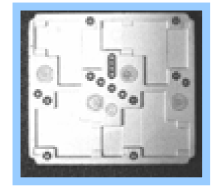
INTRODUCTION TO Composite Materials

Contents

Definition and Characteristics of Composites

Justice

- A literal meaning
  Consisting of two or more distinct materials
- Material meaning
  Two or more substances with different properties are mixed macroscopically Materials with more useful functions
- Difference between alloy material and composite material



Electronic Packaging

Brake Disk

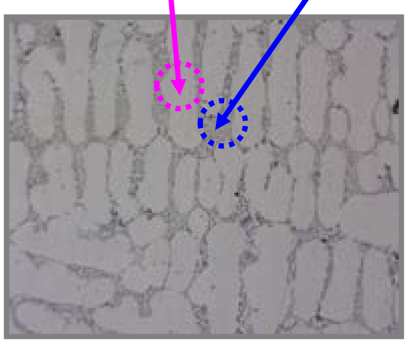
	Alloy	Composite
Mixture	Chemical mixing	Mechanical
Characteristic	Existing material is destroyed	Preserved existing material
Microstructure	homogeneous	Relatively heterogeneous

Basic Concepts of Composites

Reinforcement

base

Composite material



SEM image

Advantages

- Mixing Properties of Two Ingredients
- Material design flexibility
- Advanced material

Disadvantages

- High price
- Difficult molding process
- Disadvantage to mass production

Start of composite

- Early examples of composite materials

  Stronger than iron and lighter than aluminum!

  Propaganda relief of early composite materials

- **Glass fiber reinforcement**

  Large glass breaks well but is very strong when thin like hair Therefore, the Mechanical strength of the composite material is greatly increased.

  Epoxy resin

  Lightweight composite material

➔ Composite material with the advantages of both materials

Bulletproof helmet

Advantages and disadvantages of composite materials

- Advantages
  - Light weight --- high specific strength, specific rigidity
  - Possibility of Property Design
  - Abundant Load Transfer Path --- Fibers
  - Matrix and fiber Prolong the life of material-resistant to corrosion
  - Reduced number of parts --- Reduced price
  - Give thermal or electrical properties to material

- Disadvantages
  - Expensive materials --- high priced textiles
  - Possible physical property degradation of base materials by environment
  - Difficulty of adhesion
  - Difficulties in Mathematical Interpretation Finite Element Prediction Different from real

비행기 도어

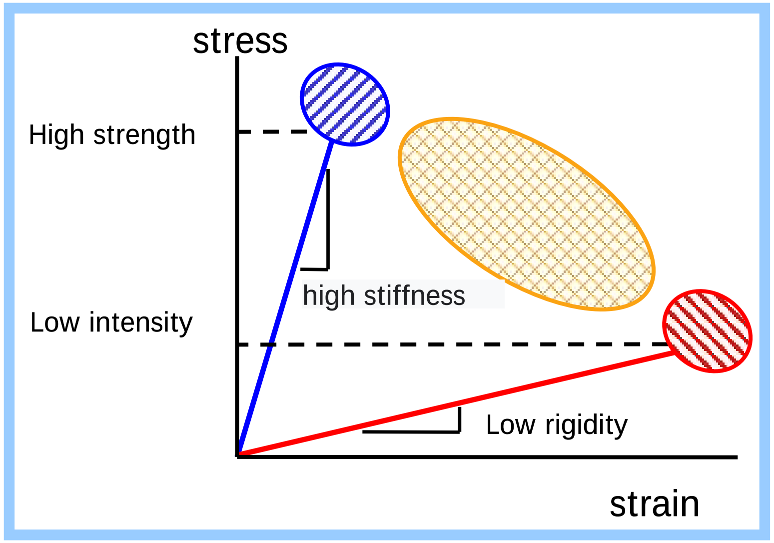
- Complex shapes can be manufactured
- 72parts → 3parts

Property Design of Composites

- There is no physical property of the composite material. ?
- Composite material is a mixture of materials with different properties
- Various physical properties can be designed depending on the combination and ratio

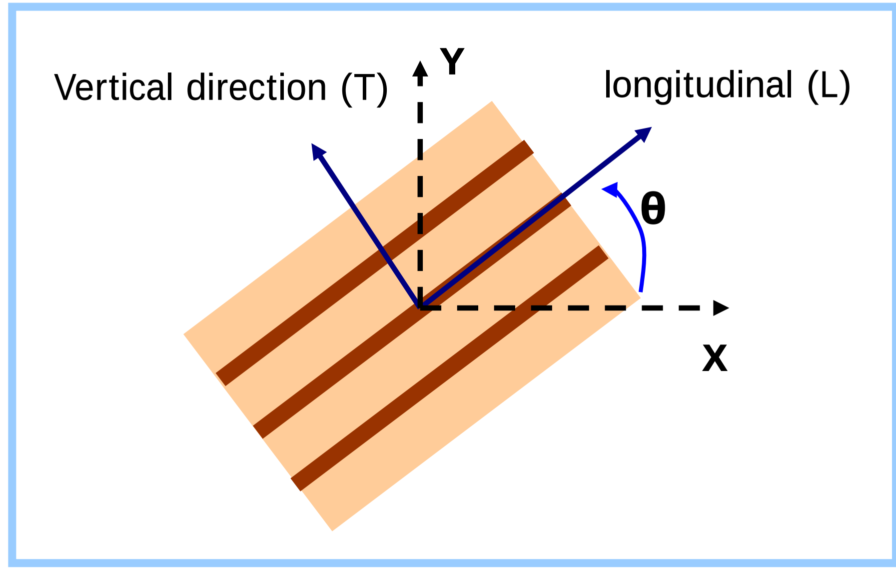
Glass fiber

There is no fixed property value !!



- Reinforcement --- high strength and rigidity
- Base material --- low strength and rigidity
- Composites --- Design a wide range of properties

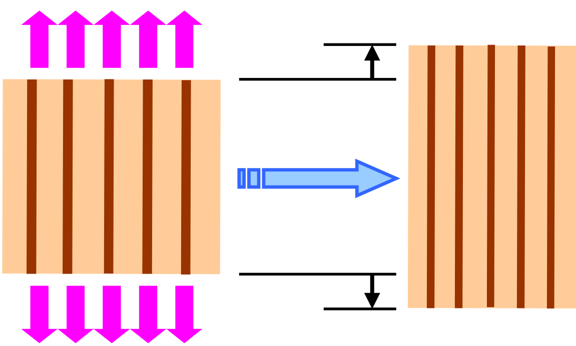
Characteristics according to the direction of the fiber



- What is the fiber direction? ?

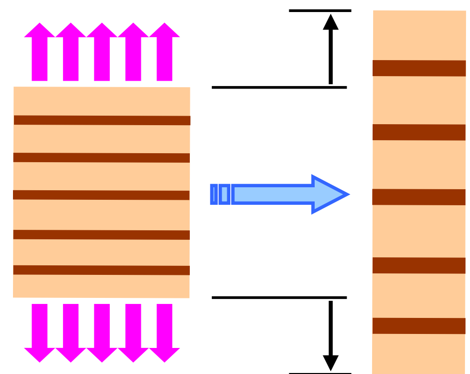
  Because the fibers are thin and long The deformation in the longitudinal direction and the vertical direction is different.

When pulled in the fiber direction



Slightly Stretched

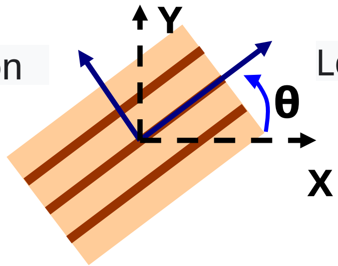
- **When pulling in the vertical direction of the fiber**



Increased

Physical Property Classification By Fiber

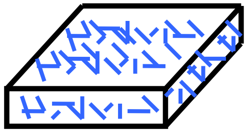
vertical direction



Longitudinal

등방성 (Isotropy)

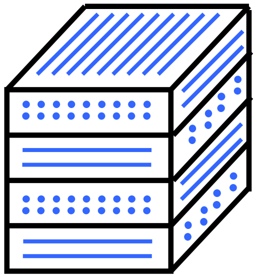
- Properties are similar regardless of Θ



- Short fibers freely
- Reinforced composite

이방성 (Anisotropy)

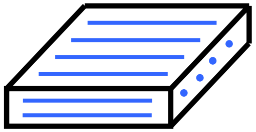
- Properties change with Θ



- Orthotropic Plate
- Laminated composite

직교이방성 (Orthotropy)

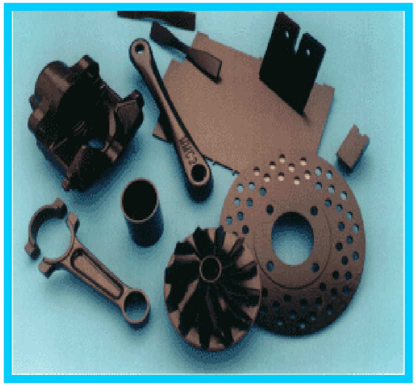
- At Θ 0° and 90° isotropic
- However, the physical properties in both directions show a big difference



- Long fibers in one directio
- Reinforced composite

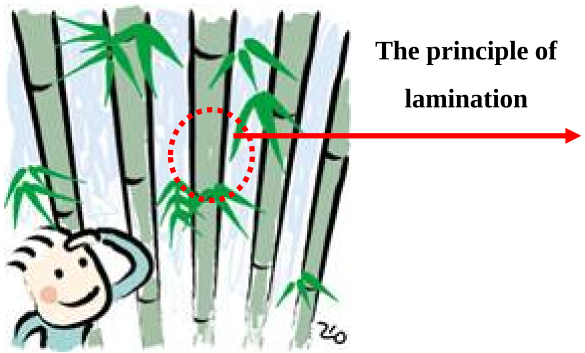
History of composites

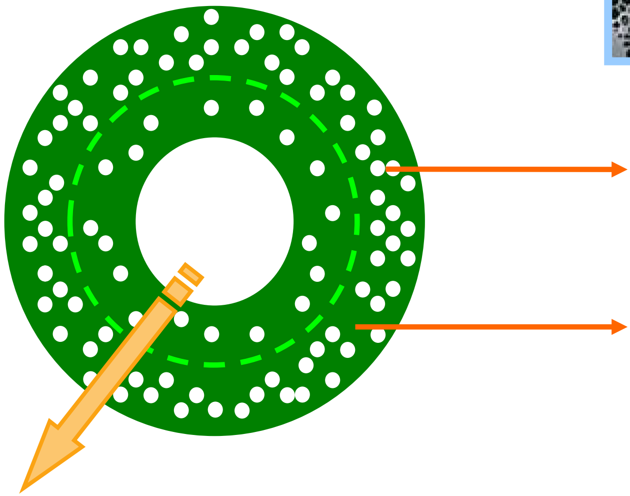




Nature's Composites

- Bamboo



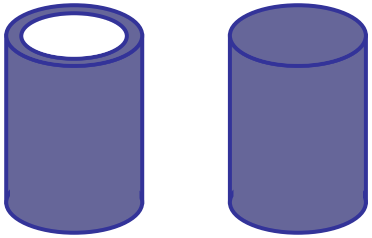


- The closer to the epidermis, the greater the force

➔ 5 times stronger than outside

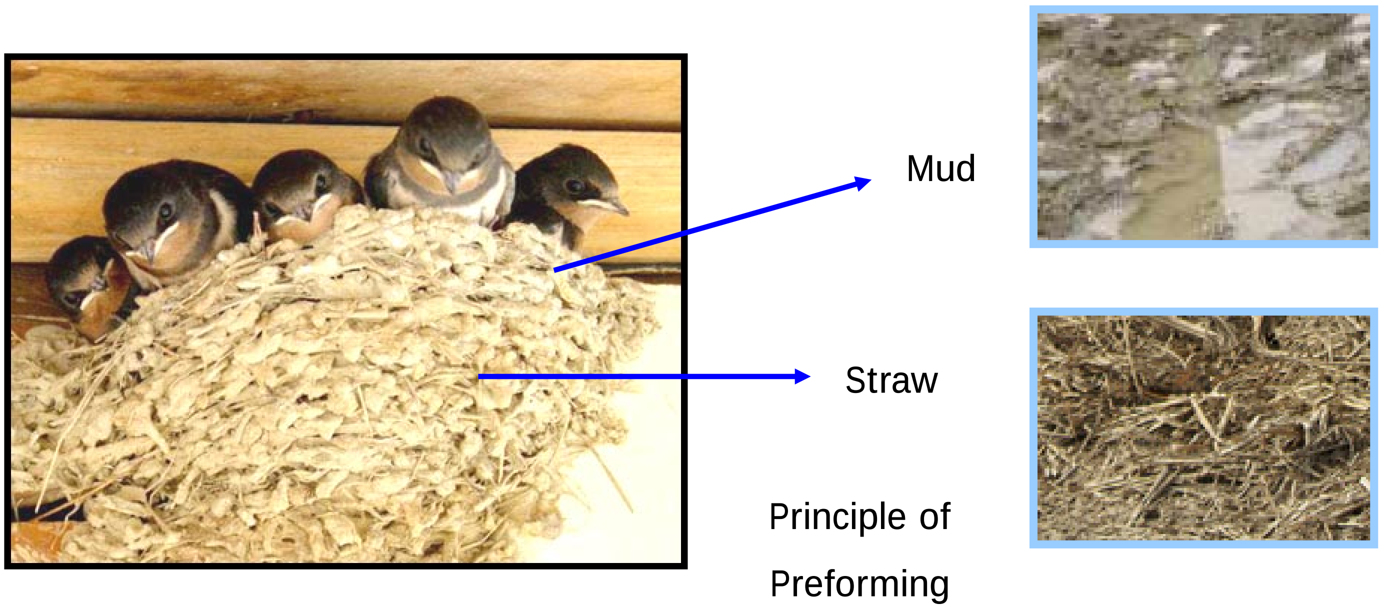
- The more the hollow, the stronger the strength
- Principle of Hollow Pipe

➔ Hollow pipes are more difficult to bend than solid pipes



Nature's composite

- Swallow House



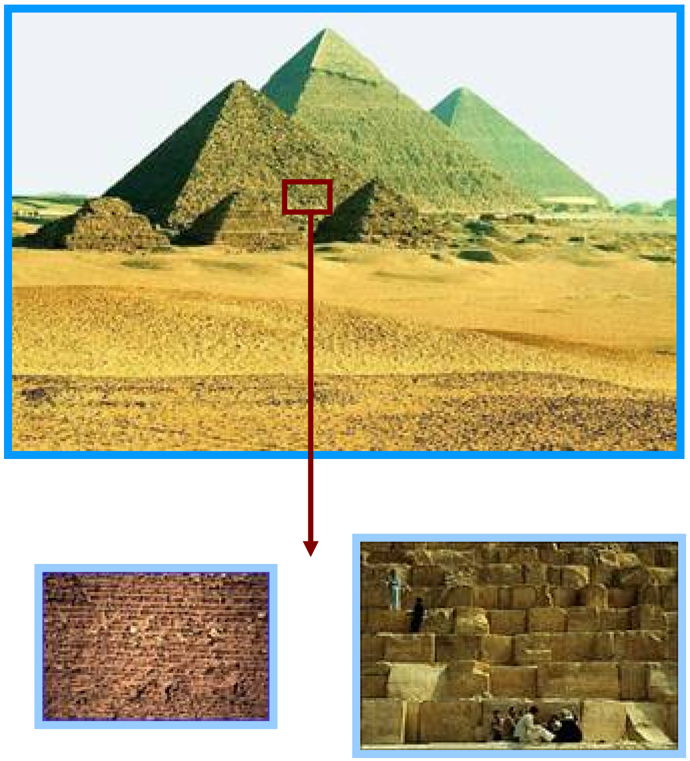
- After laying the foundation with straw

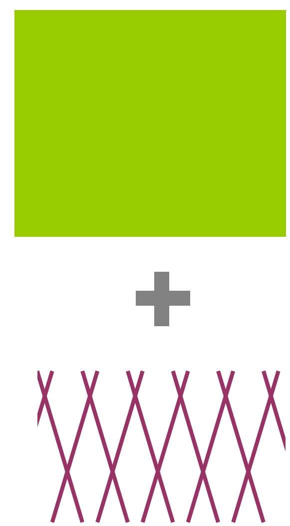
  Fill the space with viscous mud to complete a solid house
- Principle similar to preform of composite material

Past composites

Principle of textile strengthing

- Pyramid bricks





Well-covered material

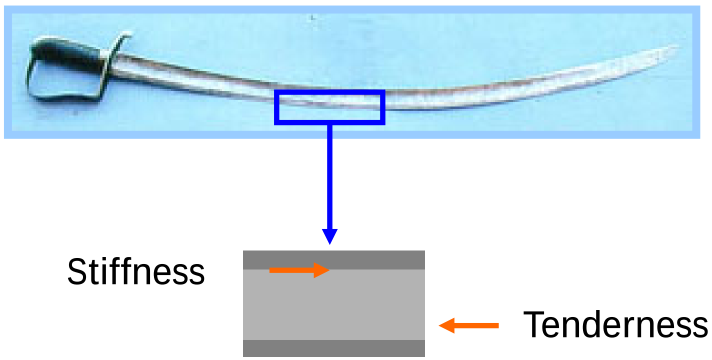
Solid material

- Reinforce the shortcoming of material

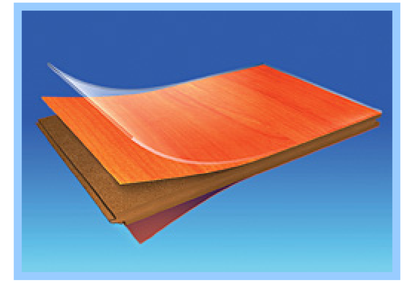
- If you use only soil and stone
- Manufacture bricks by mixing straw to increase the strength of bricks

Past composites

- Medieval swords

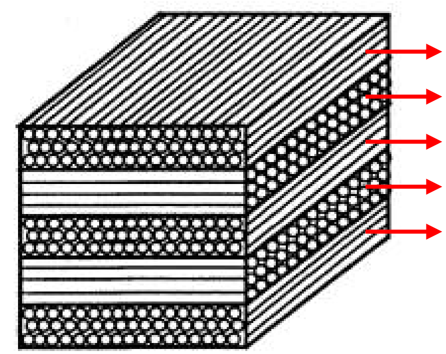


- Inside: made of ductile material Not broken
- Outside: made of brittle material In strong and sharp blade making



Laminated composite material

Principle of lamination



By stacking materials with different physical properties
Manufacture products that meet the purpose

Composites of the Past

Todam

Soil and straw

- Grass-fed quilt

Principle of resin impregnation

Principle of fiber reinforcement

Soil

Straw

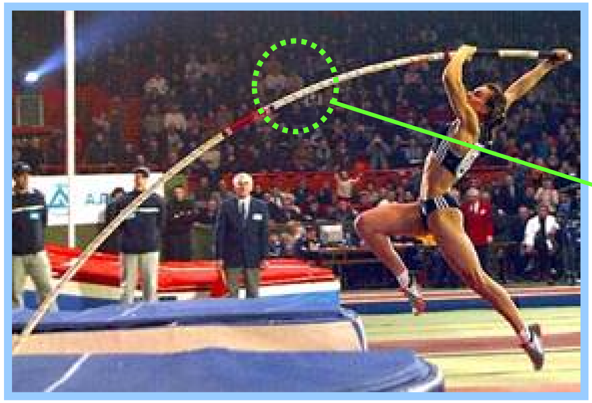
- Mud mixed with rice straw to create solid soil

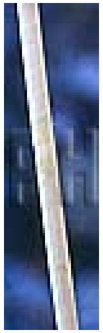
- Loosen on a futon

  Feed and make it thin.

