondary finishing:

- Sizing, Machining
- Heat treatment
- plating

CERAMIC MATRIX COMPOSITE

Ceramic as a matrix material

Matrices: Al_2O_3, C, LAS

Reinforcements, ZrO_2, Carbon, SiC, TiB_2, SI_3N_4

Example of application :

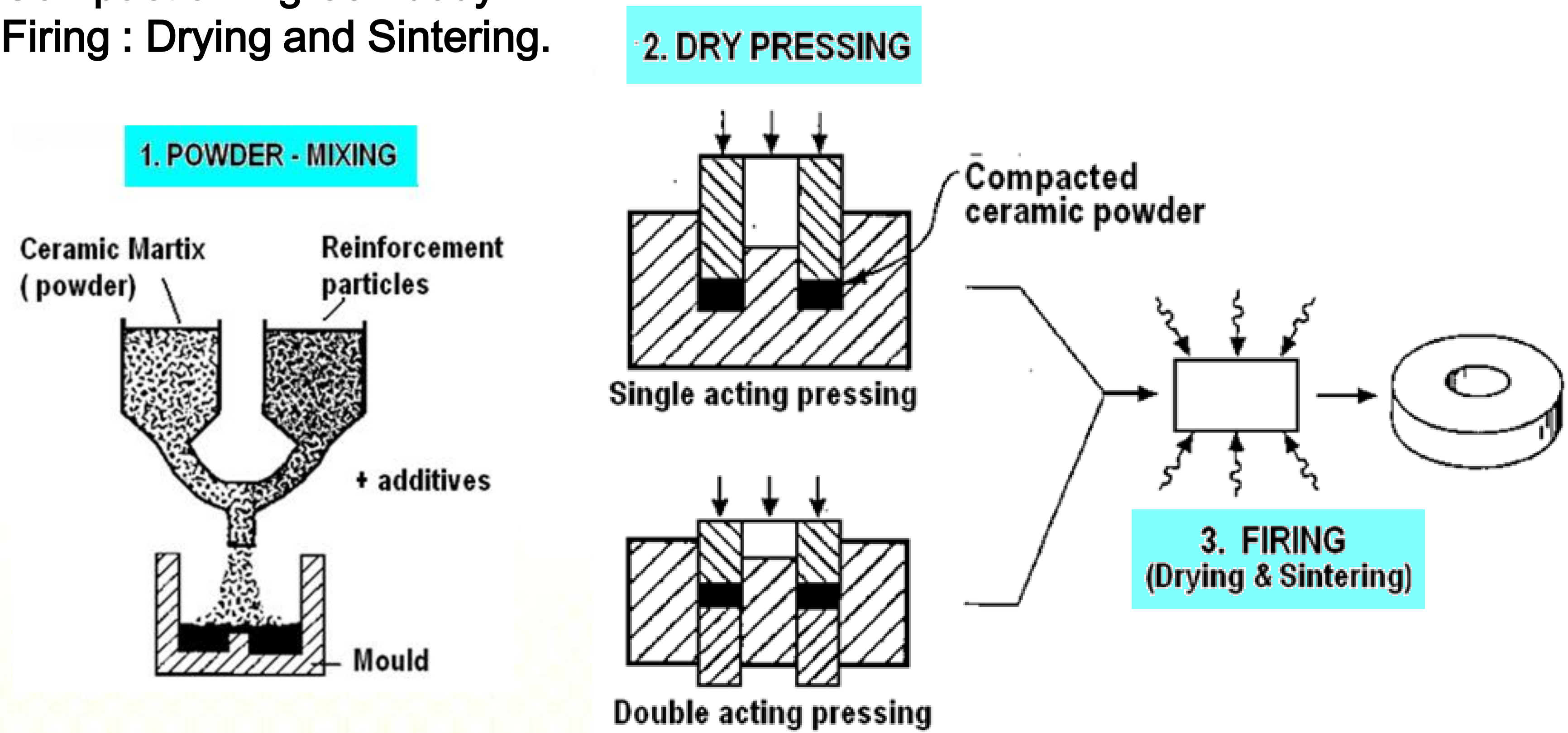
Brake disc for racing car and jet,
Gas turbine component such as nozzle,
Biomedical implant (spt tulang tiruan)

- **Continuous fiber reinforced CMCs:**
  - **SiC fibers are woven into mat and SiC is impregnated into fibrous mat by chemical vapor deposition.**
  - **SiC fibers can be encapsulated by a glass ceramic.**
  - **Used in heat exchanger tube and thermal protection system.**
- **Discontinuous and particulate reinforced CMCs:**
  - **Fracture toughness is significantly increased.**
  - **Fabricated by common process such as hot isostatic pressing.**

CERAMIC FABRICATION METHODS

1. Mixing and Pressing

- Same as being used for ceramic powder processing
  Mixing : ceramic powder + reinforcement particles + additives
  Compaction – green body
  Firing : Drying and Sintering.