Modern Composite Material

- Pole vault





폴

- Plastic dinner set

- Wooden poles, bamboo, etc. are used in the 1920s
- I use steel poles in the 1950s
- Good elasticity but heavy Use of glass fiber reinforced composite materials
- since the 1970s

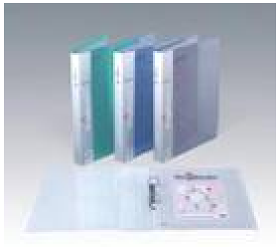
Reinforcement of elasticity, light weight of product

- Fiber Reinforced Plastic
- Composite Less physical property deterioration due to moisture

Development of Composites

Boat

Car body



Translucent Paper

- Developed fiber reinforced translucent paper
- Boat shell, car body, truck steering wheel

Commercialization of composite materials

- Various base materials
- appeared Polymers, Phenolics

Vinyl esters

1930 1950 1970

- Fiber Reinforcement Using Glass Fiber
- Plastic (FRP) appearance Radar antenna plastic
- Start commercialization with cover

- Various fiberglass appearance

E-, R- and S-glass

- Fiber appearance of other materials

Kevlar Fiber, Carbon Fiber

- Moderate strength
- Low price

- Very strong
- High price

radome

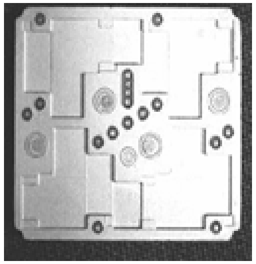
Development of composite material

Golf club

(Nanoparticle Reinforced Material)

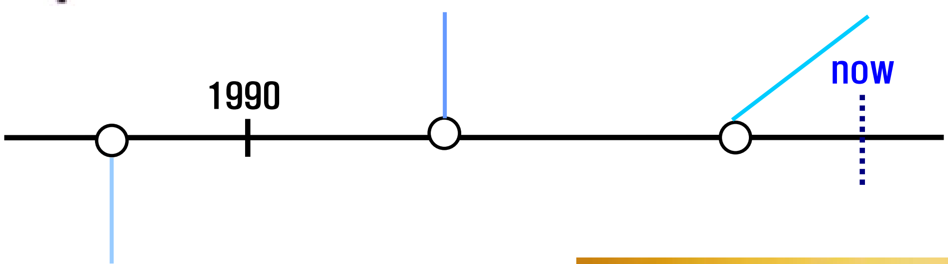
- Nano composite material

- To meet corporate
- Functional composite material development
- Conductive, Corrosion Resistant, Insulation



Electronic packaging

(Insulation)



- With the emergence of new materials

  Development of various molding processes

Fuel cell

(Electric conductivity)

Windmill blade

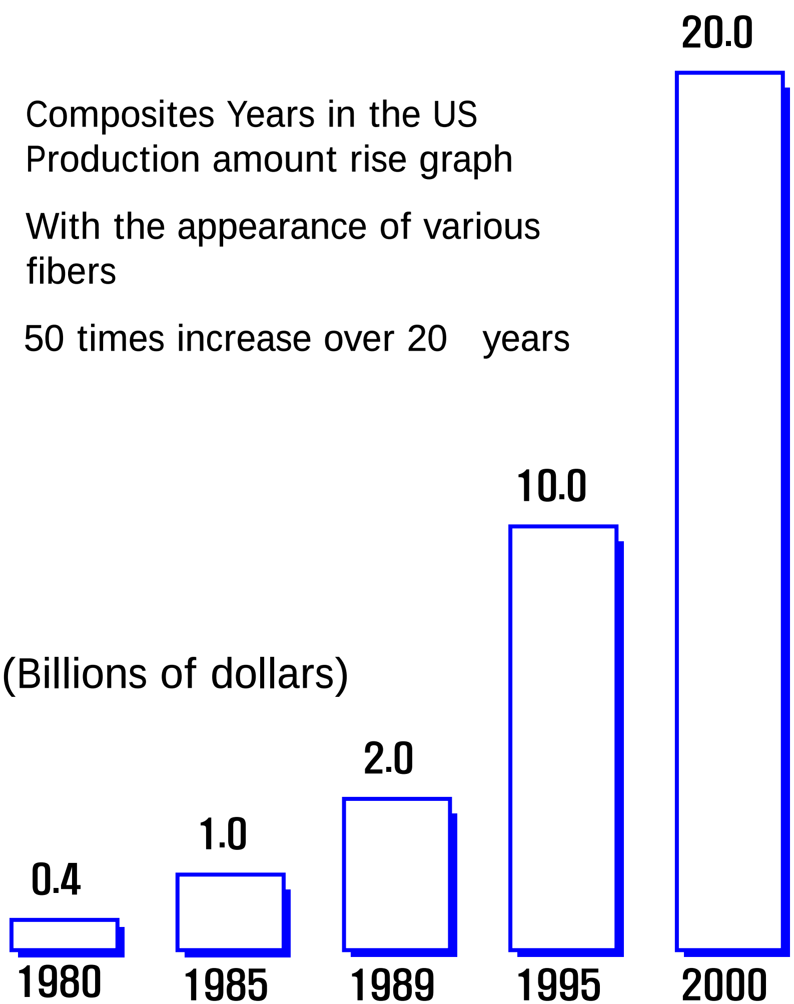
(High strength)

Application fields of composite materials

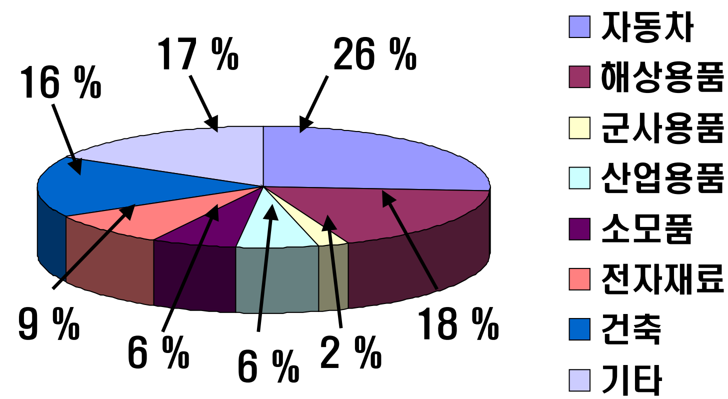
- Composites Years in the US Production amount rise graph
- With the appearance of various fibers

50 times increase over 20 years

(Billions of dollars)

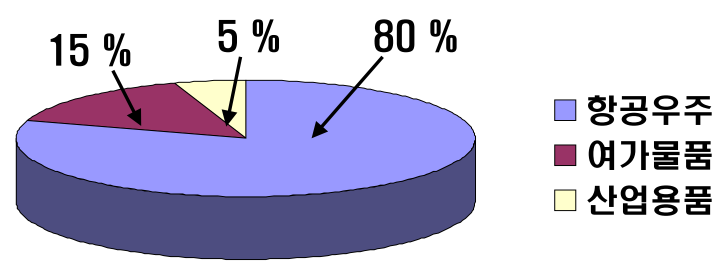


Early Composite Materials



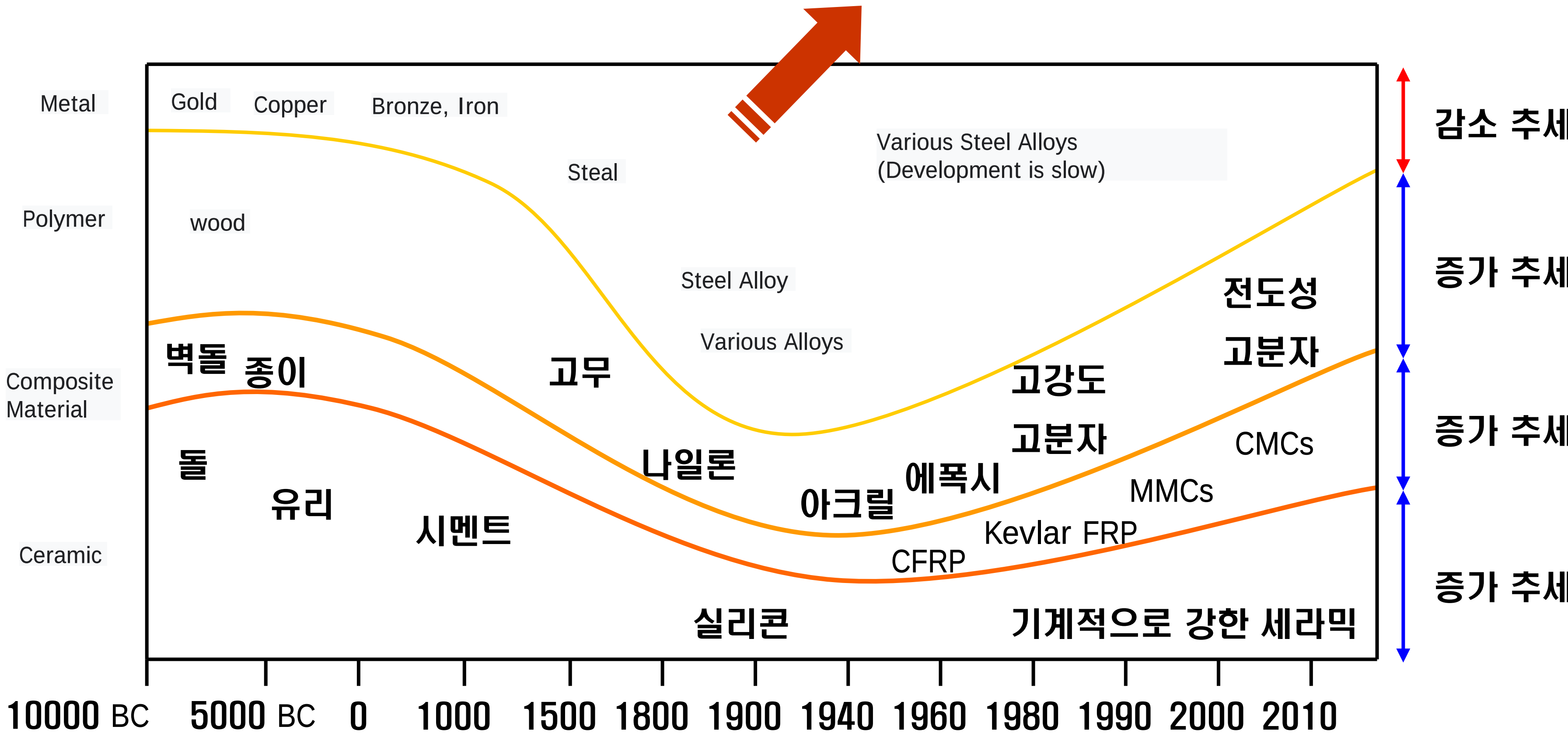
Appearance of various fibers
(Carbon, Kevlar, Boron, etc.)

Advanced Composites

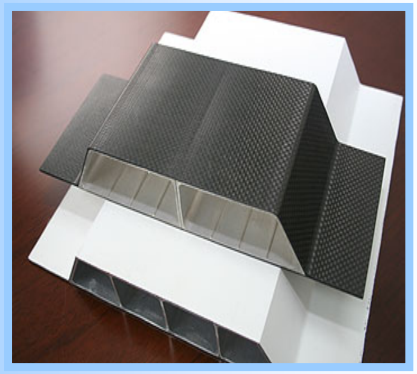


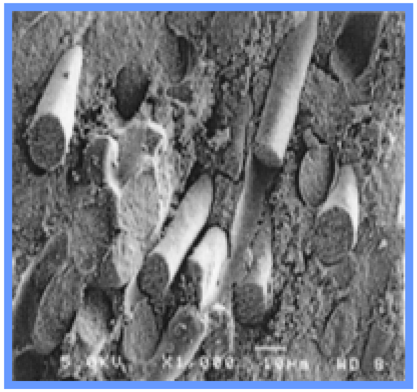
Importance of Composites

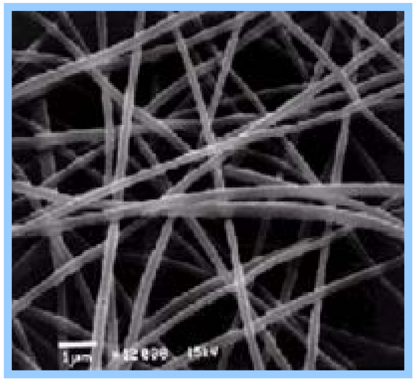
- The importance of polymers, composites and ceramics steadily increases
- The importance of metal is relatively reduced



Composition of composite material







Base (Matrix)

- role

  Binders to Fix Fibers
- Stress transfer between fibers Protect fiber from the outside Resistance to mechanical abrasion
- Mechanical features

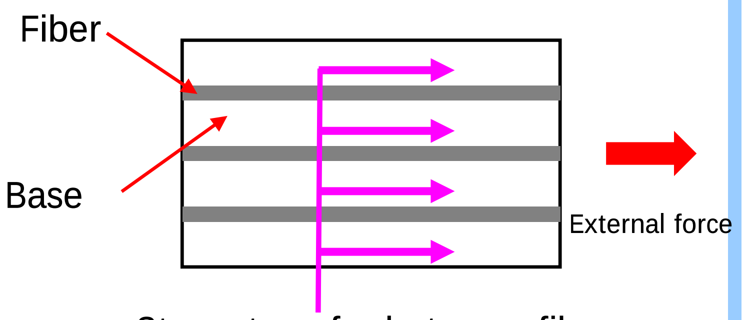
  Important role in shear properties in plane

  Suppression of buckling of fibers under compressive stress

  Insufficient resistance in tensile stress
- Reinforcement and Correlation

  Proper mixing ratio of the two materials is very important to achieve the desired properties

  The interaction of two materials is important for the design of damage-tolerant structures



Stress transfer between fibers

Base (Matrix)

- Kinds

- Mainly use thermoplastic polymer with very good processability
- Metal and ceramic bases are mainly used at high temperatures

Polymer resin (Polymer)	열경화성 수지 (Thermosetting)	Epoxy (mostly used for space aircraft) Polyester, vinyl ester (used for automobile, ship, chemistry) Phenolic (used for f functional composites) Polyimide (used for high temperature space applications)
	열가소성 수지 (Thermoplastic)	Nylon, Thermoplastic Polyester (PET, PBT), Polyacetal PAI,PEEK, PSUL, PPS and PEI etc
금속 (Metal)		Aluminum, Titanium Alloy, Magnesium Alloy Stainless Steel-High Temperature (300 ~ 500°C)
세라믹 (Ceramic)		Aluminum Oxide, Carbon, Silicon Carbide

PAI : Polyamide imide, PEEK : Polyether ether ketone, PSUL : Polysulfide,

PPS : Polyphenylene sulfide, PEI :Polyether imide

Base (Matrix)

- Characteristics of Multiple Base Materials

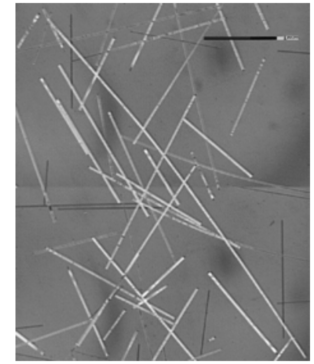
Ceramic matrix composites

Noise absorption plate of high temperature part

Carbon	High heat capacity per unit mass Used for rocket nozzles, clutches and brake pads in aircraft	More than 3000°C
Ceramic	Generally brittle Mainly used in extreme environment (high temperature, etc.)	1093~1649°C 이상
Glass	Low rigidity Reinforcement material uses carbon fiber and metal oxide fiber	
Metal	Used for high temperature materials in oxidizing environments	800~1371°C
Polymer	Most used, low price Good formability and mechanical properties, strong adhesion	Below 427°C

(Reinforcement)

- Role
- Important role in the strength and rigidity of materials
- Reinforcing material selection criteria
- Specific gravity ☐ material weight
- Tensile Strength and Tensile Stiffness Composite Material Properties Design
- Compressive strength and compressive strength
- Fatigue Strength and Fatigue Breaking Mechanism
- Electrical and Thermal Conductivity ☐ Functional Composite Design
- Price 판별 Determination of Mass Production Potential
- Known Material and Interrelationship
- Determine the type, amount, lamination angle, etc. of the
- reinforcement to achieve the desired properties

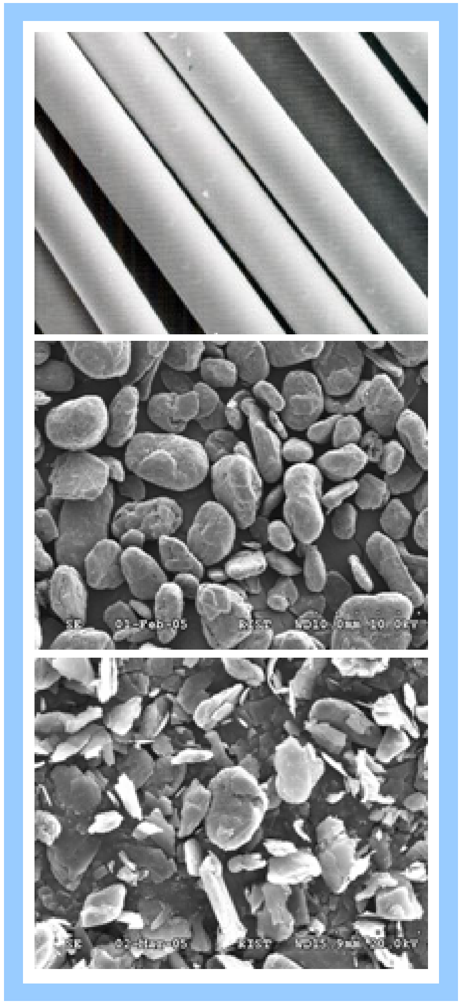


Glass fiber

Glass fiber

강화재 (Reinforcement)

- Kinds
  - 섬유 (Fiber)
    - long cylindrical
    - When forming a composite material with a brittle base material, Suppresses the occurrence of cracks
  - 구상입자 (Particle)
    - No long part and almost spherical
    - relatively easy to crack
    - The tension is very small even under load.
    - Suppress plastic deformation When hard particles are reinforced, they are concentrated Weak reinforcement
  - 판상입자 (Flake)
    - Flatter than spherical particles
    - Features similar to spherical particles



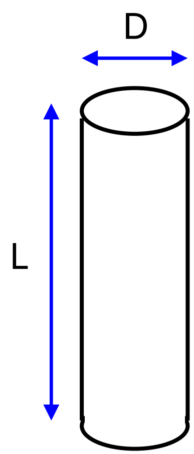
Fiber

Conception

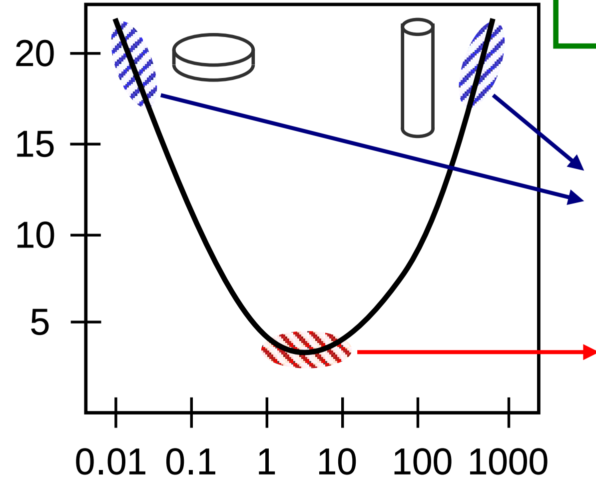
Plate

Property principle of fiber reinforcement

- Principle of fiber property
  - □ Shape



Unit sieve fitness surface area : A / V



Aspect ratio : L / D

Large base and contact surface

➔ Stress transfer is good

Good physical property

Lack of physical property

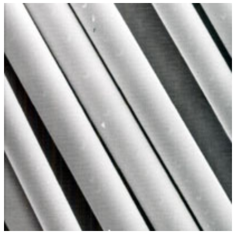
  - □ Principle

Disorderly

Distribution of fibers

Giant form

- Increase sortability of fiber
- Tensile strength increase



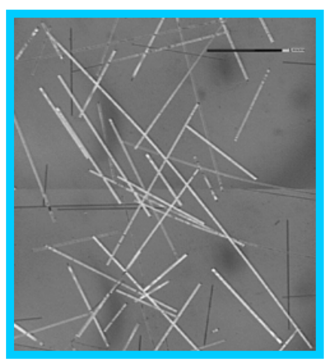
Fine fiber form

Classification of Fiber Reinforcements

- Classification of fibers by form
- Whiskers: short fibers that grow in crystals
- Short fiber: short fiber obtained by cutting long fiber
- Long fiber: long fiber
- Strand: Bunch of Long Fibers
- Chopped Strand: Chopped Strand

Long Fiber Mat

Whisker



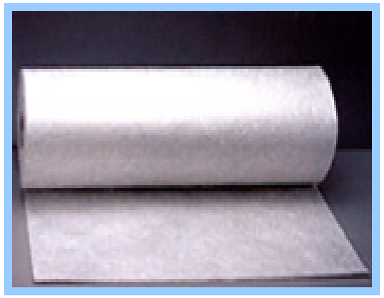
Short fibers

Long fiber

Chopped Strand

Classification of Fiber Reinforcements

- Classification of fibers by type (Cont'd) Roving: 20 strands of strands combined
- Weaving roving: Woven fabric
- Chopped strand mat
- Filament Mat: Mat with Long Stranded in One Direction
- Yarn: a fabric shaped like a yarn
- Fabric: Thin and wide fabric made of rovings Mainly used for additive forming



Strand mat

roving

Weave roving

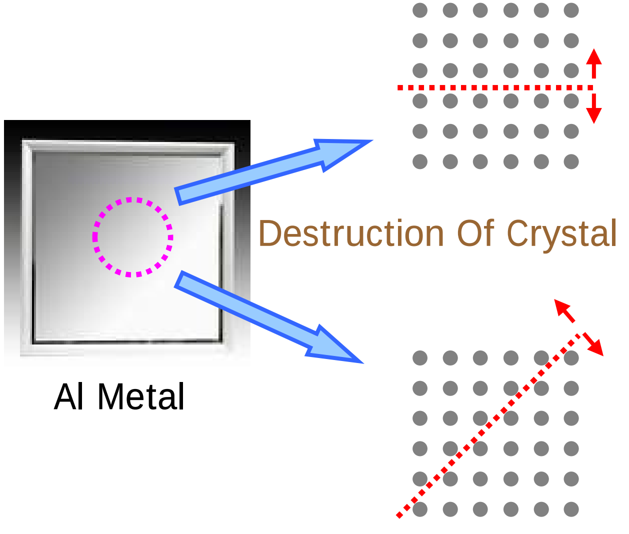
yarn

fabric

Discovery of Fiber Reinforcements

- First fiber discovery
- Similar to cat whiskers
- Good physical properties but difficult to manufacture
- Only a few mm and a few cm in length
- Principle of Whisker Strength

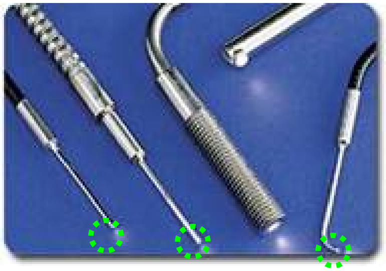
Cat Whisker



- Dislocation: Disturbance of Atomic Array
  Gradual shift that started at dislocation gradually transfers
- Deterioration of strength of metal due to electric potential
- The principle of repeating the blacksmith's patting and knocking
- Increased strength even without dislocations
  Whiskers are thin and long with little dislocations

Fiber glass

- Glass fiber
- Reinforcing materials that have been used steadily since the 1930s Weak strength compared to other fibers
- Use with other chemicals because of low wettability
- Mainly manufacturing polymer resins and composite materials
- Many uses for products with general physical properties



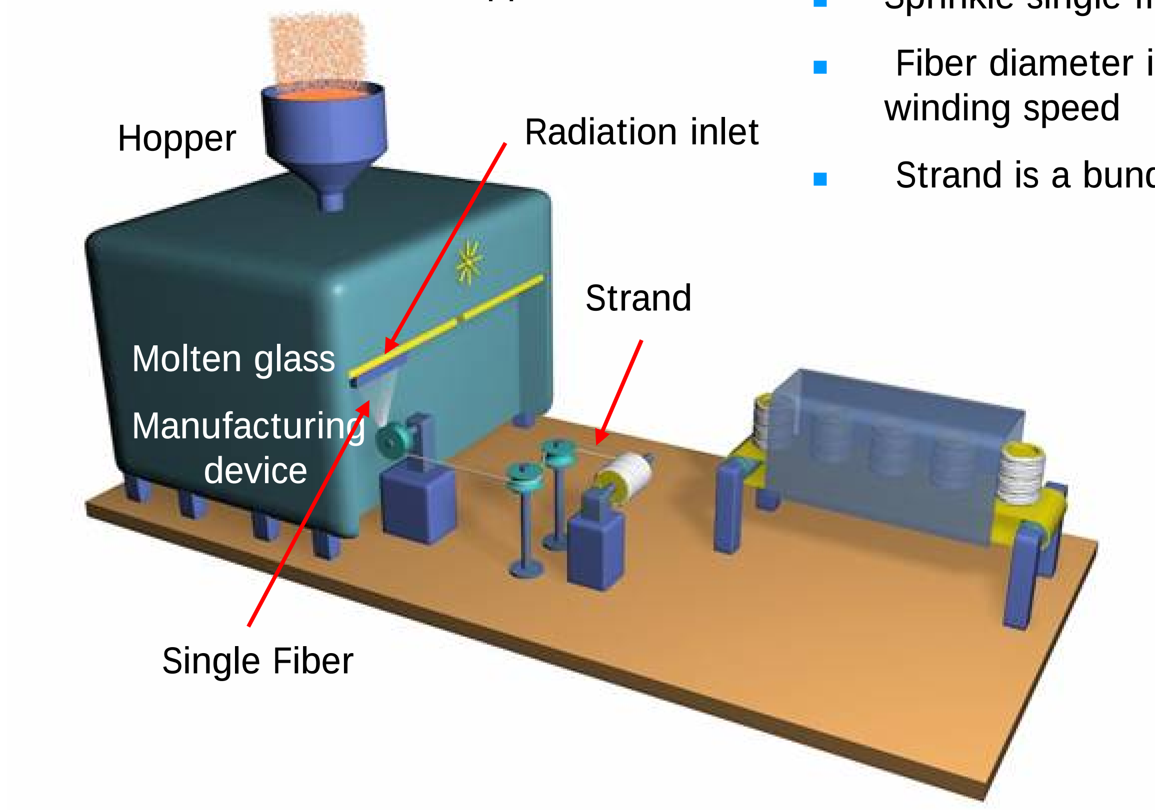
Fiberglass Reinforced Tips

Advantages	Disadvantages
■ Convenience of manufacturing ■ Low price ■ High tensile strength	■ Low stiffness coefficient ■ Low wear resistance ■ Low wetting

Fiberglass Fabric

Glass fiber manufacturing

- Manufacturing



- Sprinkle single fiber to cool the heat
- Fiber diameter is controlled by controlling the winding speed
- Strand is a bundle of single fibers

Classification of glass fiber

- Classification of Glass Fibers
- E-glass fiber: Manufactured by resin injection method Used as the main material of composite materials

  Not very strong but cheap
- S-glass fiber: used in aviation industry and missile development Light weight and very strong

  high price
- S-2 glass fiber: similar to the performance of S-glass at a lower price Mainly mixed with other fibers (Hybrid form)

Structure using glass fiber

Fiberglass rope

Fiberglass tape

Kevlar fiber

- Kevlar fiber (representative of Aramid fiber)
- First introduced by Dupont company in the early 1970's

Characteristic

Kevlar gloves

advantages

- Low specific gravity
- High tensile strength
- High tensile stiffness
- High shock absorption
- High fatigue strength

disadvantages

- Low compressive strength
- Weak processability
- Low limit tensile

1/8 of tensile strength

Loss of isotropy due to high speed rotation during manufacturing

Microbuckling occurs during compression

Structurally robust but fragile

long and strong polymer chain

Types of Kevlar fiber

Types of Kevlar Fiber

Types	Characteristics	Application
Kevlar 29	Low mechanical rigidity	
Kevlar 49	High mechanical rigidity	Aircraft,heliopter,pressure vessel
Kevlar 129	Very high ‘’	
Kevlar 149	Very high mechanical stiffness Low hygroscopicity	“ ,” ,sporting goods
Kevlar Hp	Property similar to aircraft helicopter Smooth surface High impact resistance	Sporting goods Marine sectors requiring good physical properties

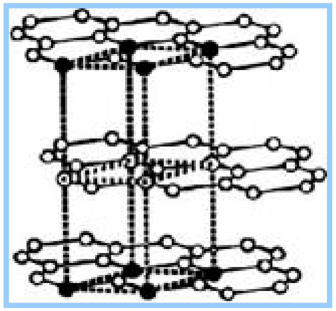
Common uses of Kevlar 49

Kevlar 49 is also available in the form of roving's, yarns, fabrics

Carbon fiber

- Carbon fiber
- Reinforcements have been used since the 1970s
- Beginning of Advanced Composites
- Excellent mechanical properties

Excellent mechanical properties due to the microstructure of the plate-like layer



Fine Structure Of Carbon Fiber

Advantages

- Low density
- High tensile strength
- High tensile stiffness
- Low coefficient of thermal expansion
- High heat resistance
- High wear resistance
- High conductivity

Disadvantages

- Low limit tensile
- High manufacturing cost
- Low wetting

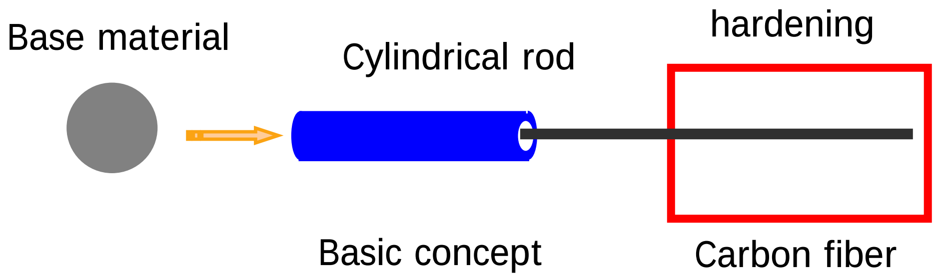
Carbon Fiber Fabric

Method of manufacturing carbon fiber

- Carbon Fiber Manufacturing Method
- Conventional Spinning Technique: Principle of injecting a base material into a thin hole and pulling it out like a thread
- Representative base material

  PAN (Poly acrylonitrile): Polymeric material used as carbon fiber material
- Pitch: Petroleum oil residues, thermoplastics

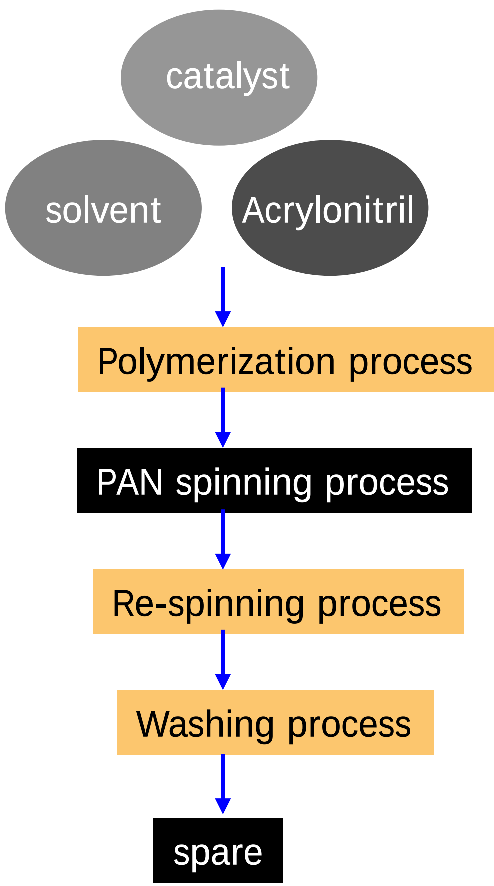
Carbon Fiber



Basic concept

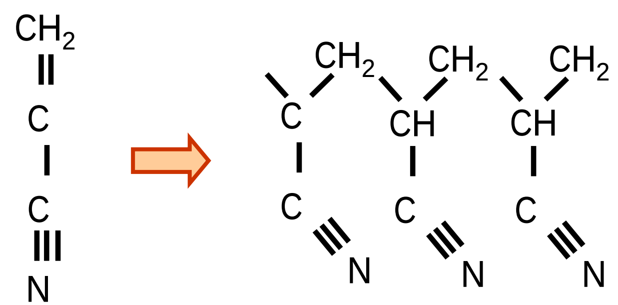
PAN-based carbon fiber

- Manufacture of PAN-based Carbon Fiber Spare Body



Polymerization process

Polymerize monomer with polymer



spinning

Fine spinning of polymer raw materials

In the next chapter explain in detail

Re-spinning process

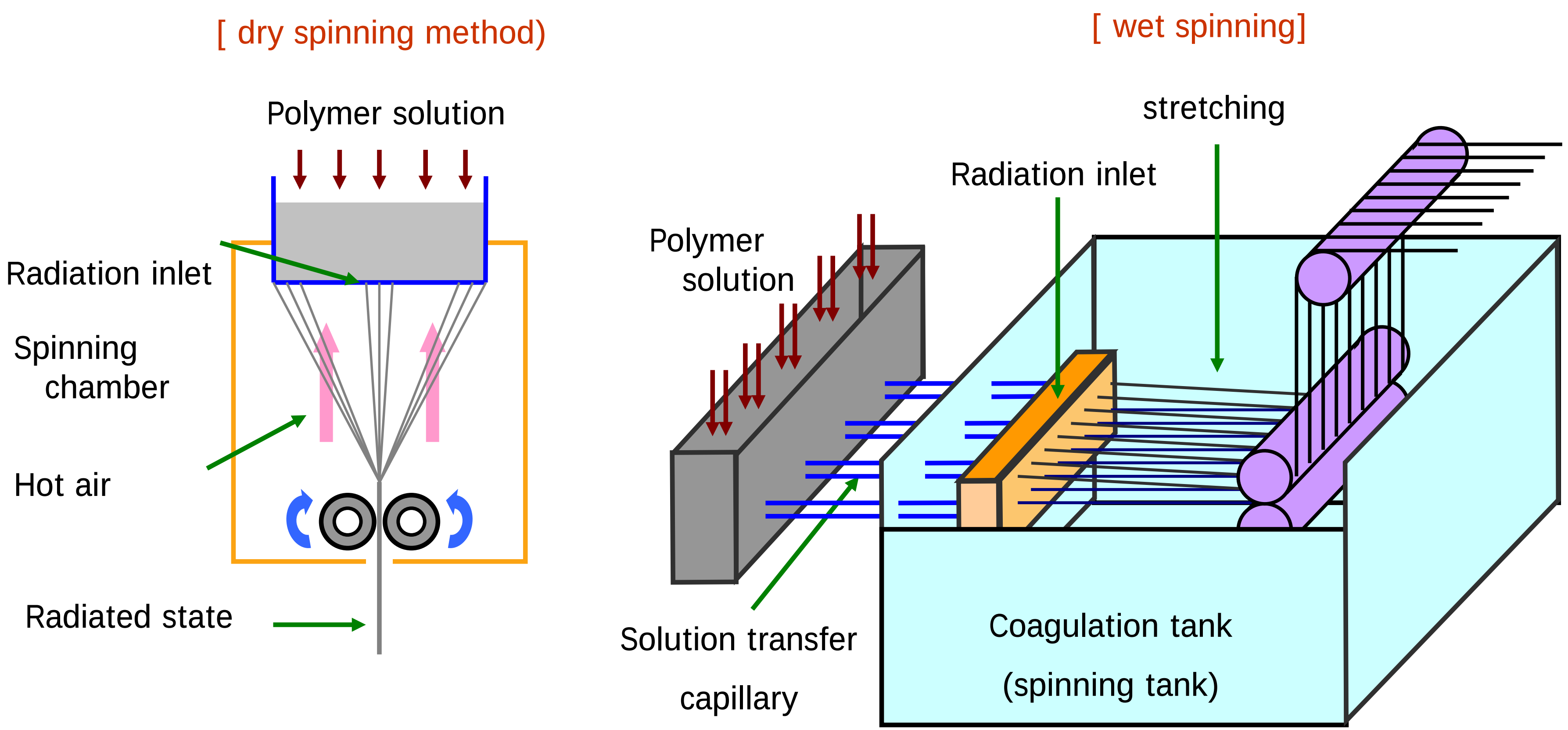
Re-stretch what is emitted

Washing process

Washing the radiate material

PAN based carbon fiber

- PAN spinning process
- There are many, but only two representative



PAN-based carbon fiber

- Preparation of Carbon Fibers from Preparative Materials

spare

↓

Oxidation process (250-300 C acid air)

↓

carbonziation process (1000-1500 c) neutral air

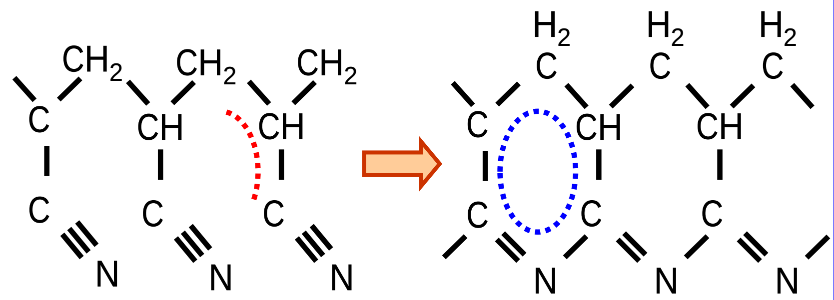
↓

Surface and size treatment → Carbon fiber

Graphitization process (More than 2000˚C neutral air)) → Surface and size treatment → Graphite fiber

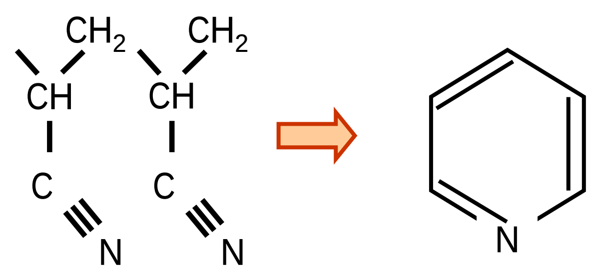
Oxidation Process

Stabilize open PAN fiber



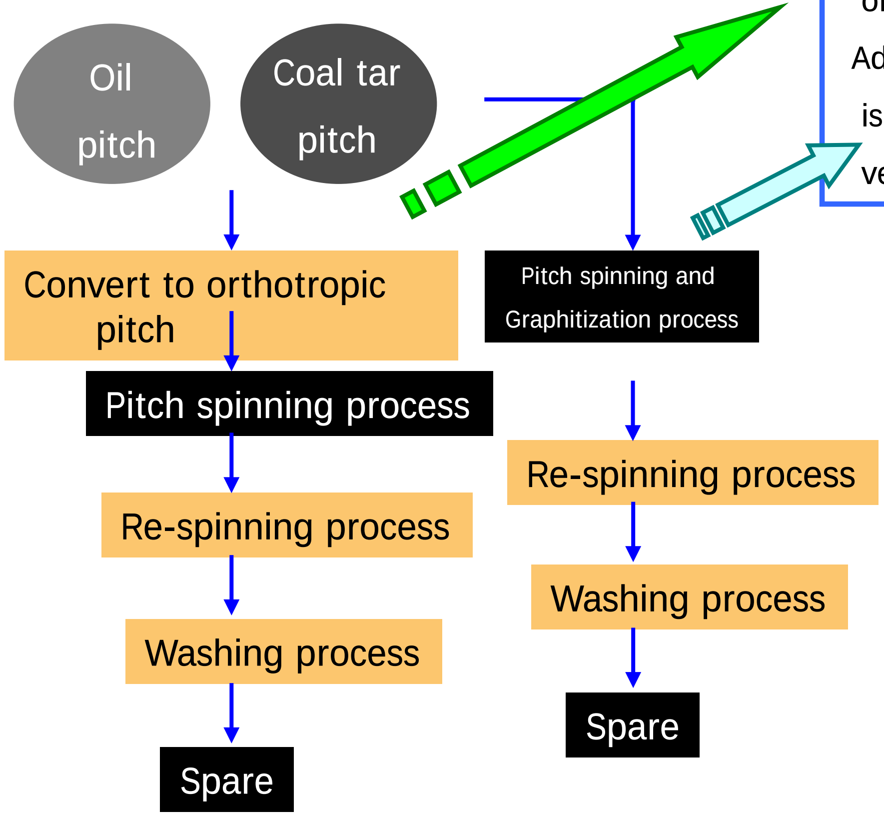
Carbonization Process

Non-oxidizing excess N, H of stable PAN fiber



Pitch carbon fiber

- Pitch-based carbon fiber prefabrication



Convert to Orthotropic Pitch

Fibers are long orthotropic in one direction

Therefore, the raw material is converted to orthotropic

Addition of graphitization process when using isotropic raw materials

very expensive process

Spinning process

Fine spinning of polymer raw material

Melt spinning

Re-spinning process

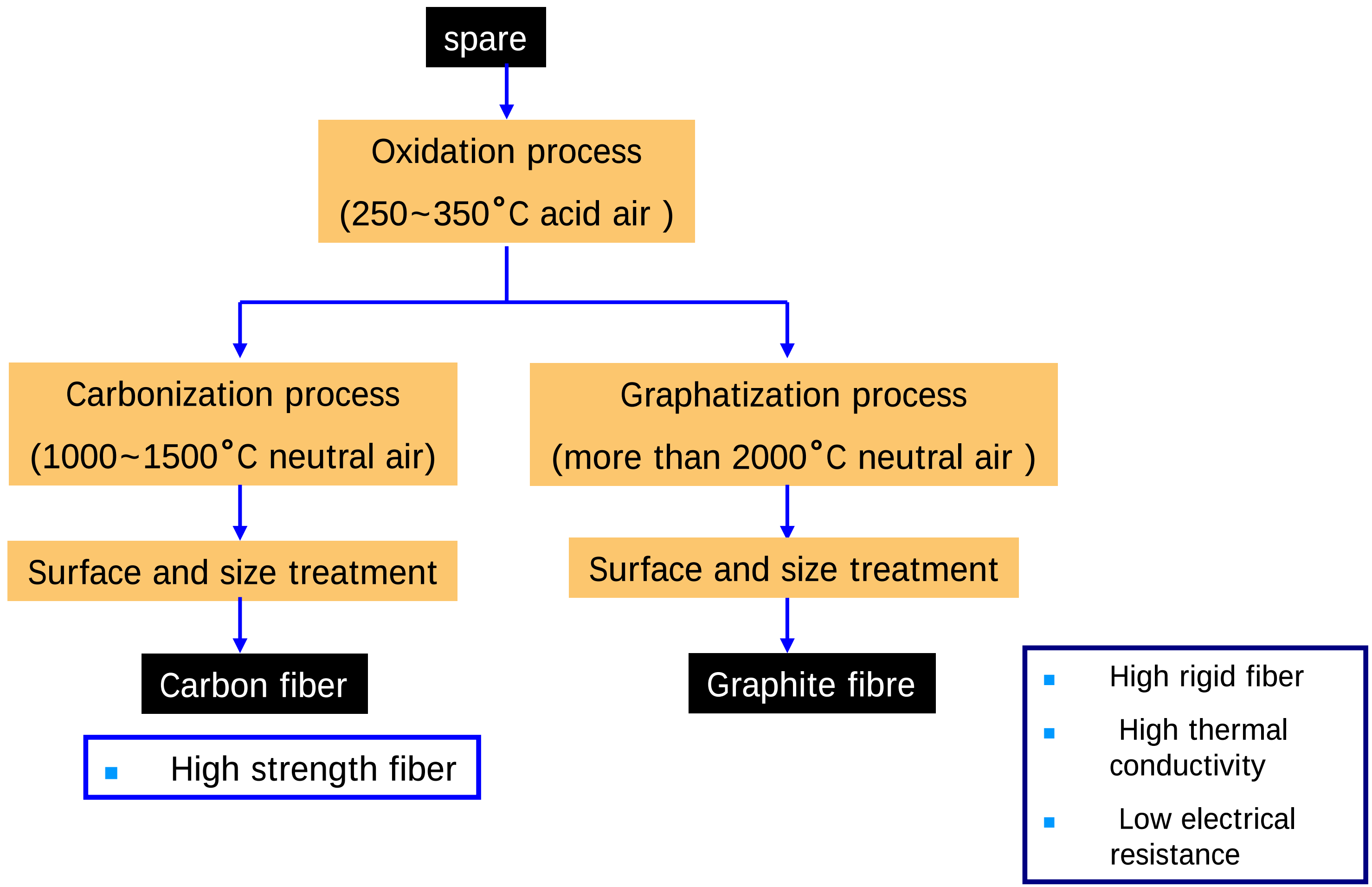
Re-Strecth what is emitted

Washing process

Wash the radiated material

Pitch carbon fiber

- Preparation of Carbon Fibers from Preliminaries



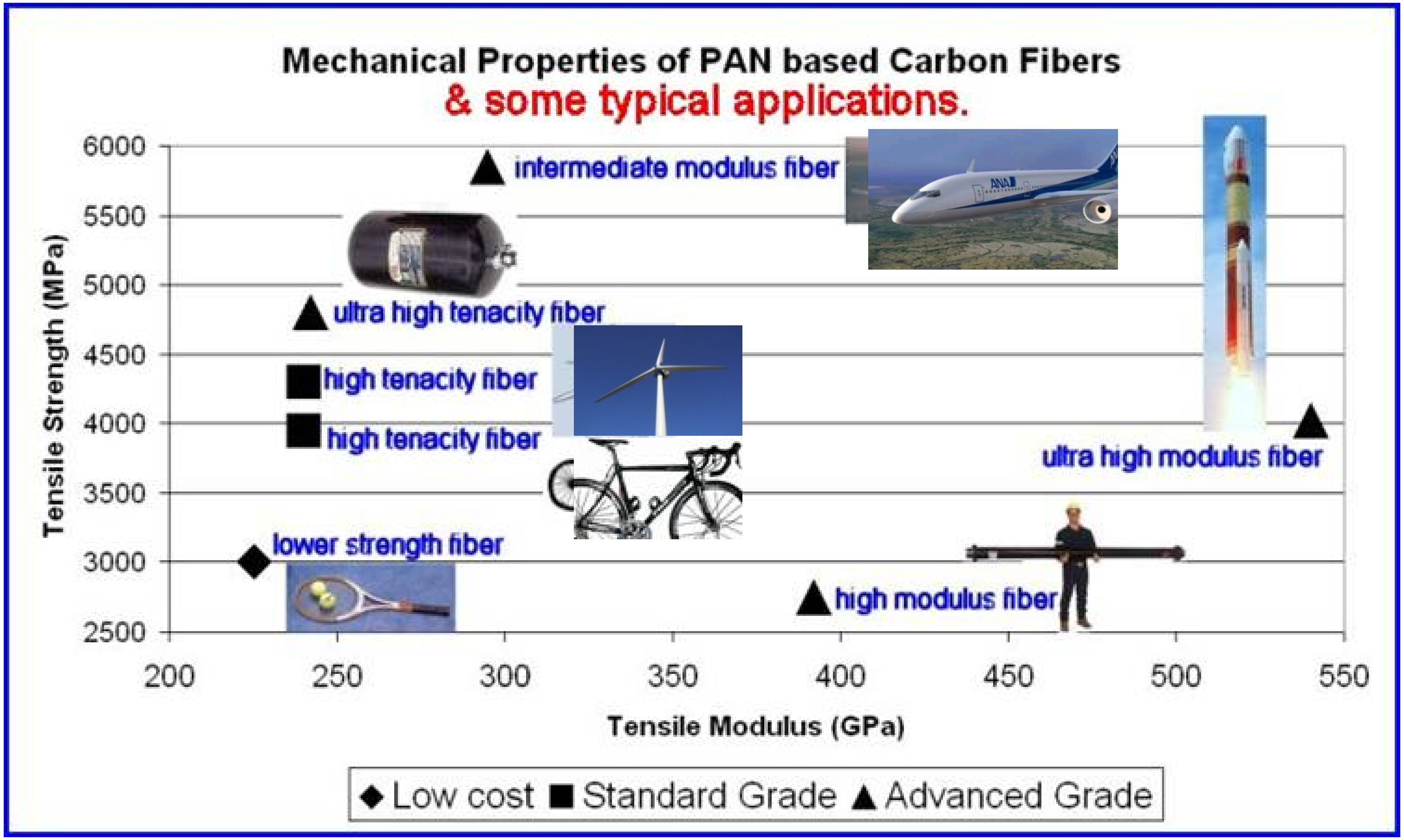
Classification of Carbon Fiber

- **Classification according to the performance of carbon fiber**

Kinds	burglar (MPa)	rigidity (GPa)	Nasal strength
GP (general purpose	Lower strength and rigidity than other types Higher limit tensile rate than other types		
HP (PAN based high performance)	Higher strength and rigidity than other types Lower limit tensile rate than other types PAN HP has better physical properties than Pitch HP		
HP (pitch sys high performance)			
HM high rigidity	Low	More than300	r < 0.01
IM (medium rigidity	Low	More thn100 less than 300	r > 0.01
LM (rigidity)	Low	100 or less	r << 0.01
HT high strength	More than 3000	Low	0.02 < r < 1.5