2. Sol Gel Processing

Sol = precipitates of fine particles ~ 100 nm
(from chemcial reaction)

Eg : $ZrOCl_2 + NH_3 + 3H_2O \longrightarrow 2NH_4Cl + Zr(OH)_4$

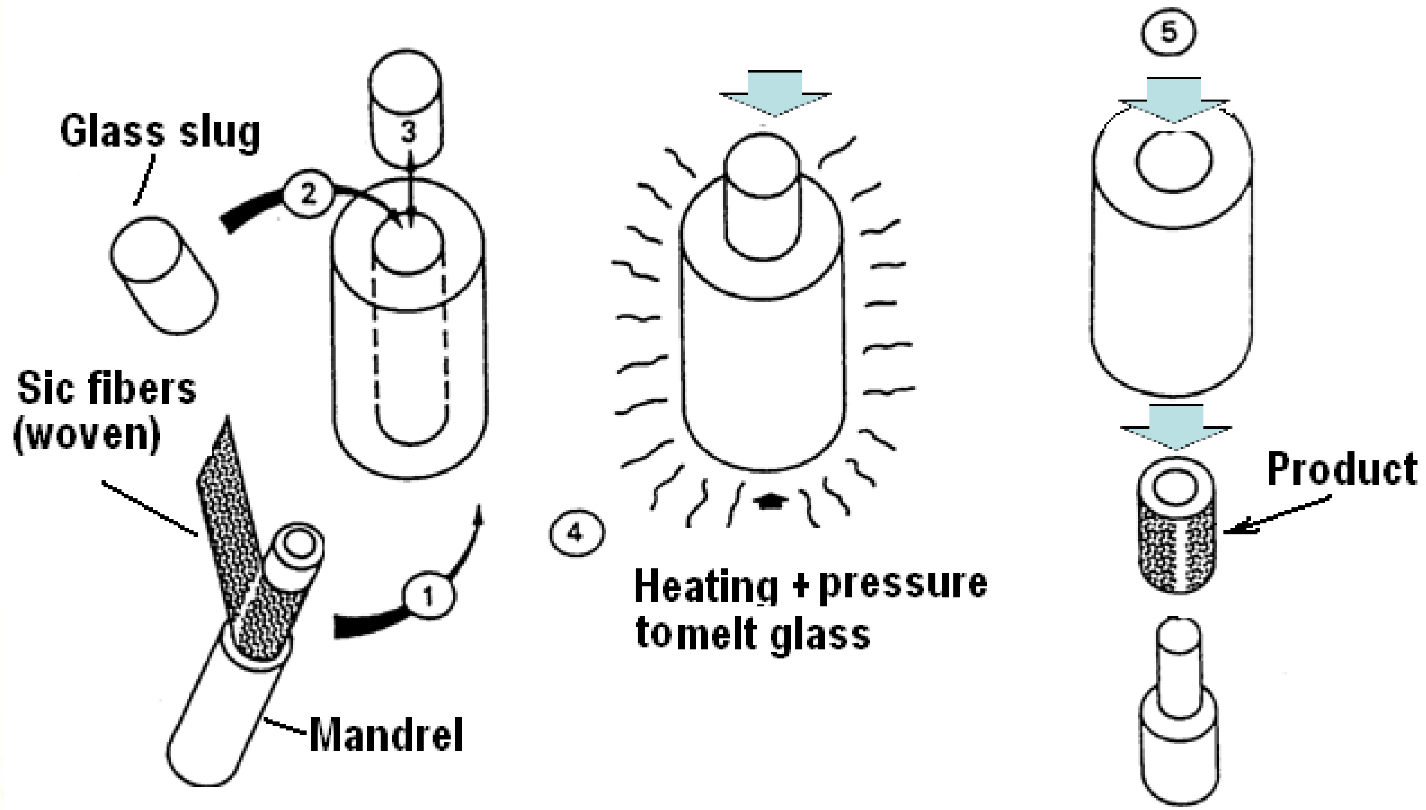
Gel = high concentration of sol

Processing steps

1. **Preform preparation** (continuous fiber)
2. **Pouring sol into preform**
3. **Drying**
4. **Repeat step 1-3 until the desired density is achieved**
5. **Drying and Sintering**