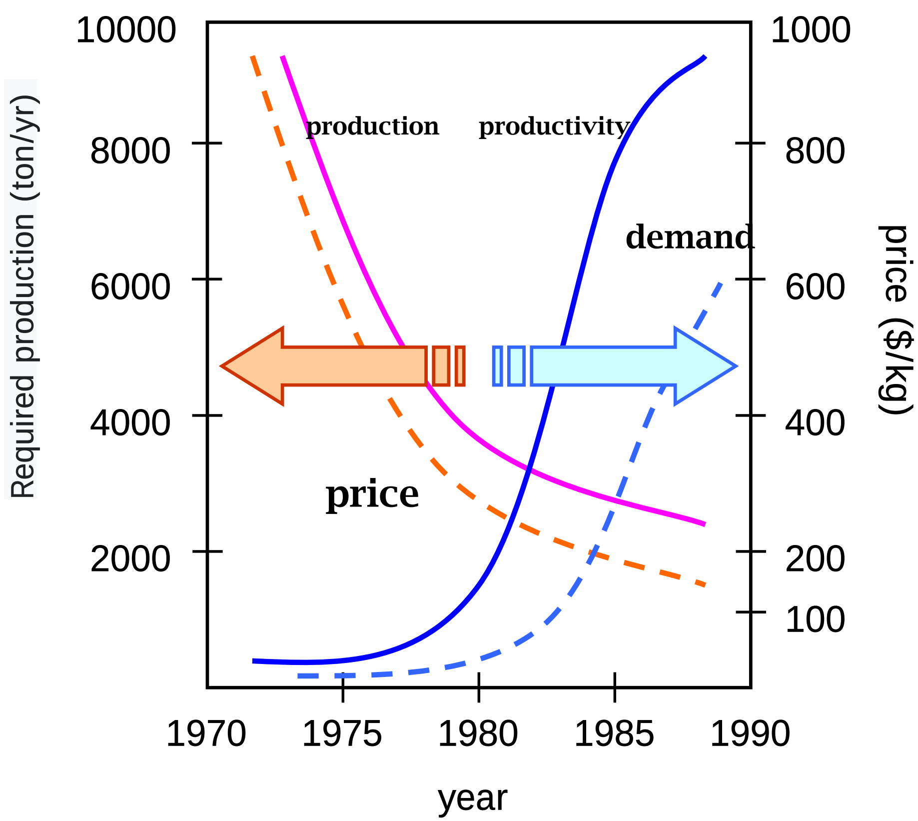
Classification of Carbon Fiber

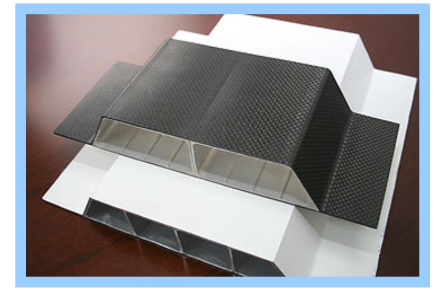
- **Classification by strength of carbon fiber (PAN base material)**



Trend of Carbon Fiber

- **Carbon fiber as advanced material**





빔 구조물

Increased productivity ≤ Materials and process development

Reduced production : Increased likelihood of mass production

Sales decline!

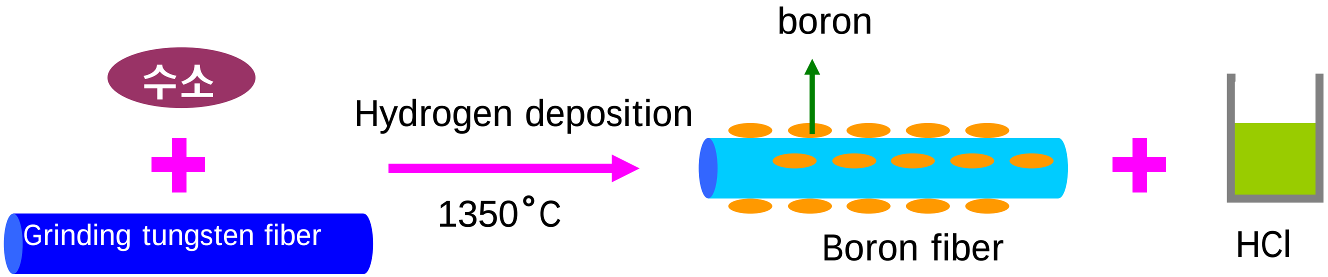
Increase in demand!

Boron fiber

- Boron fiber
- First developed in the United States in the 1960s
- Boron fibers range from 50 to 200 μm in diameter
  About 10 times the size of other regular fibers
- 3000 ~ 3500MPa Strength, 400GPa Stiffness
- Disadvantages of higher density than other fibers
- Widely used in the aerospace industry but limited by high prices

Boron fiber reinforced Shovel

- Boron Fiber Manufacturing
- Chemical vapor deposition



Silicon Carbide (SiC) Fiber

- Silicon carbide fiber
- Fine fiber: diameter of 10-15μm, rigidity of 180GPa
- Coarse fiber: 140μm diameter, 450GPa rigidity
- High oxidation resistance, high temperature property retention (1200 ~ 1400°C)

Used for high temperature metal and ceramic composite material

Manufactured by chemical vapor deposition

Recently developed, application areas are now starting

Commercially available silicon carbide long fibers

Silicon Carbide Whiskers

극 내열성 섬유

Diameter --- 8~20μm

- length --- 30μm

Extrusion, rolling, forging, etc.

Easy to apply to metal forming process

Aluminum Oxide (Al2O3) Fiber

- Aluminum oxide fiber Mainly used as reinforcement for metal composite materials
- Various properties are possible depending on Al2O3 / SiO2 composition ratio
- Available from 1400 to 1700°C
- Pure Al2O3 is very inert
- Stable up to 1200°C

manufacturer	Distribution name	shape	Composition ratio
Dupont	Fiber FP	C	100% Al_2O_3
	PRD-166	C	20% ZrO_2
3M	Nextel 312	DC	24% SiO_2, 14% B_2O_3
	Nextel 440	DC	28% SiO_2, 2% B_2O_3
Sohio	Fibermax	DC	50% SiO_2
ICI	Saffil	DC	4% SiO_2
Sumitomo	Sumika	C	15% SiO_2
Denka	Alcen	DC	20% SiO_2
Mitsui	-------	C	100% Al_2O_3

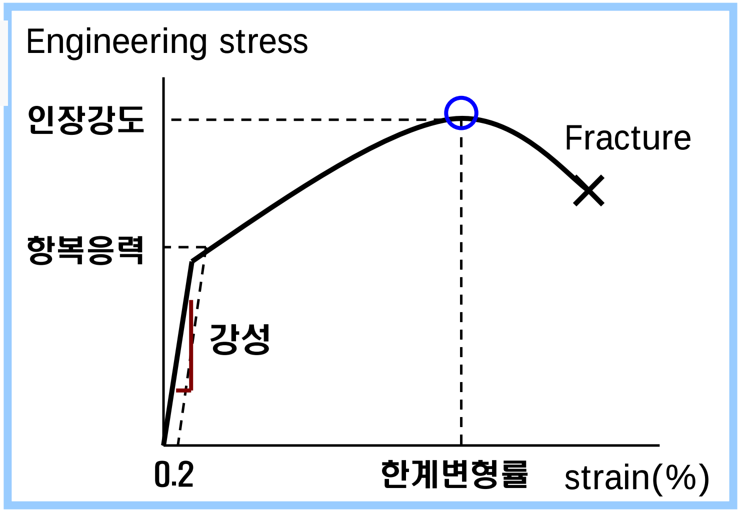
40% increase in strength

C : continuity

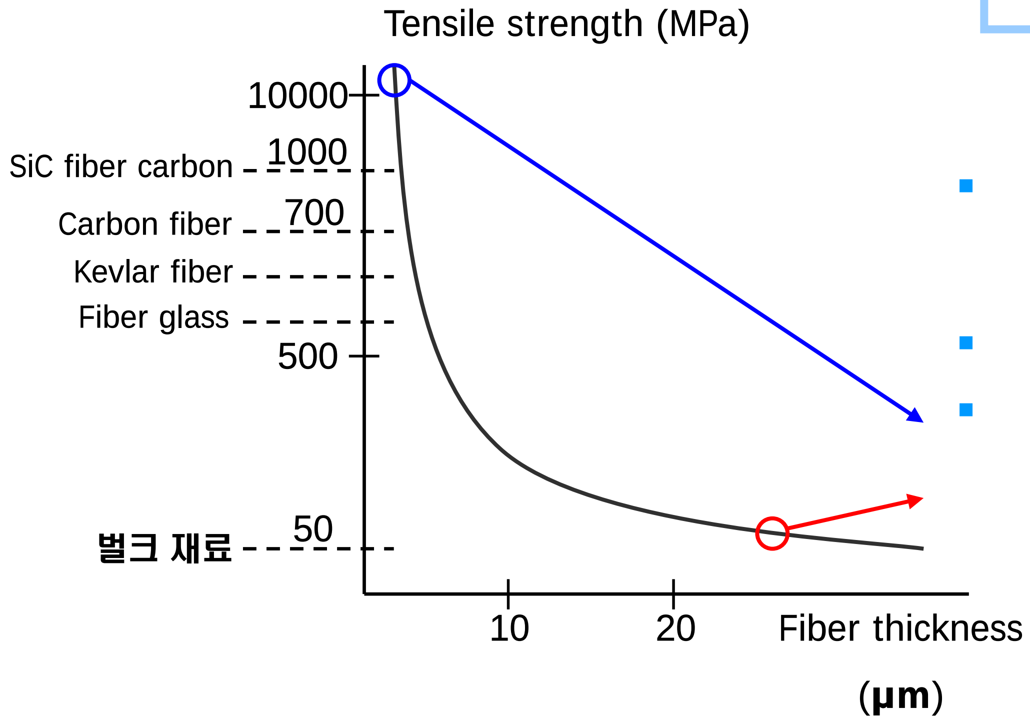
DC : discontinuity

General properties of fibers

- Fiber thickness and tensile strength
- Thinner thickness increases specific strength



Tensile test graph



- Increasing the thickness of the fibers causes cracks on the surface Tensile strength is reduced.
- Thin fiber atomic level strength
- Coarse fiber bulk material strength

Comparison of fibre properties

- Average Physical Properties of Fibers

Tensile strength / density

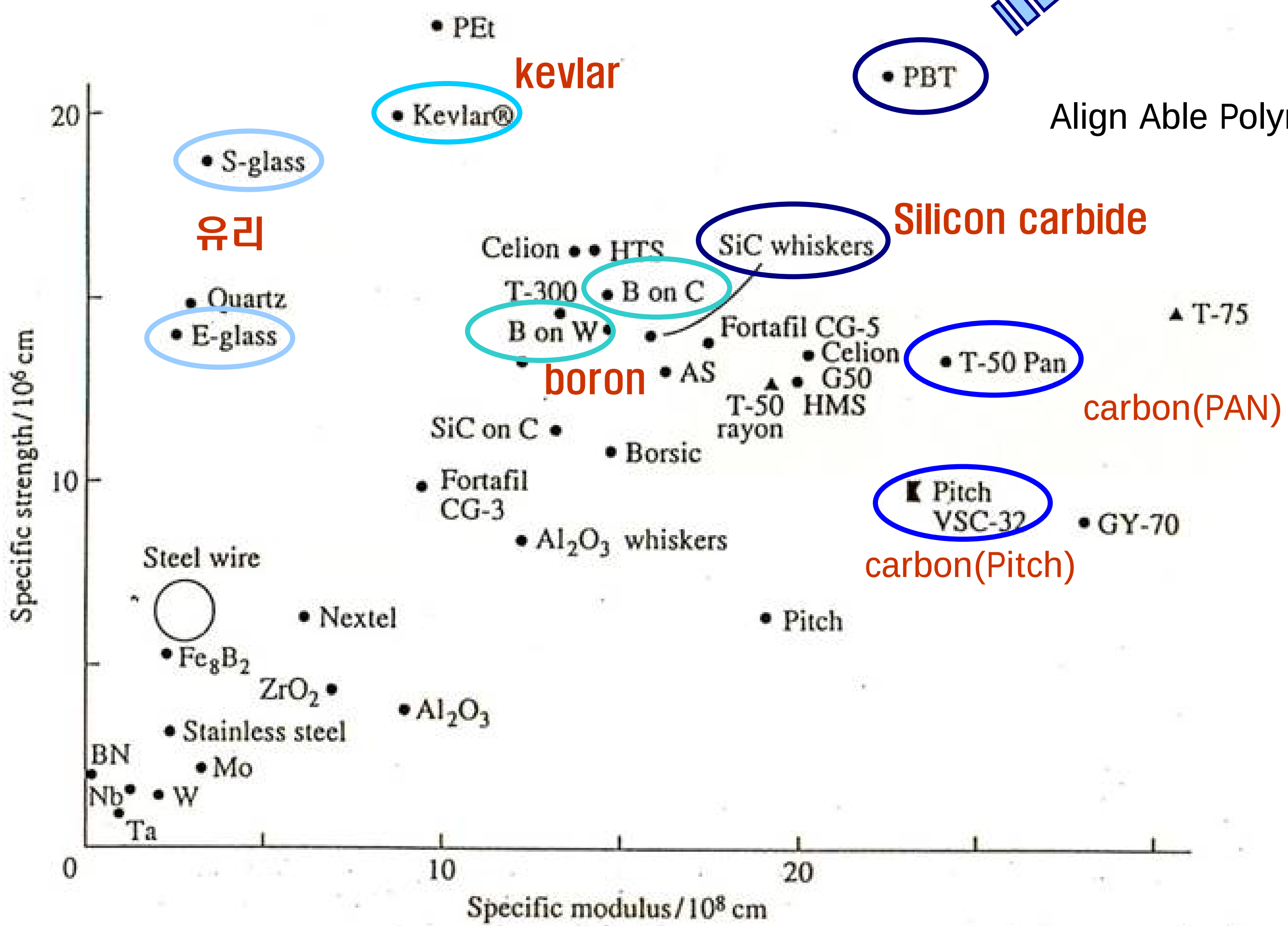
	종류	Tensile strength (MPa)	stiffness (GPa)	density (g/cm^3)	Nasal str ($x 10^6$)
Reinforcement fiber	Glass fiber	3450~4300	73~87	2.5	1.4~1.8
	Carbon fiber	1900~5600	230~760	1.8~2.1	1.1~1.3
	Kevlar fiber	3450~3620	130~180	1.46	2.3
	Boron fiber	3450	400	2.5	1.4
	Sic fiber	3440	400	3.3	1.1
	Al_2O_3 fiber	1400	380	3.95	0.4
metal	aluminum	260~410	69~73	2.71	0.1~0.15
	steel (normal)	450~830	207	7.87	0.06~0.1

- Carbon fiber properties vary, but production costs are high
- Fiber is lighter than metal and has excellent mechanical properties

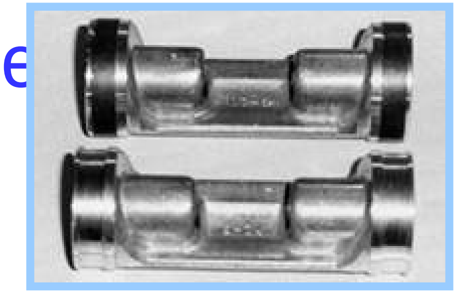
Change in fiber properties

- Increased mechanical properties
- Price reduction

Align Able Polymer Fiber



Formability of matrix and reinforceme

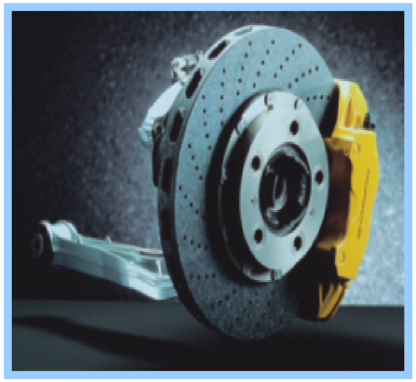


Ac Compressor

- Criteria for selecting base materials and reinforcement materials
  High formability
  Possibility of satisfying customer's required property

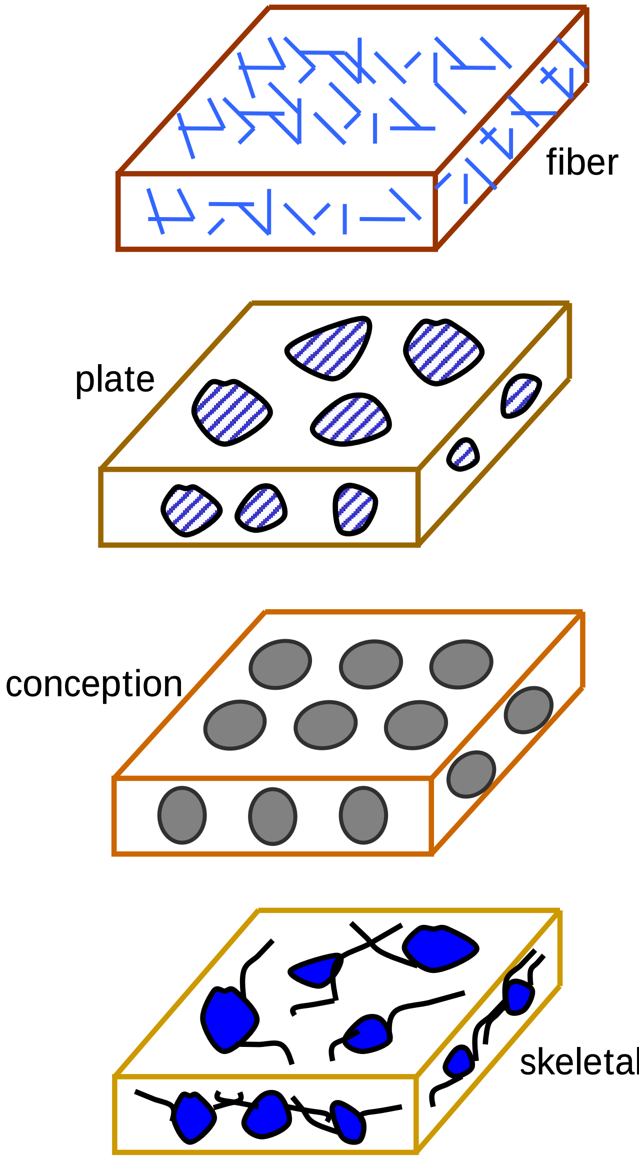
Reinforcement / Base		glass	carbon	Kevlar	Yuri Kevlar	boron	Silicon carbide	alumina
Plastic (polymer)	Unsaturated polymer	prize	하	하	하			
	Epoxy	중	prize	중	중	중	하	하
	Polyamide		중			하		
	Thermoplastic Resin	중	하	하				
Metal	Aluminum		중			중	중	중
	Titanium					중	중	
	Magnesium					하	하	하

Classification and Properties of Composites

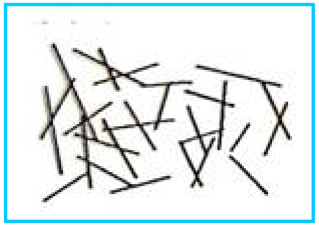


Class 1: Particle form of reinforcement

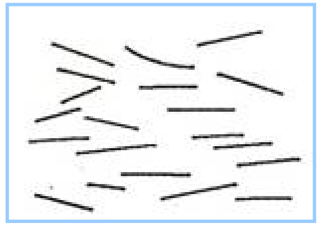
- Fiber Reinforcement Strengthen with long or short fibers
- Flake Enhancement Reinforced flat reinforcement material in composite base
- Particulate Enhancement Enhance the mechanical and chemical properties by adding spherical fine particles
- Skeletal Enhancement Reinforcement with continuous skeletal reinforcement fiber



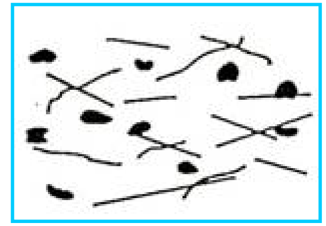
Category 2: Reinforcement type of reinforcement



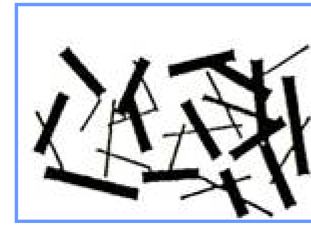
Random short fiber



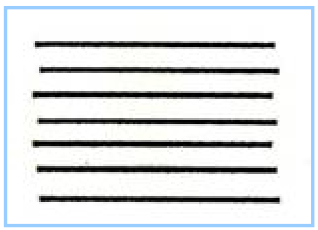
Aligned short fiber



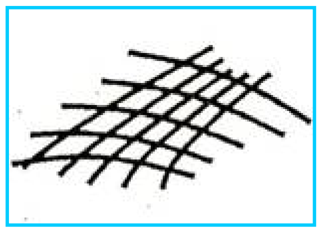
Fiber/particle hybrid



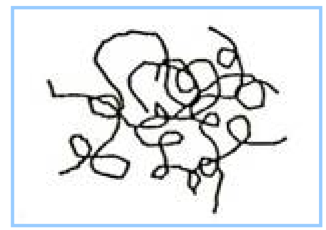
Short fiber hybrid



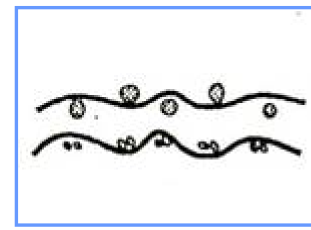
Unidirectional continuous fiber



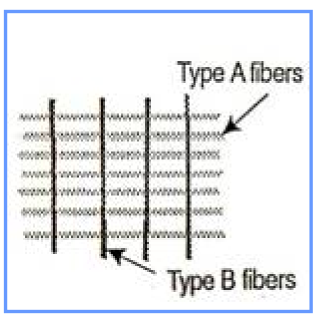
Filament winding



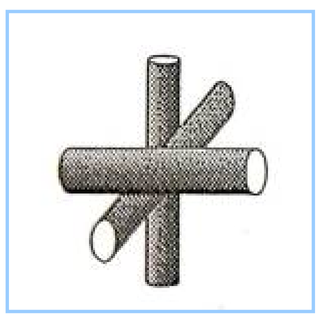
Long/interpenetrating



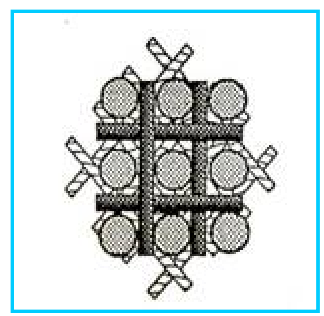
Woven fabric



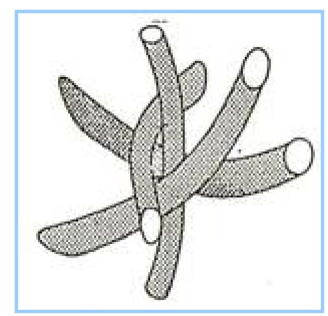
Continuous/hybrid



Orthogonal 3-D



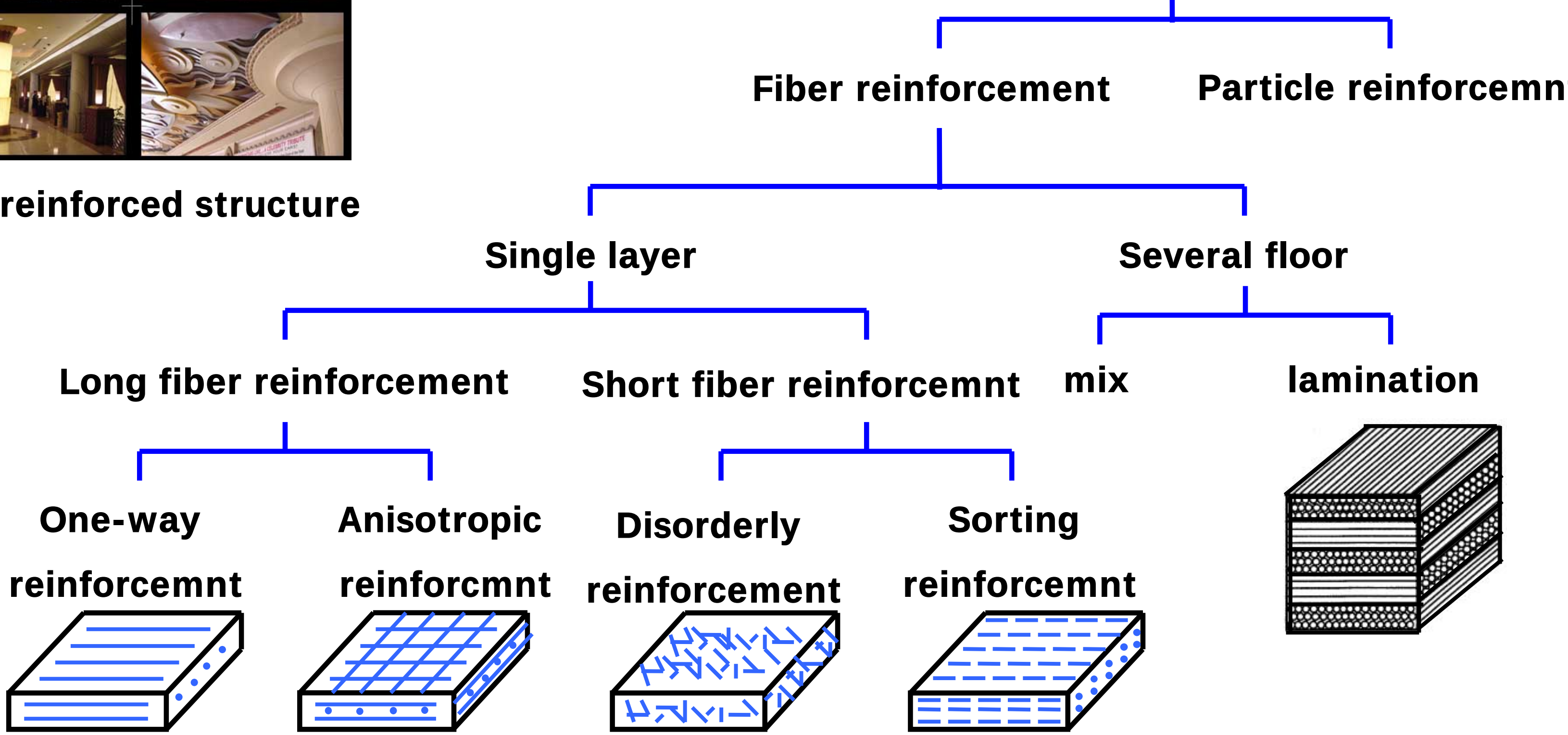
3-D Weave



3-D Braid

Category 1 & 2: Synthesis of Two Classes

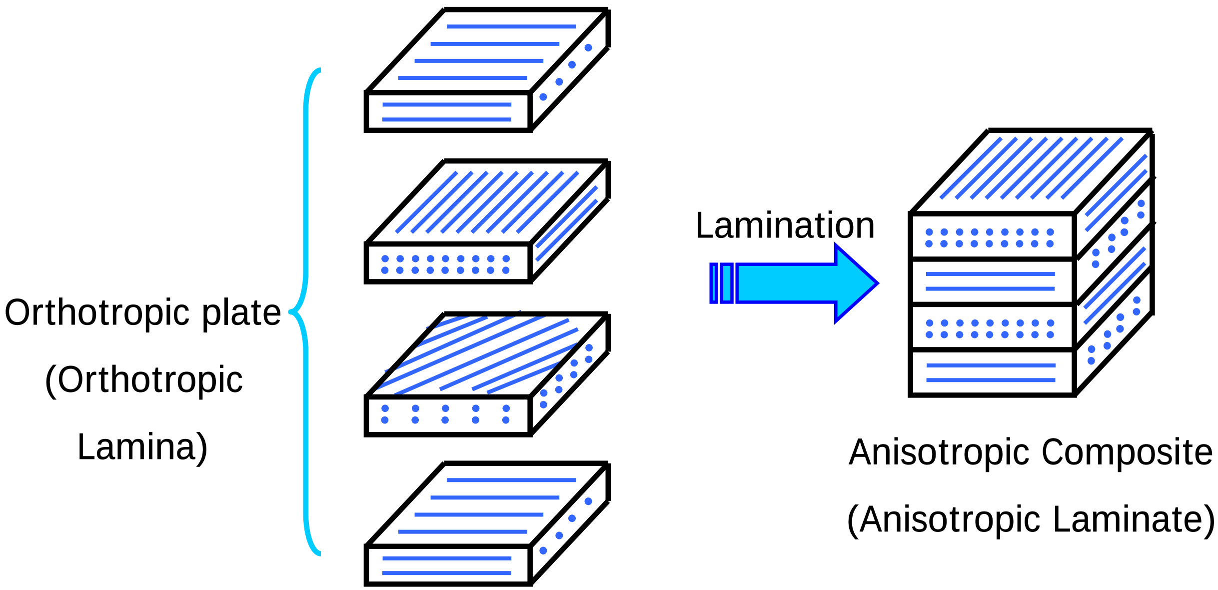
Fiber reinforced structure



Category 1 & 2: Laminated Composites

Plywood

- Laminate Composite
- Composite material made of several stacked sheets of fiber reinforced
- Each plate has different properties depending on the type and direction of the fiber

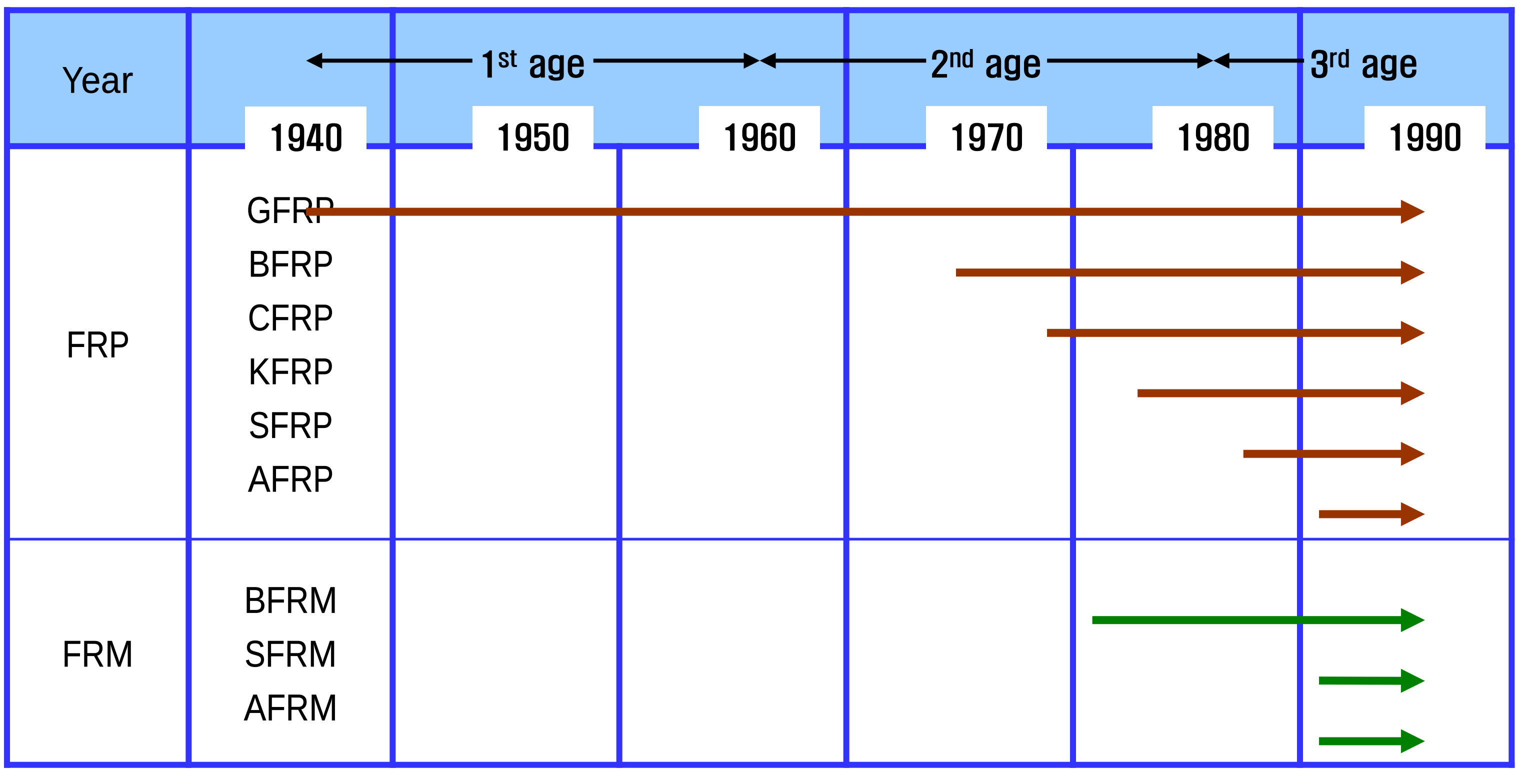


Coupling Effect

On each floor Because the angle is different, Composite warping

Category 3: Bases and Reinforcements

- Fiber : G (glass), B (boron), C (carbon), K (Kevlar), Sic (silicon carbide), A (aluminum)
- Base
  - Plastic (P) : Epoxy, Polyester, Phenolic, Polyamide
  - Metal (M) : Aluminum, Magnesium, Copper, Titanium



Fiber reinforced plastic

- GFRP (glass fiber reinforced plastic)
- Glass fiber reinforced plastic Steadily used since it first appeared as a reinforcement for composite materials
- Economically most advantageous lightweight, high strength structural material
- Why glass fiber was first used in composites

Vegetable fiber

- Stronger than wool, cotton and nylon
- Tension degree is suitable as reinforcement

- Unsaturated polyester resin is used for the first time

- Molding at room temperature and pressure
- Good wettability increases the effectiveness of fiber

Animal fiber (wool)

Fiber reinforced plastic

- CFRP (**탄소섬유강화 플라스틱**)
  - Carbon fiber reinforced plastic
  - Beginning of Advanced Composites
  - Lightweight, high strength, high rigidity materials Essential for aerospace
  - Carbon fiber of various physical properties is present.

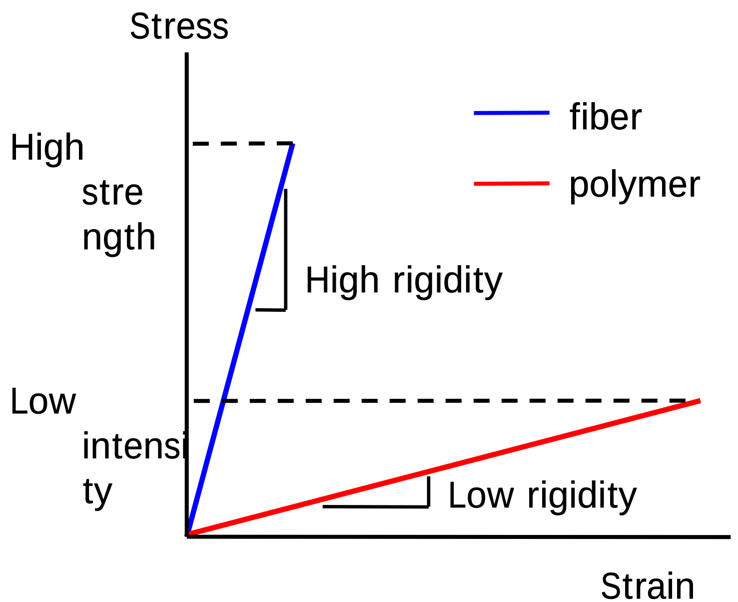
CRTP **응용 삼각대**

- FRTP (**섬유강화 열가소성 복합재료**)
  - Fiber Reinforced Thermoplastic
  - Unlike general composite materials, thermoplastic resin is used as base material
  - Excellent flow during molding, easy to handle and high productivity
  - Can only be used at relatively low temperatures

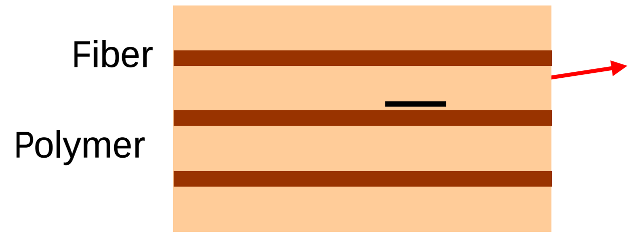
FRTP Application Cover

Polymer composites

- PMCs (Polymer matrix composites)
  - Include all FRPs described previously
  - Most applied composite materials
  - Large and complex shapes can also be manufactured
- Reinforcement --- High specific strength and specific rigidity
- Polymer --- Corrosion and Water Penetration Prevention
- PMCs --- Light and Strong Materials



Large difference in flexibility, high probability of cracking

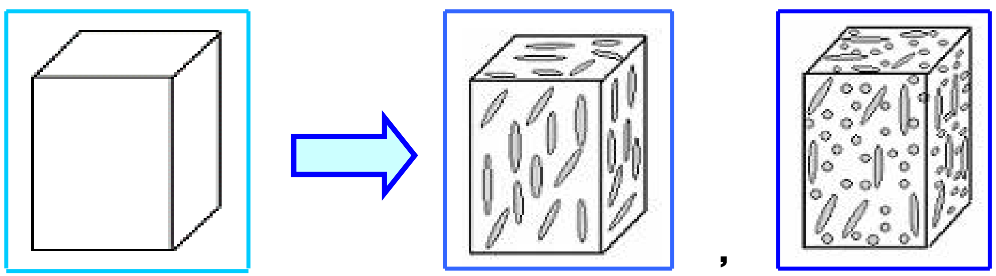


At the interface between fiber and polymer Cracks due to flexibility differences

Metal composites

- MMCs (Metal matrix composites)
  - MMCs (Metal matrix composites) Not as well as PMCs, but increasingly in scope
  - The price is high but it is getting lower due to the development of manufacturing technology.
  - Fiber reinforced, particle reinforced, fiber / particle mixed reinforced

- Reinforcement --- High specific strength and specific rigidity
- MMCs --- Heat resistant, wear resistant, light



[Matrix] [F MMC] , [F/P MMC]

The areas of heavy wear Manufactured by MMC

Connection rod

Metal composites

- Types of Fiber Used in MMCs

Metal matrix	Fiber Form	종류
aluminum	Long fiber	Boron(B), SiC, Alumina, Graphite
	Short fiber	Alumina, Al-SiC
	whiskers	SiC
	particle	Sic, BC
magnesium	Long fiber	Alumina, Graphite
	whiskers	SiC
	particle	Sic, BC
titanium	Long fiber	SiC, Coated Boron
	particle	TiC
copper	Long fiber	SiC, Coated Boron
	wire	NbTi
	particle	SiC, BC, TiC

Metal composites

- Advantages of MMCs
- Compared with ordinary metal
- High specific strength
- High specific rigidity
- High fatigue resistance
- High temperature properties
- High wear resistance
- Low thermal expansion rate

- Compare with PMCs
- High temperature properties
- Strong against fire
- High shear strength
- High shear stiffness
- Very low hygroscopicity
- High electrical conductivity
- High thermal conductivity
- Whiskers and Particle Enhancements

Disadvantages of MMCs high material prices Manufacturing technology limitations Difficulties in mass production

⇒

The development of manufacturing technology is a big challenge!!

Ceramic composite

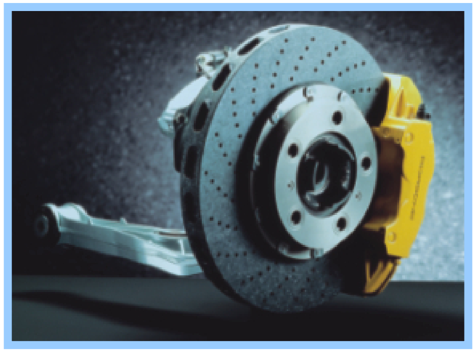
- CMCs (Ceramic matrix composites)
- Necessity in space industry with very high temperature
- Progress in research to obtain fiber resistant at high temperature
  - Reinforcement --- High specific strength and specific rigidity

    Lack of fiber that resists oxidation and maintains physical properties
  - Ceramic --- Very resistant to heat

    Very brittle and fragile

    Strong creep resistance

    Toughness is very high
  - The ceramic itself cannot be used for structural purposes
  - Ceramic Fiber Reinforced
  - CMCs Available ☐ Damage tolerant material design



car brake

- CMCs can be used up to 1650°C
- To maintain physical properties at temperatures above

  Need Textile Development

  Currently using coating method
- Carbon fiber is highly applicable

Carbon-carbon composites

- CCCs (Carbon-carbon composite
- Manufactured by liquid infiltration or chemical vapor deposition
- Difficult manufacturing process and weak oxidation ➔ Complemented with a coating

- Maintains high properties at very high temperatures (3300°C) and above 강도
- Strength increases up to 2050°C
- 물 Physical property falls slightly after 2200°C
- Very high wear resistance, abrasion resistance
- Very low creep progress
- Strong against thermal shock ☐ No crack or disturbance
- Very light ☐ about half the density of CMCs

Application field

Non-structural

Aircraft brake
nozzle

structure

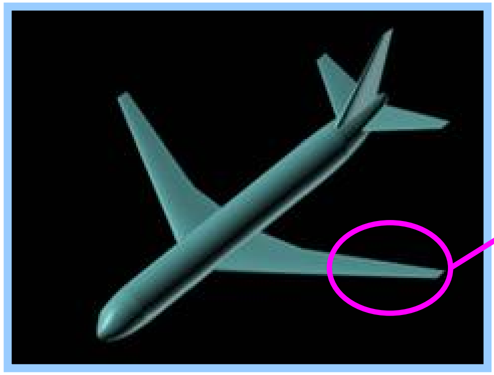
Engine part
Missile part
satellite

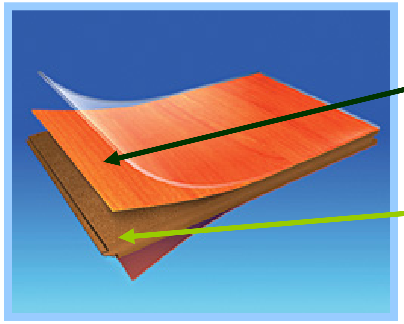
Because of high requirement
Need more research

As the most advanced composite material, it is used for ultra high temperature and ultra high speed applications.