3. Matrix Transfer Moulding)

Suitable for continuous fibre + glass matrix



4. Chemical Vapour Deposition

Example : To produce C-graphite composite

Matrix material : Carbon
Hydrocarbon gas such as methane, propane, or benzene

Reinforcement materials : graphite fiber

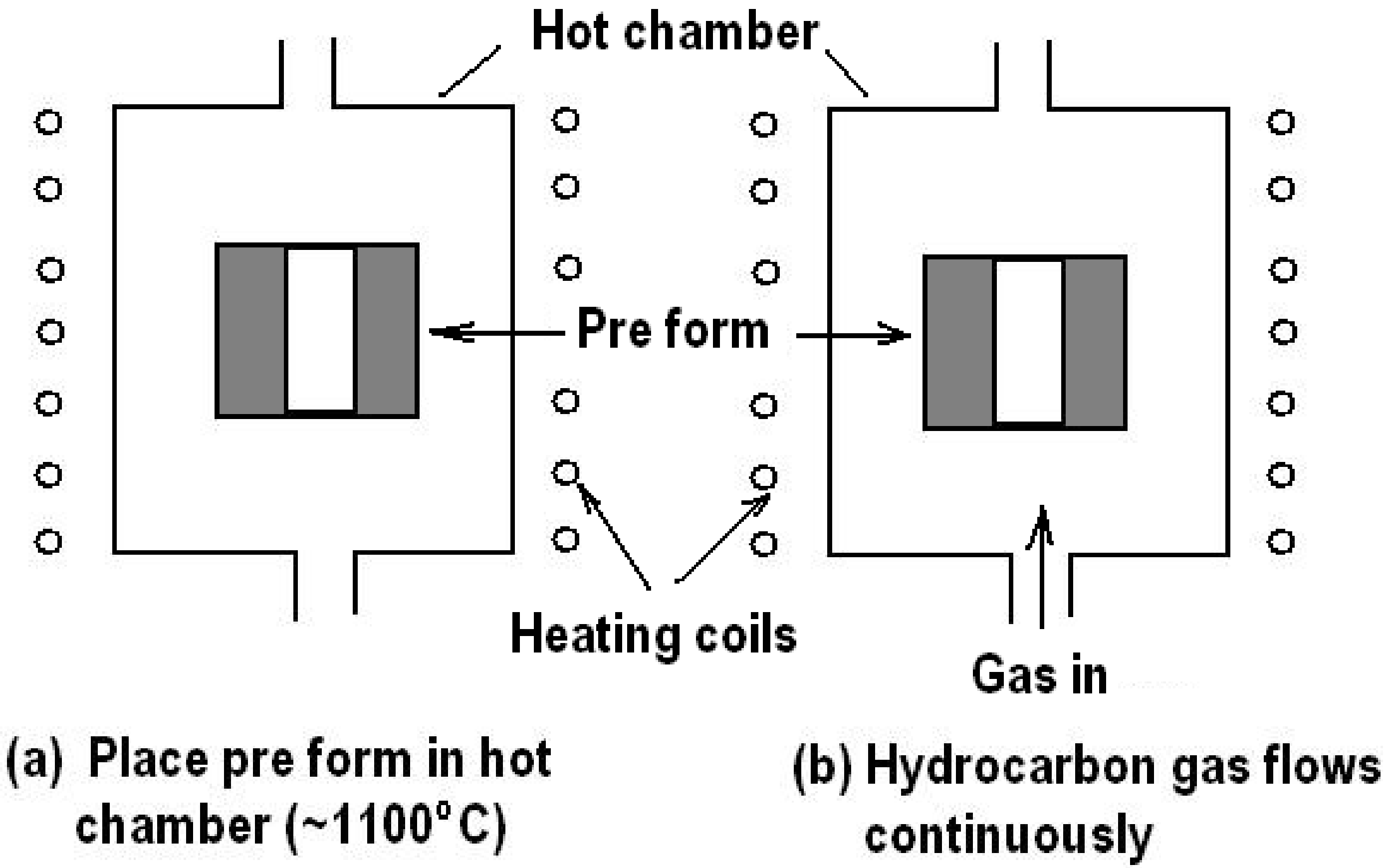
Method : .

1. Prepare a pre form (graphite fibers)
2. Hydrocarbon gas - flow into the hot chamber (1100°C),

   - thermal decomposition of hydrocarbon gas

$$CH_{4(gas)} \longrightarrow C_{(solid)} + 2H2$$

2. Carbon will deposited on pre form (Graphite fibers)
3. Proceed – required density



Chemical vapour deposition (CVD)

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