Mixed composite material

- Hybrid composite
- Composite material with two or more reinforcing materials mixed in one base material
- Mixed Laminated Composite Examples





Kevlar/epoxy

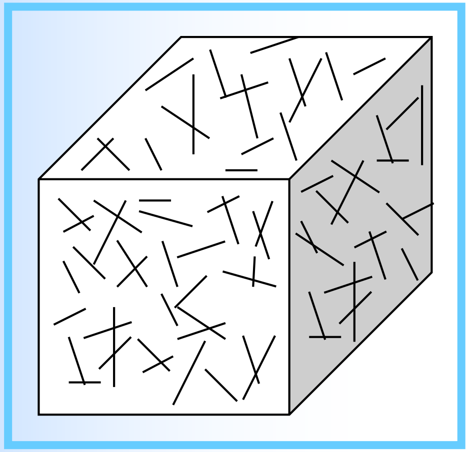
Aluminum alloy

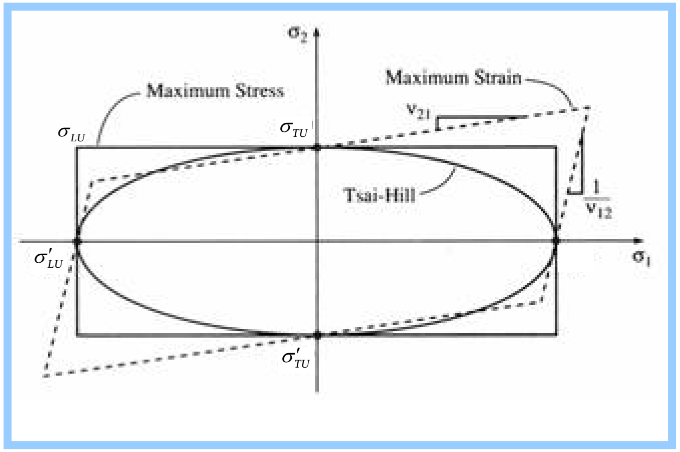
Used as a subsonic aircraft wing material

Multiple mixed composite material

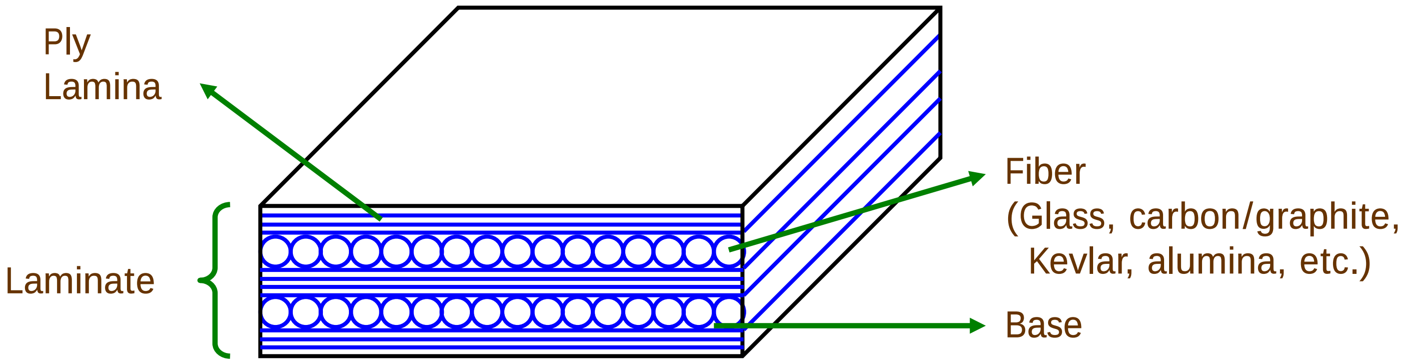
- Selective reinforcement
- Intelligent surface and structure
- Heat treatment material
- Ultra light material

Basic dynamics of composite materials

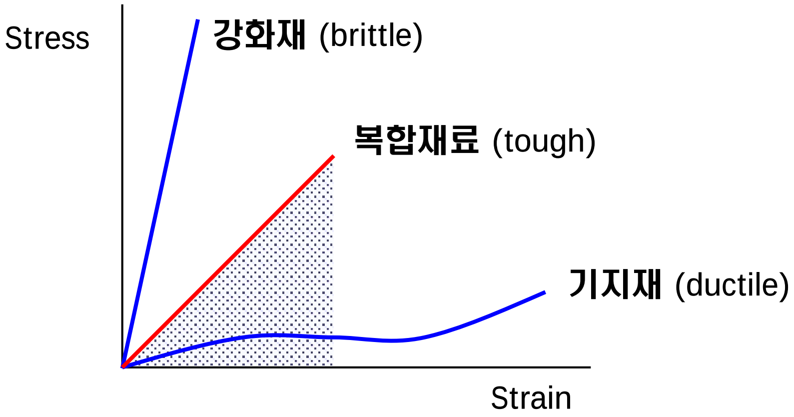




one-way composite



- Behavior of unidirectional composite materials



- Excellent specific strength and non-stiffness
- Toughness increase

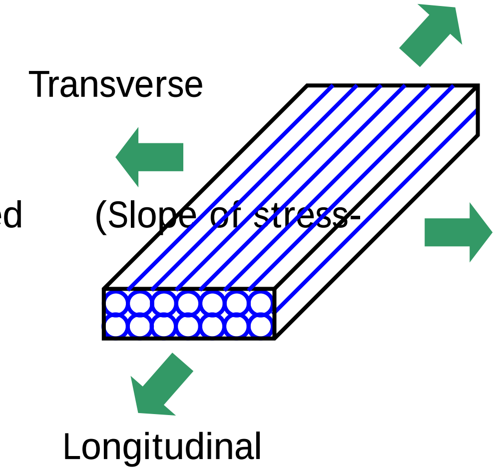
  Toughness :Area under the graph

  Necessary for the material to be destroyed

  Energy

Stiffness prediction

- What is stiffen
- The degree to which a material resists its deformation when deformed (Slope of stress-strain curve)
- **길이 방향 강성** (Longitudinal stiffness)



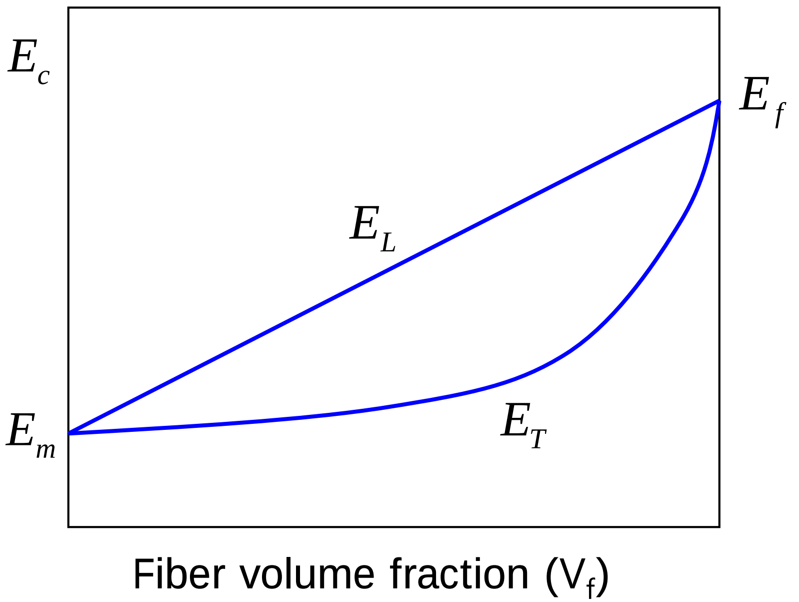
$$\varepsilon_f = \varepsilon_m = \varepsilon_c$$

$$E_c = E_f V_f + E_m V_m$$

- **횡 방향 강성** (Transverse stiffness)

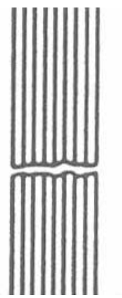
$$\rightarrow \sigma_f = \sigma_m = \sigma_c$$

$$\frac{1}{E_c} = \frac{V_f}{E_f} + \frac{V_m}{E_m}$$

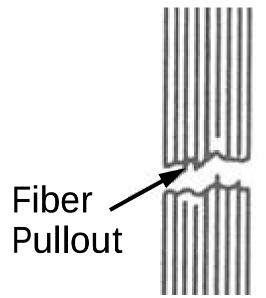


Destruction mode

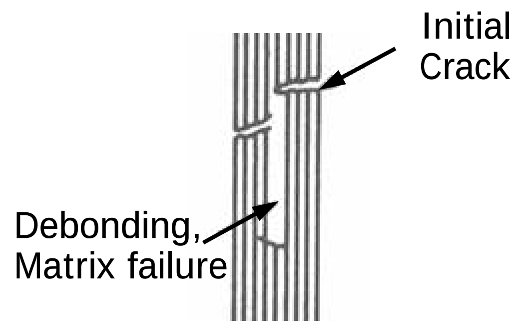
Fracture by longitudinal tensile load



1. Brittle

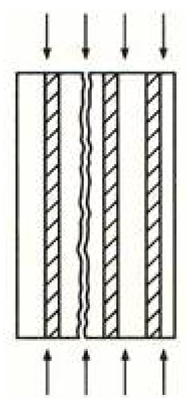


2. Brittle and fiber pull out

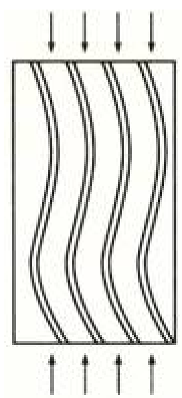


3. Fiber pull out and debonding

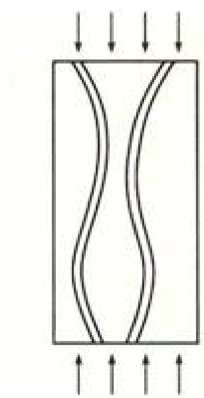
Failure due to longitudinal compressive load



1. Transverse tensile mode

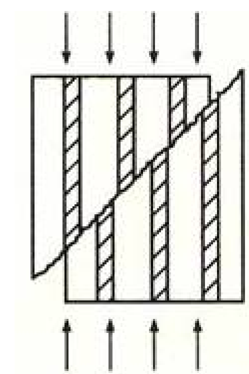


Extension mode



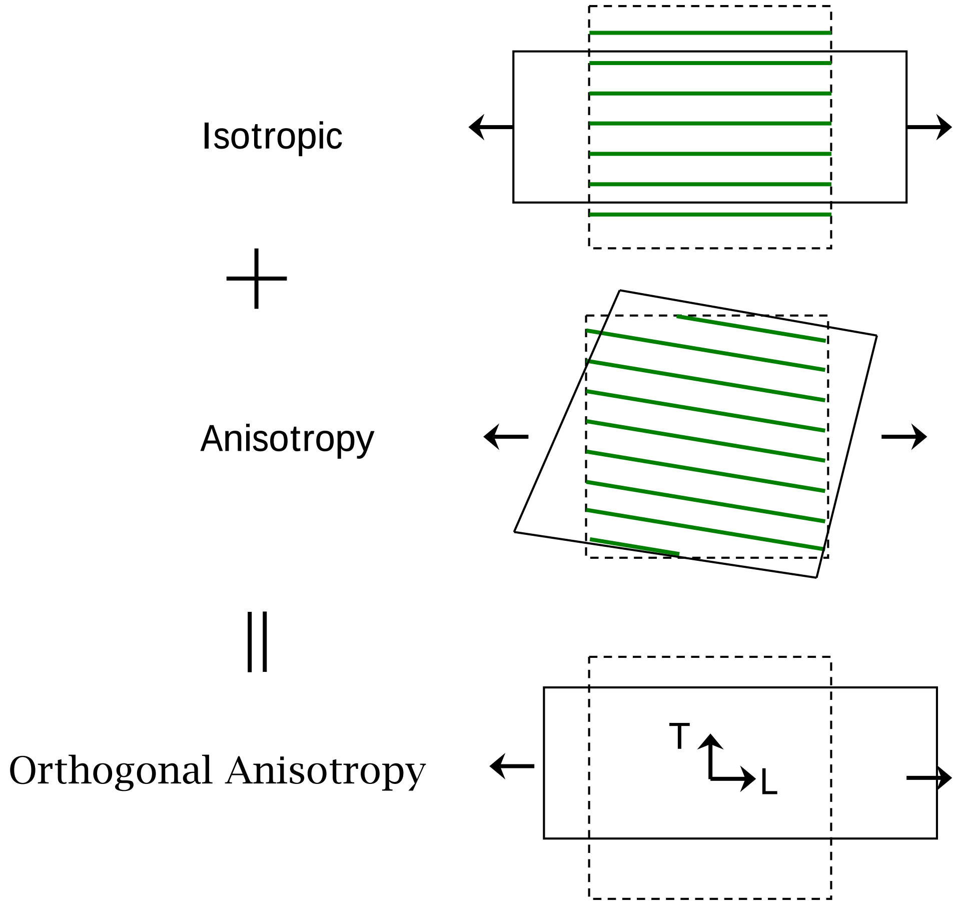
Shear mode

2. Fiber micro buckling



3. Shear failure

Orthotropic Lamina

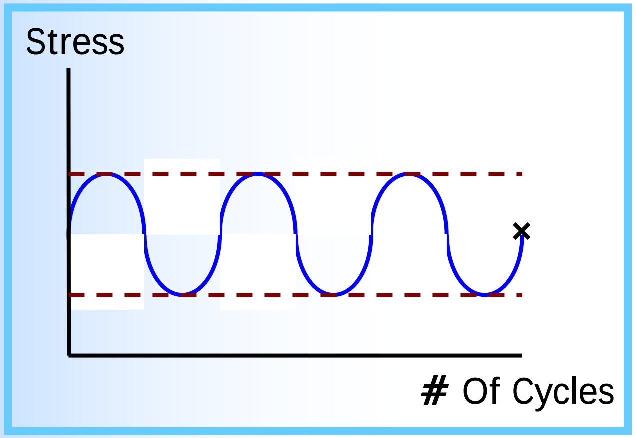


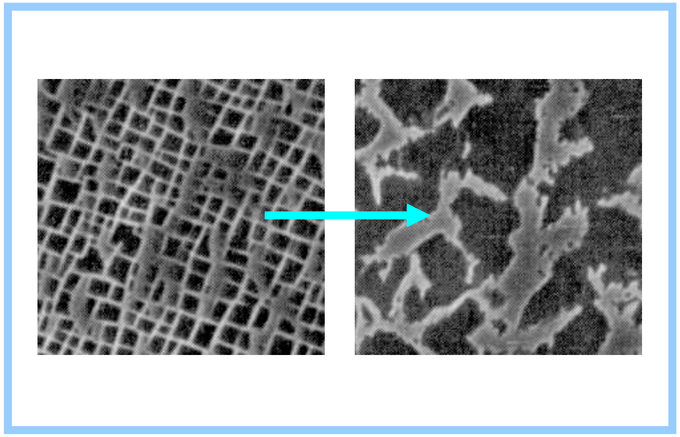
Orthotropic Laminate:

Fiber Arrangement Direction --- Isotropic

Other directions --- Anisotropy

Mechanical properties of composite materials

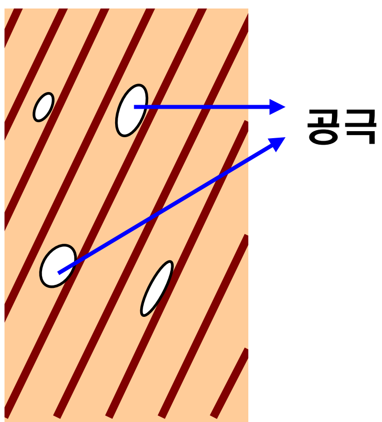




Effect Of Void

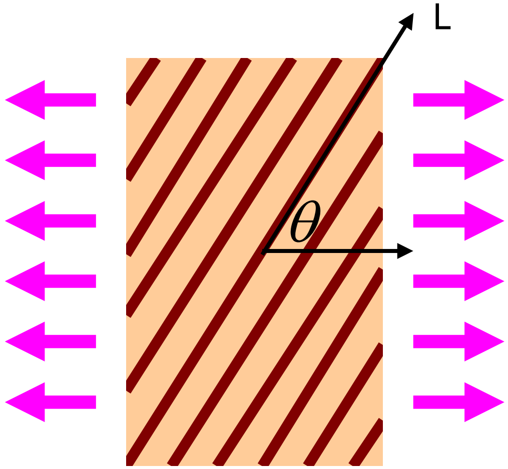
- Air gap
- Composite material is formed by mixing two materials
- Possibility to trap voids inside during molding

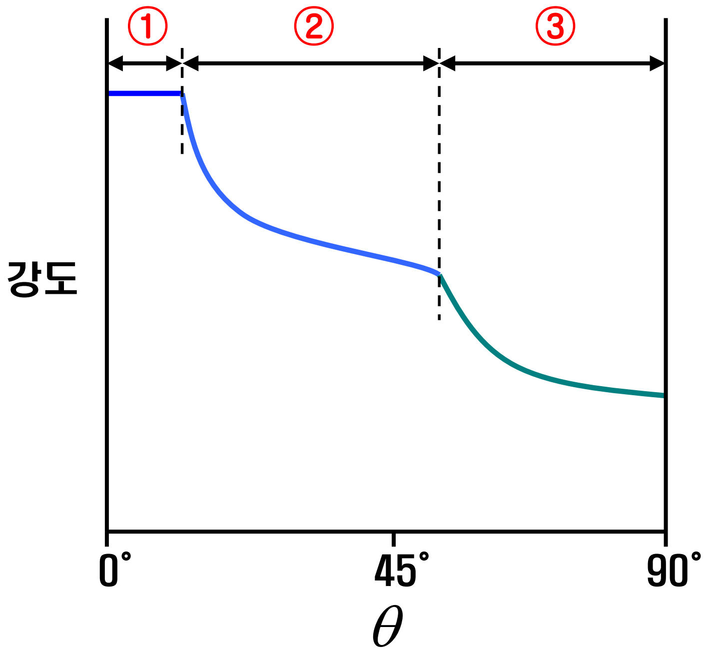
초 정밀 저울로 밀도 측정



- Calculate porosity by difference between measured density and theoretical density
- Concentration of stress in the air gap} Reduction of fatigue resistance
- Easy penetration of moisture into pores □ Poor physical properties due to moisture
- Color change by sunlight
- Dispersion of strength and stiffness data 어려움 Difficult to accurately measure physical properties

Properties according to fiber direction





① : The direction of the fiber and the direction of the load are almost identical. The fiber is subjected to tensile stress. Maintains physical properties.

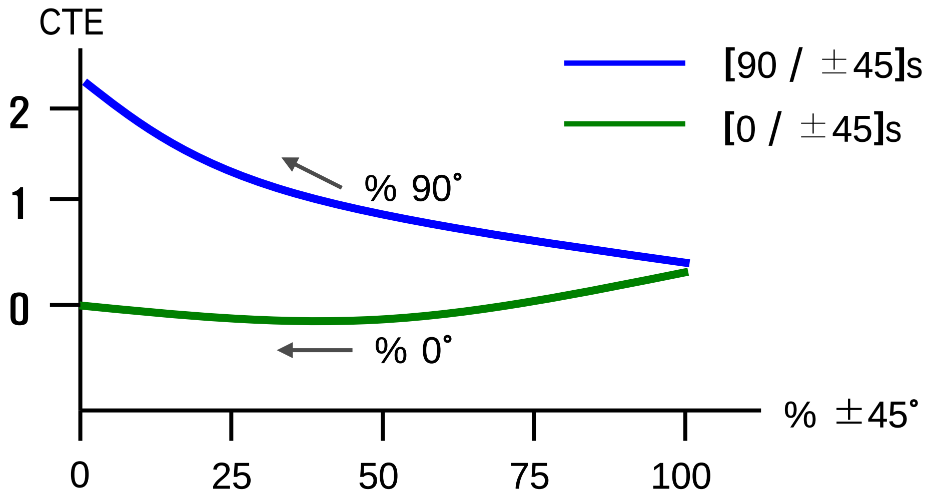
② : Inconsistency between fiber direction and load direction ☐ Base material is subjected to shear stress 저하 Poor physical properties.

③ : The direction of the fiber and the direction of the load are almost perpendicular ☐ The base material is subjected to tensile stress 저하 Poor physical properties.

Designing the properties of composite materials by stacking plates reinforced at various angles

Coefficient of thermal expansion

- CTE (Coefficient of thermal expansion)
- Polymers have a larger CTE than metals, but are smaller due to fiber reinforcemen
- CTE can be adjusted according to fiber properties, reinforcement angle, and lamination method

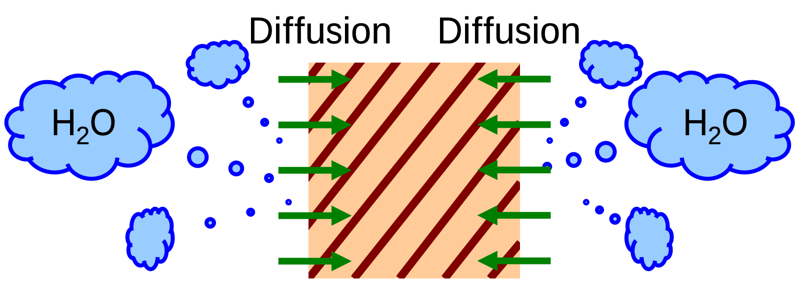


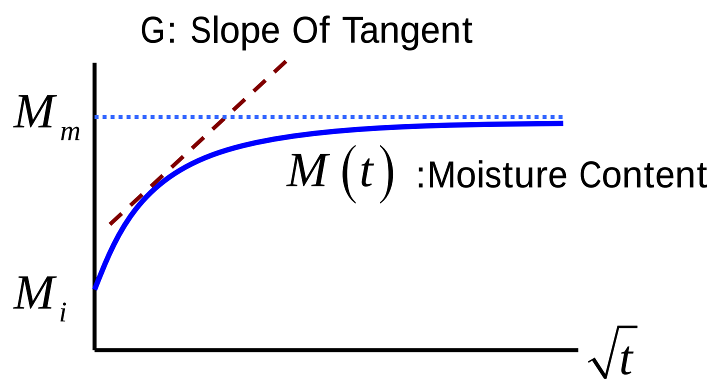
- 0° Ply - CTE is affected by fiber Almost zero
- 90° Ply - CTE Is affected by base material Have a high value

- For [0 / ± 45] s, the higher the ratio of 45°, the higher the CTE.
- For [90 / ± 45] s, the higher the ratio of 45°, the lower the CTE.

Influence of moisture

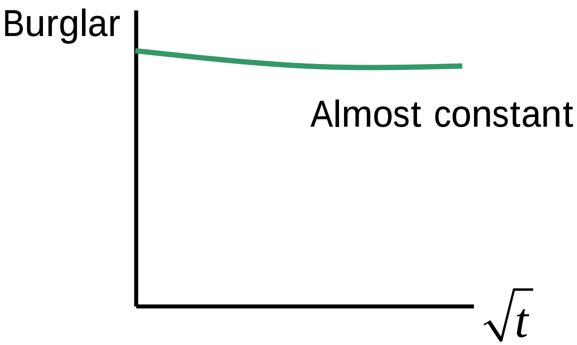
- Hygroscopicity of base materials
  When plastic is exposed to moisture, it absorbs moisture by diffusion
  Initially, the moisture content increases, then gradually becomes constant.



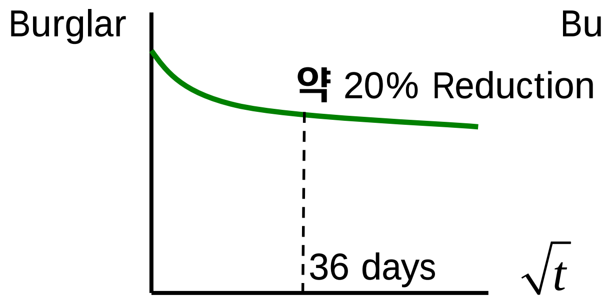


- **확산도** (D : Diffusivity)
  - Rate of increase in moisture content (G is determined by diffusion and temperature)
  - Low diffusion can be induced by controlling the order and angle of lamination
  - Initially, it has a positive slope, then gradually converges to zero (similar to G)
  - Diffusion increases with increasing temperature

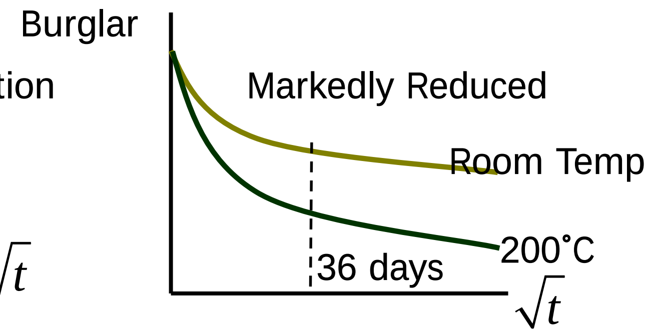
- Poor physical properties of composite materials
- Weight gain
- Deterioration of the physical properties of the base material and deterioration of interfacial adhesion
- There is no oxidation by moisture like metal



[0˚ Ply at −40~150˚C]

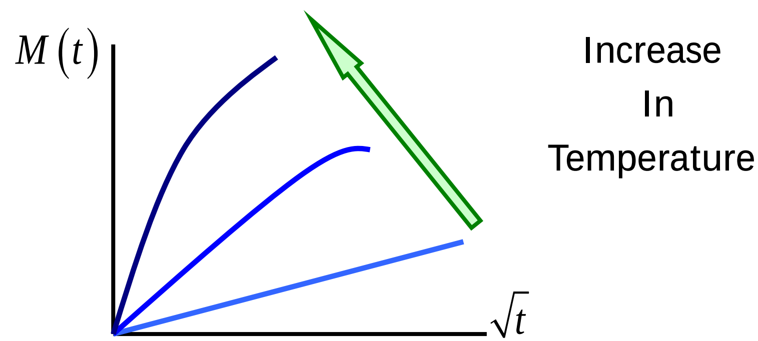


[0˚ Ply at 230˚C]



[90˚ Ply at −40~230˚C]

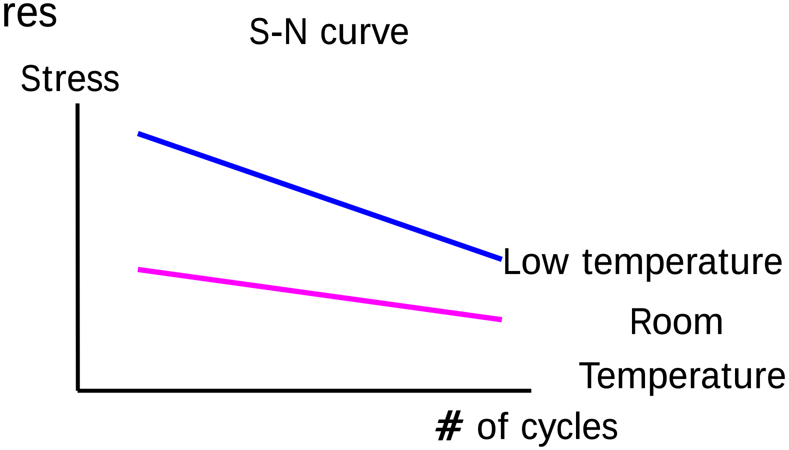
- Influence of temperature
- As the temperature increases, water absorption becomes faster.



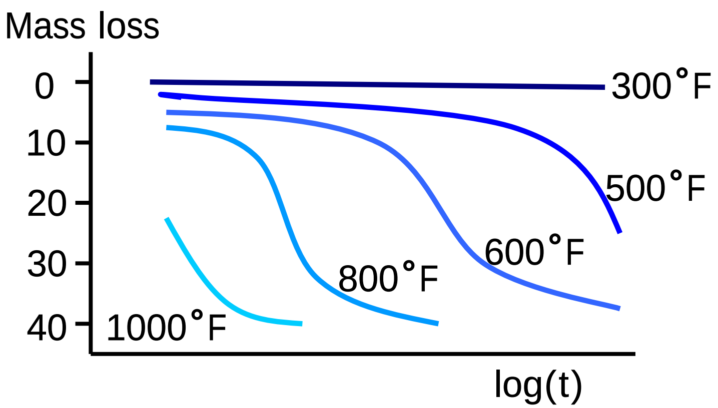
Influence of temperature

- Low temperature properties
- In general, excellent properties at low temperatures

properties	Feature composite to room temp
Nasal strength	About 2 time increases
Non-rigid	10~20% increases
destruction Toughness	40% increases
Destruction Strain	Slightly increases

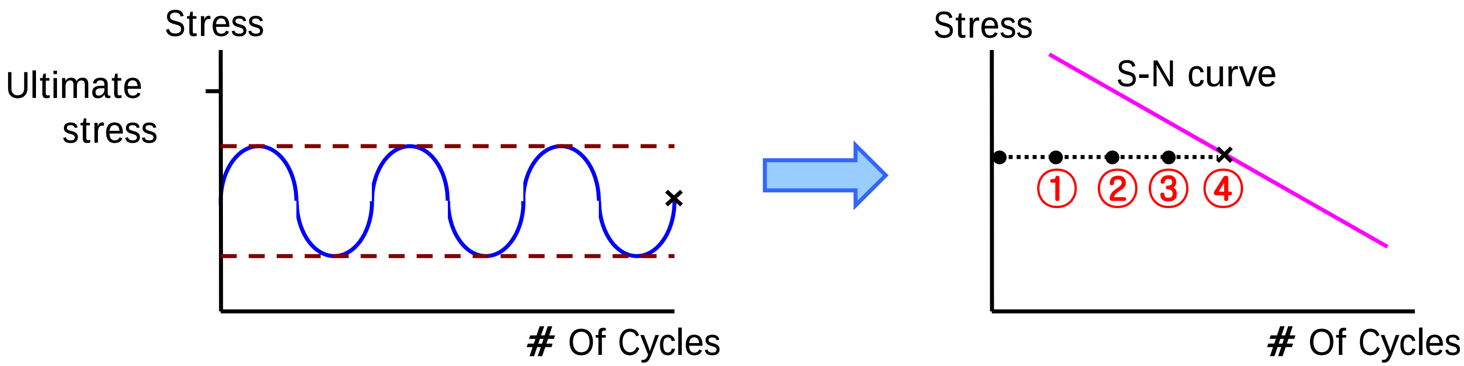


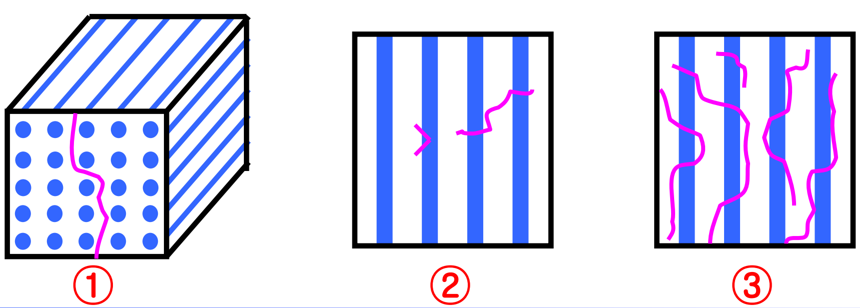
- High temperature characteristics
- Polymer matrix is thermally unstable at high temperatures
- Decomposition of base materials
- Reduction of specific strength and specific rigidity



Fatigue properties

- Fatigue destruction
- When repeated loads are applied to the material, destruction occurs even without reaching the ultimate stress.
- The composite material is discontinuous due to the interface between the crack propagation base material and the reinforcement material.
- 4 ~ 8 times better in fatigue properties than ordinary metal

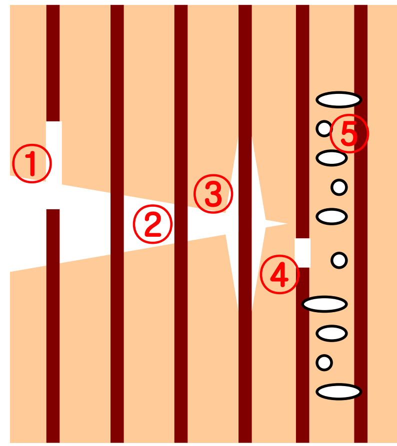




①: Base material deformation and cracking
②: Reinforcing material deformation and crackin
③: Interface Delamination
④: Composite material destruction

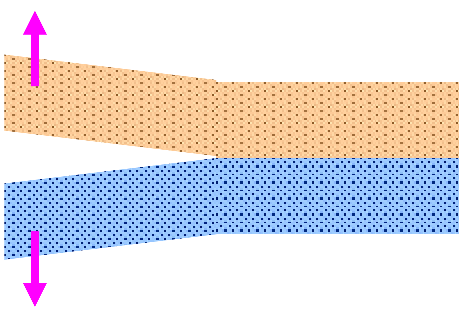
- Fine damage form

Crack of base material

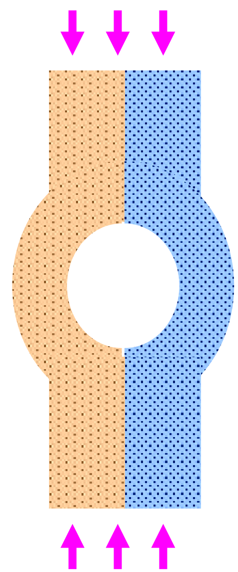


① : Fiber pull out
② : Fiber bridging
③ : Fiber/Matrix Debonding
④ : Fiber failure
⑤ : Matrix cracking

- Macroscopic damage form

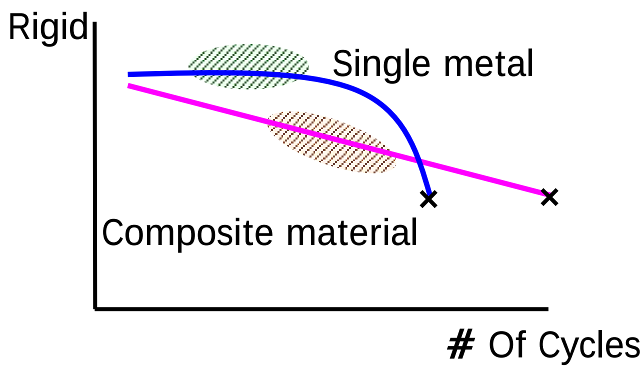


Delamination



Buckling Delamination

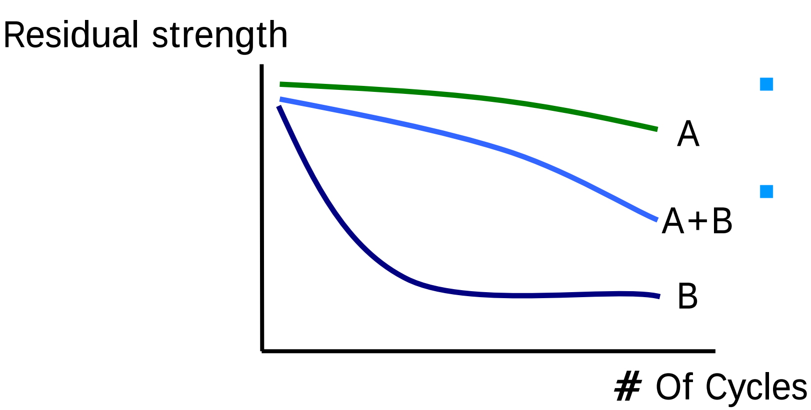
Deterioration of strength due to repeated loads



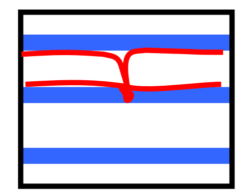
- Single metal
- It remains stiff before cracking, Rapid decrease after cracking

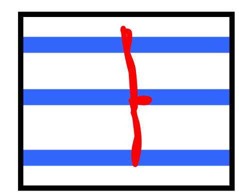
- Composite material
- Because small cracks occur steadily, Slowly falling from the beginning

Fracture behavior due to the adhesive properties of the interface



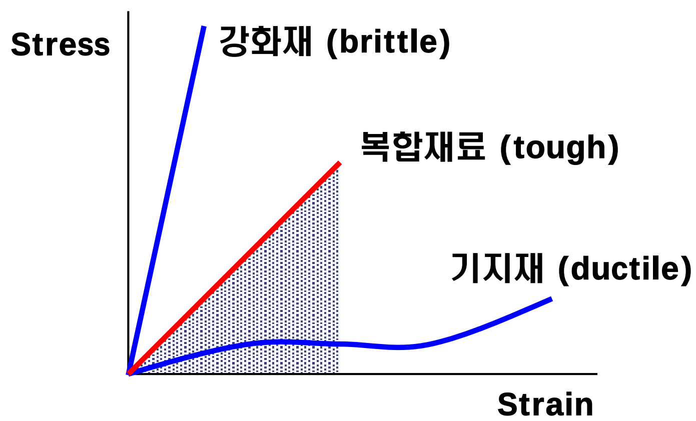
- A : Weak interface Deformation and destruction of base materials
- B : Strong interface Destruction of fibers





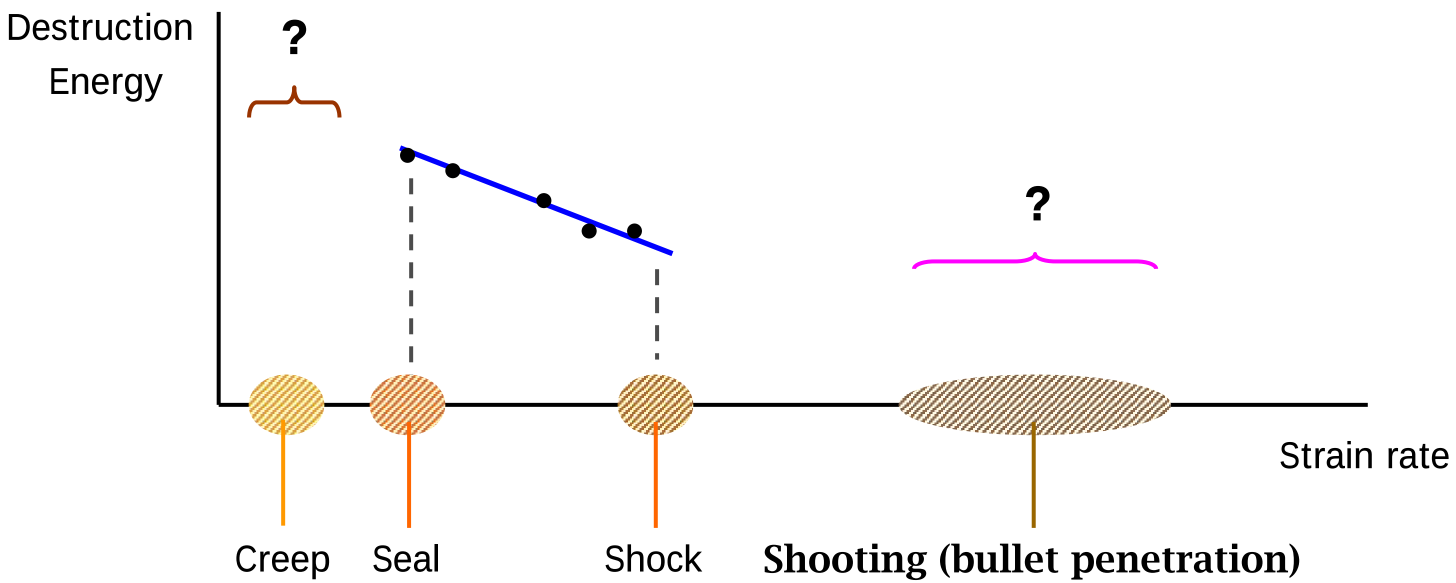
Toughness of composite material

- Toughness of composite materials
- Energy required for material destruction 파괴 Area under the stress-strain graph



- Composite materials have many cracks between the fibers and the base material, and eventually destruction occurs.
- Destruction at lower stress than reinforcement
- Destruction at lower strain than base material

Various properties test

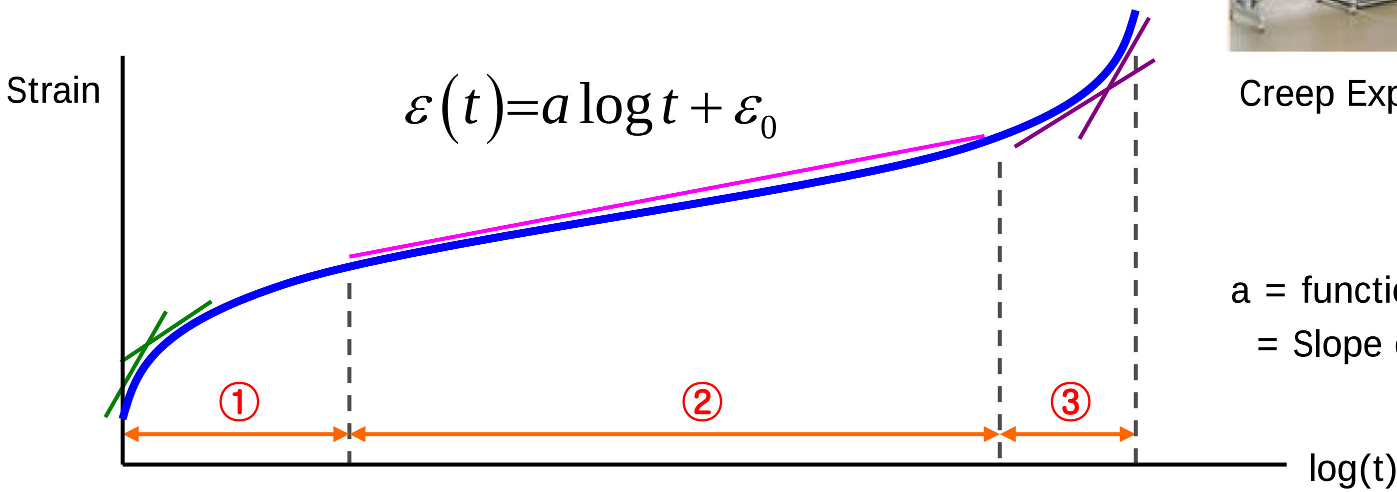


- Creep Experiment: Experiment in a condition where the strain increases very slowly
- Experiment takes a long time
- Tensile Experiment: Experiment at normal strain rate
- Impact test: Experiment at a higher strain rate than tensile test
- Shooting Experiment: Experiment at very large strain rate
- Do a lot in the defense industry

Creep characteristics

- Creep
- Deterioration of physical properties over a long period of time under constant load
- Common creep graph

Creep Experiment Device



a = function (time, load)
= Slope of the graph

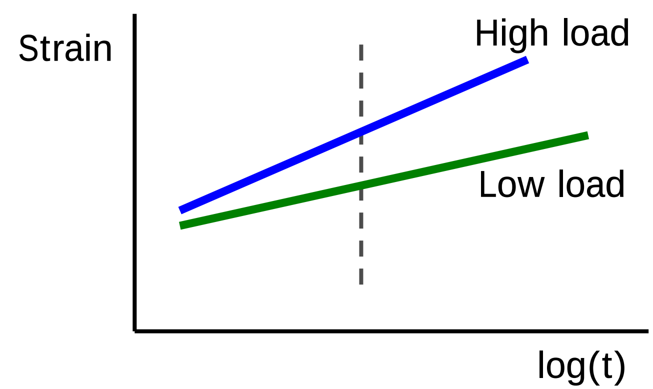
① : Transient creep ➔ The section where the strain rate stabilizes, gradually decreases and becomes constant

② : Linear creep ➔ Strain rate is constant

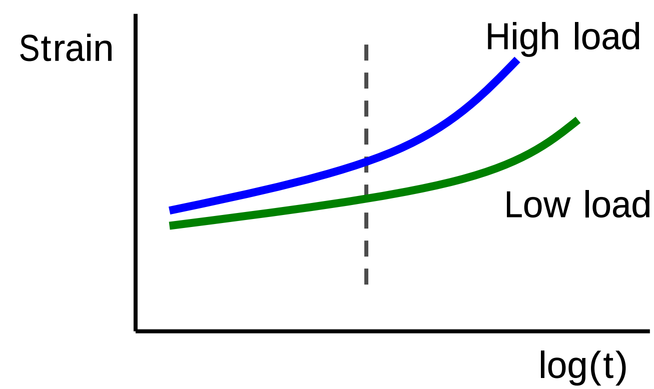
③ : Tertiary creep ➔ The section where the strain rate increases rapidly, destruction occurs

Composite Creep

[Reinforcement]



Base material



- Tilt almost constant over time
- The higher the load, the greater the strain value

- Initially, the slope is small, but gradually increase
- The higher the load, the greater the strain value

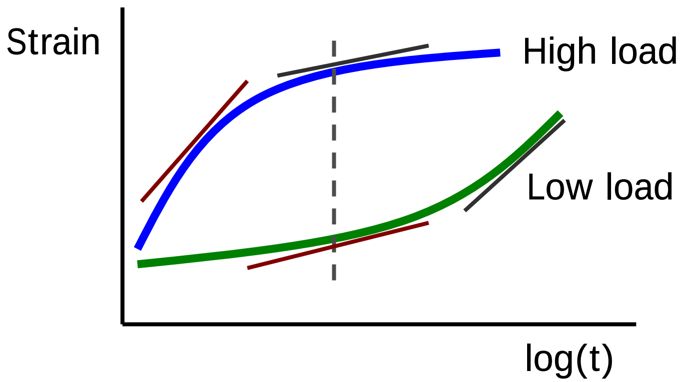
$$\varepsilon(t)=a\log t+\varepsilon_0$$

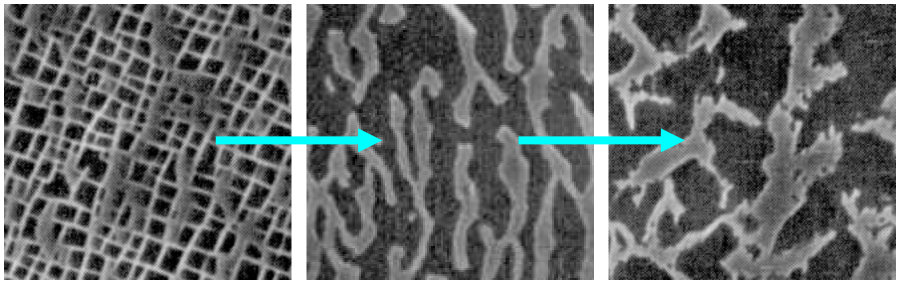
a = function of time

$$\varepsilon(t)=a\log t+\varepsilon_0$$

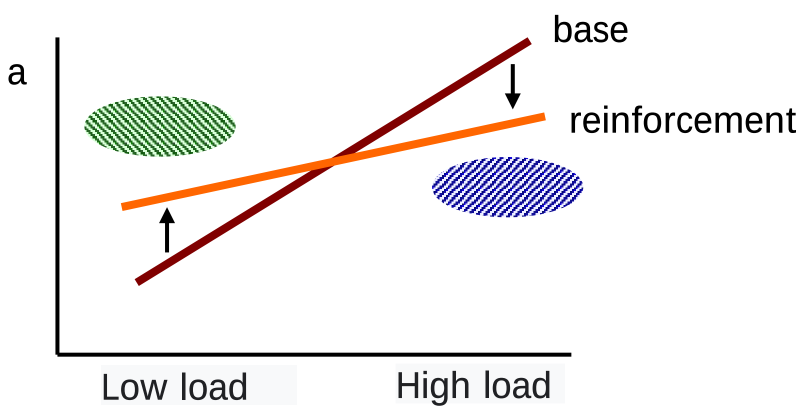
a = fctn (time)

Composite material





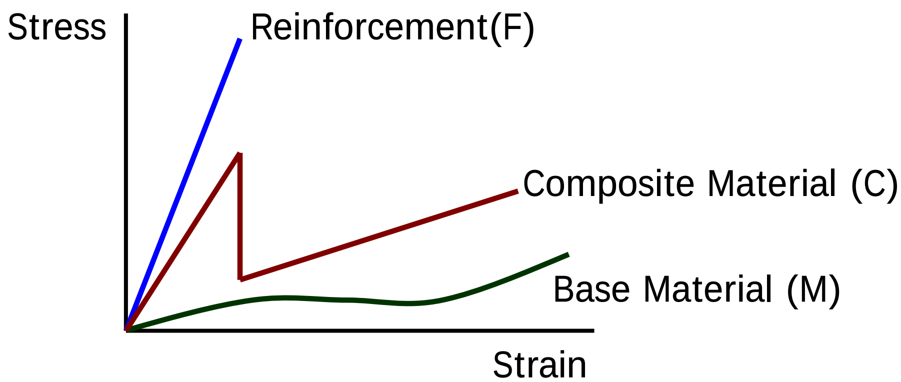
Changes in microstructure over time

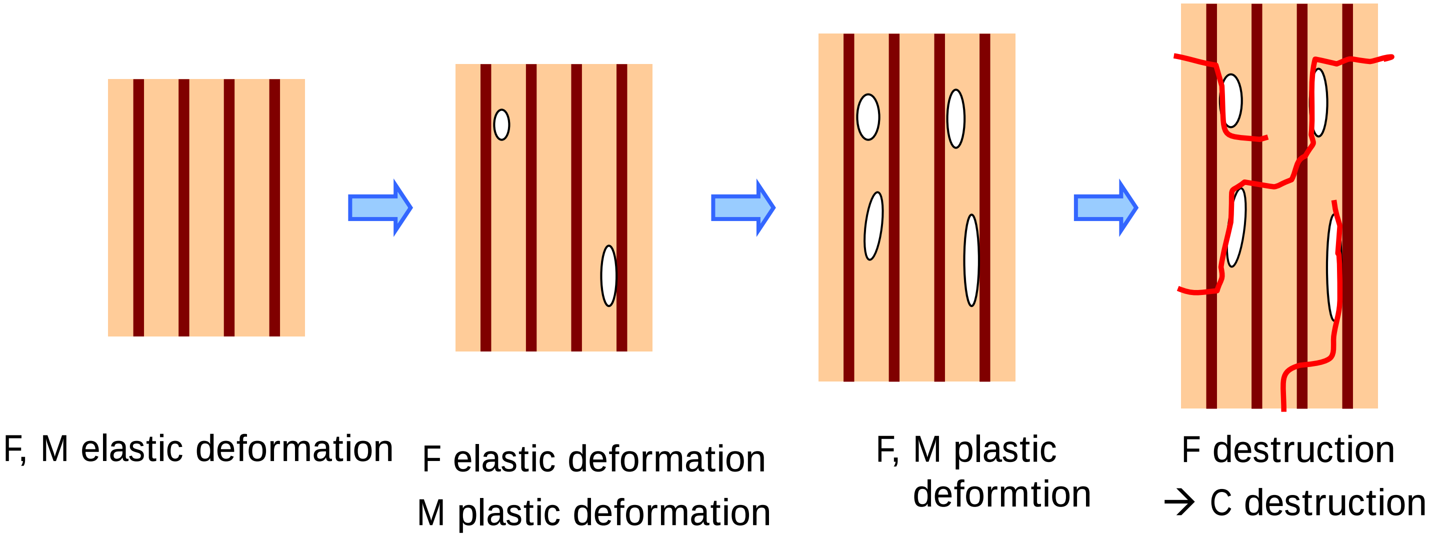


- High load: initially a large but smaller
- Low load: initially a is small but gradually increases
- Regardless of the load,
  Initially affected by base material
  Lately affected by reinforcing fibers
- Unlike normal materials, there is no linear creep section

Tensile Properties Of Composite Materials

- Step-by-step transformation of base and reinforcement



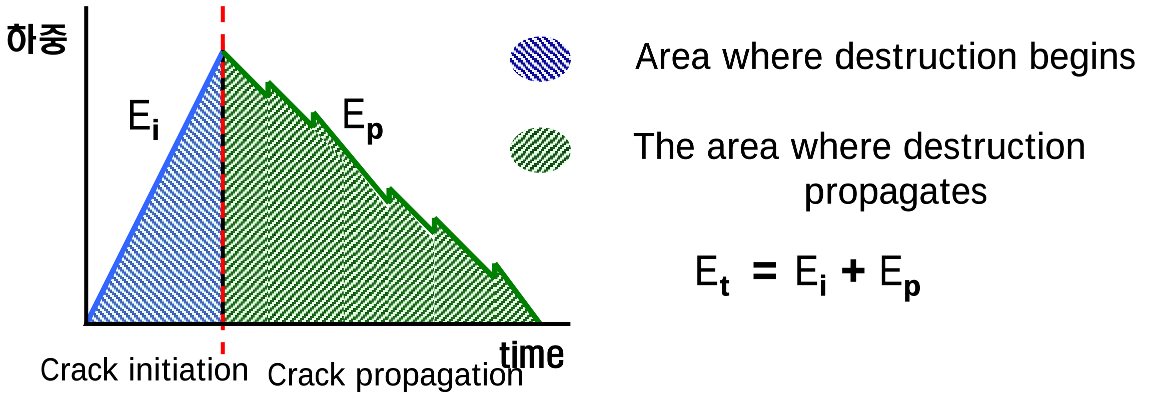


Impact properties

- Impact properties of composite materials

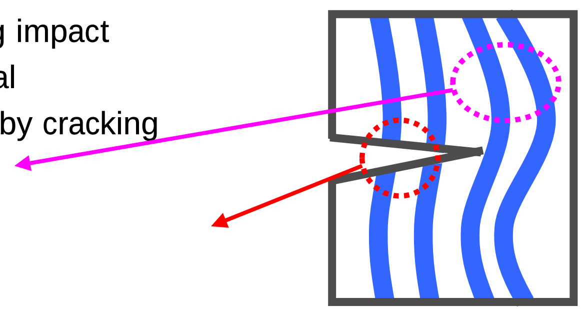
Composite materials can be designed to compromise strength and impact properties!

- Impact test load graph

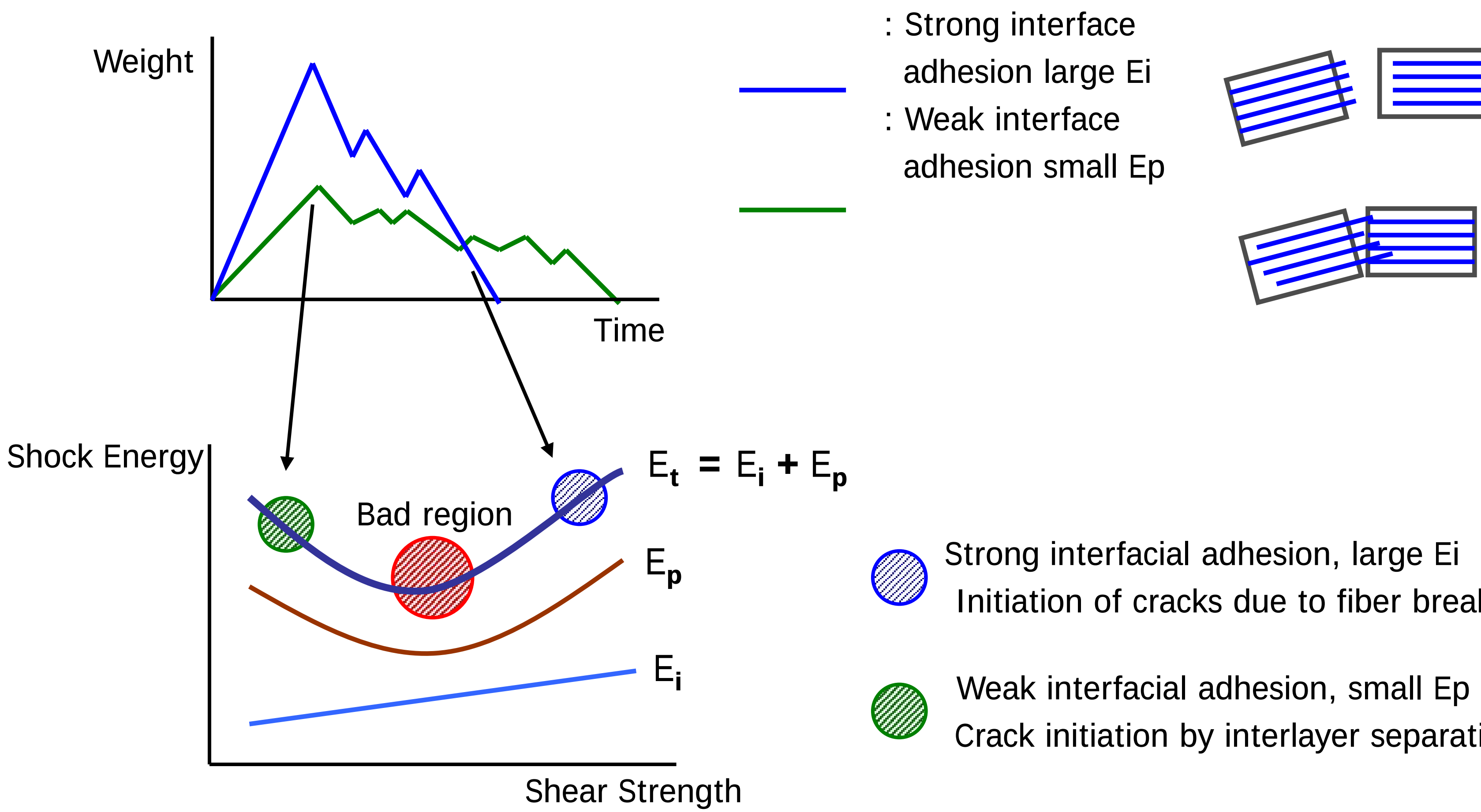


$E_t = E_i + E_p$

- Energy absorption mechanism during impact
- Absorption by deformation of material
- Absorption due to surface formation by cracking



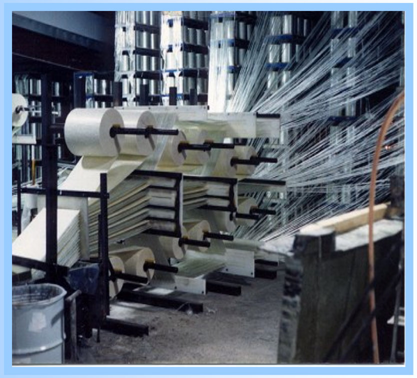
Impact characteristics due to the adhesive properties of the interface



Strong interfacial adhesion, large Ei
Initiation of cracks due to fiber breakage

Weak interfacial adhesion, small Ep
Crack initiation by interlayer separation

Manufacturing method of polymer composite material



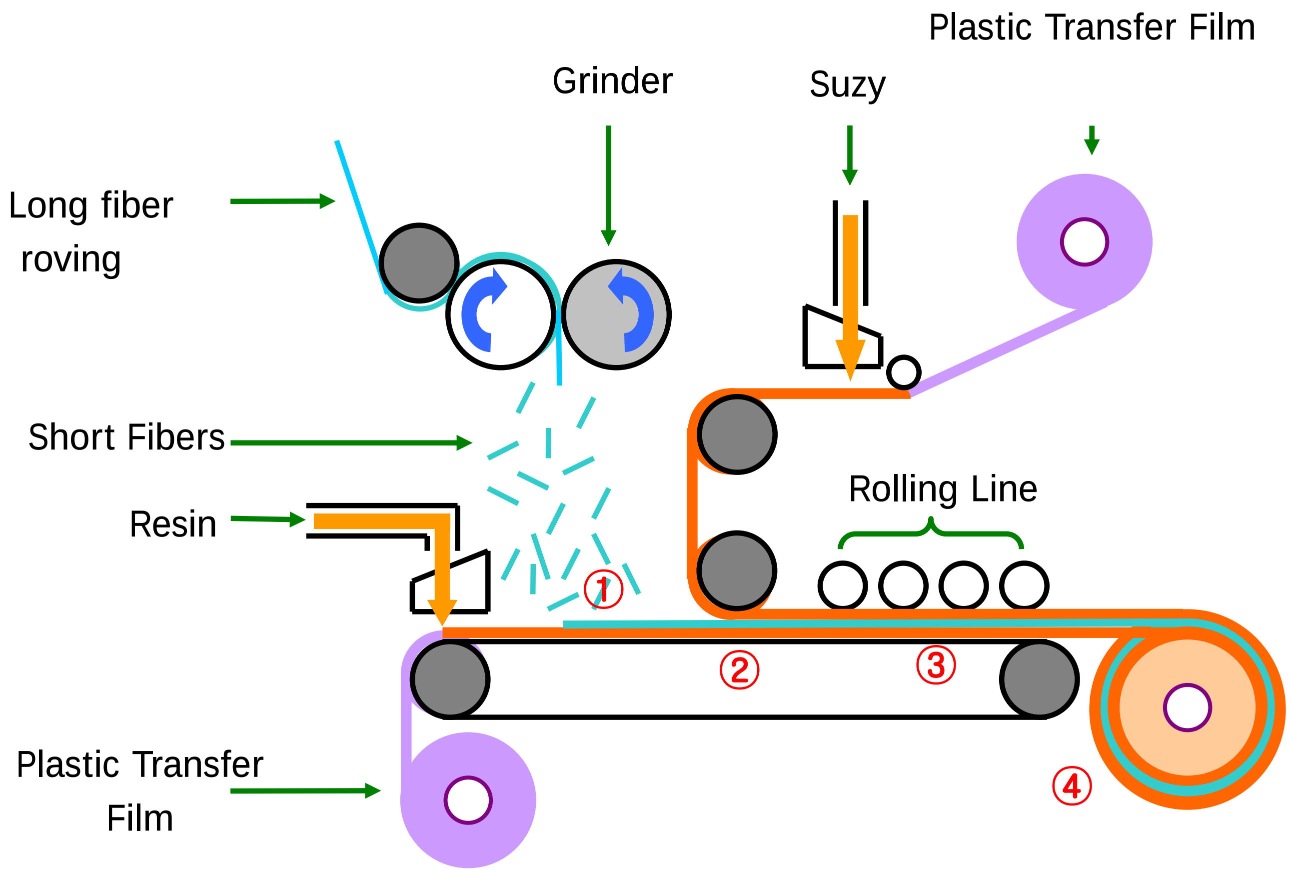
Classification of manufacturing method

- Preform manufacturing
- Sheet Molding Compound (SMC)
- Bulk Molding Compound (BMC)
- Prepreg

- Production of the molded body
- Hand layup
- Spray up
- Vacuum bag molding
- Filament winding
- Electron beam filament winding
- Resin transfer molding (RTM)
- Resin Injection Molding (RIM)
- Compression molding
- Pultrusion
- Thermoplastic resin molding process

Sheet-molding Compound (SMC)

- Process Schematic



- Process Order

① A mixture of fiber and resin
Transfer over transfer film

↓

② For transporting mixtures
Covered with film

↓

③ Stacked sheets
Rolling while heating

↓

④ The finished sheet
Winding in a cylinder

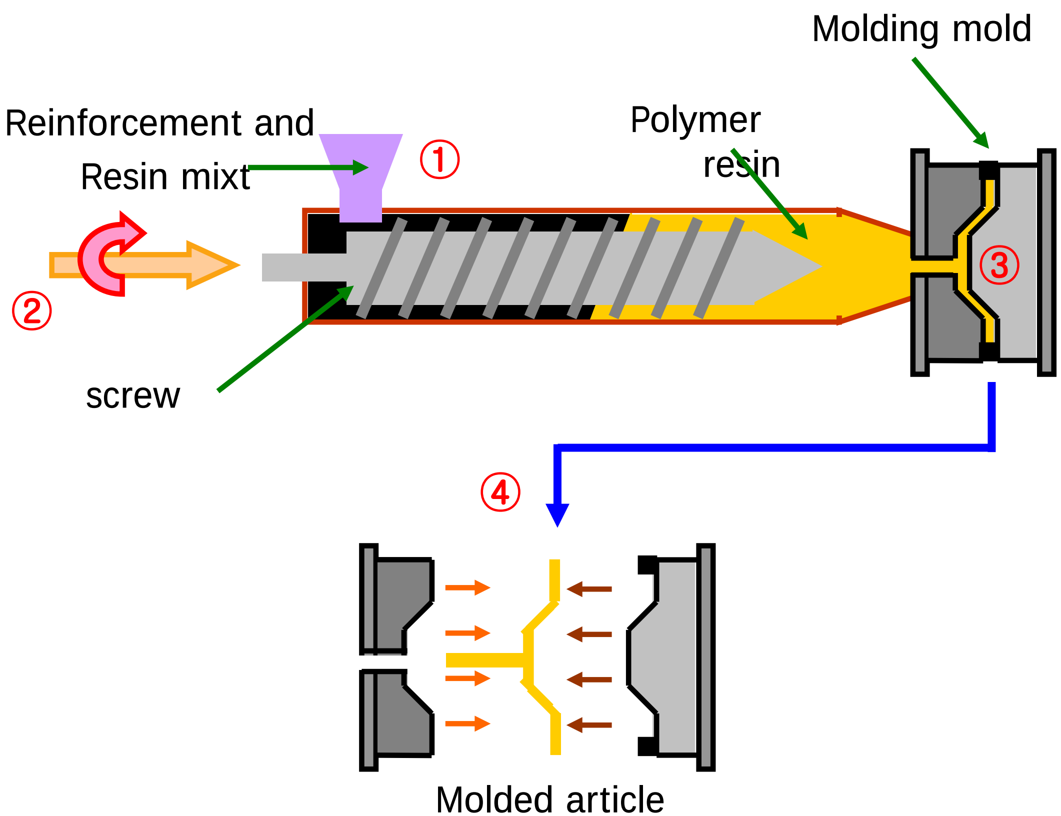
Sheet-molding Compound (SMC)

- **Process features**
- character tics
- Reinforcing material uses cut fiber roving --- 25 ~ 50mm
- High fiber ratio --- 20 ~ 35%
- The finished sheet is a semi-cured clay-type soft product
- Advantageous for mass production
- **Applications**
- Complete the actual product by high temperature and high pressure molding after individually or laminating the finished sheets.
- Used as a flexible thin plate by impregnating adhesive resin

실제 생산 라인

Bulk Molding Compound (BMC)

- Process schematic



- Process order

① A mixture of short fibers and resin Injection into the screw space

↓

② Turn the screw Transfer the mixture to the mold

↓

③ Compression or injection molding

↓

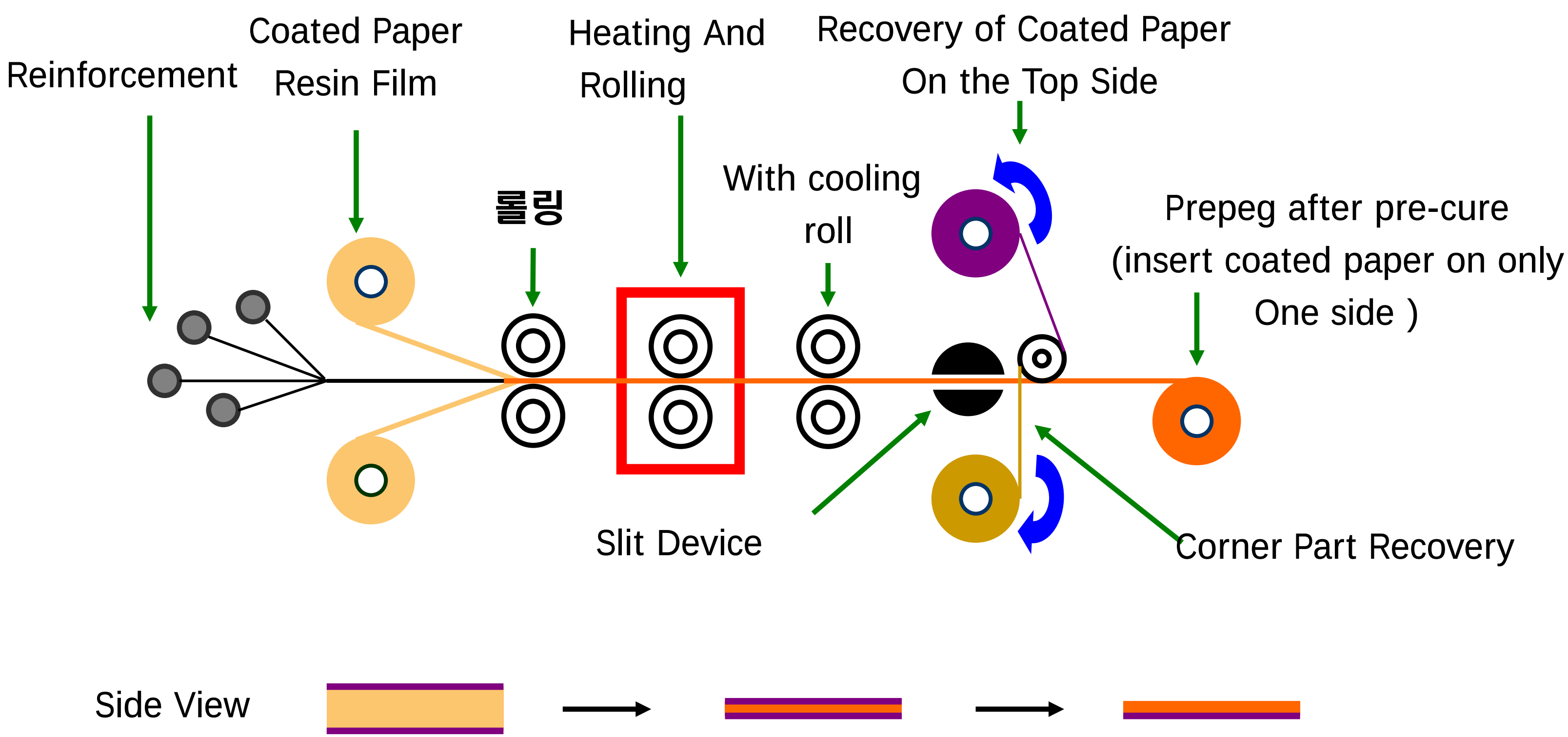
④ Molded products

Bulk Molding Compound (BMC)

- **Process features**
- Purpose --- Preparation of 3D bulk form mixture
  - Reinforcing materials use cut fiber roving --- 6 ~ 12mm
  - The proportion of fiber --- 15-20%
  - The proportion of fiber is lower than SMC
  - Inferior in strength than SMC due to the inability to use very long fibers
  - The injection state is a liquid mixture, but completely cured after compression and injection molding.
  - Advantageous for high speed mass production
  - **Applications**
  - Products of complex shapes, such as electrical equipment and automotive part

Prepreg (프리프레그) 제조

- Prepreg manufacturing method: Hot-melt prepreging process



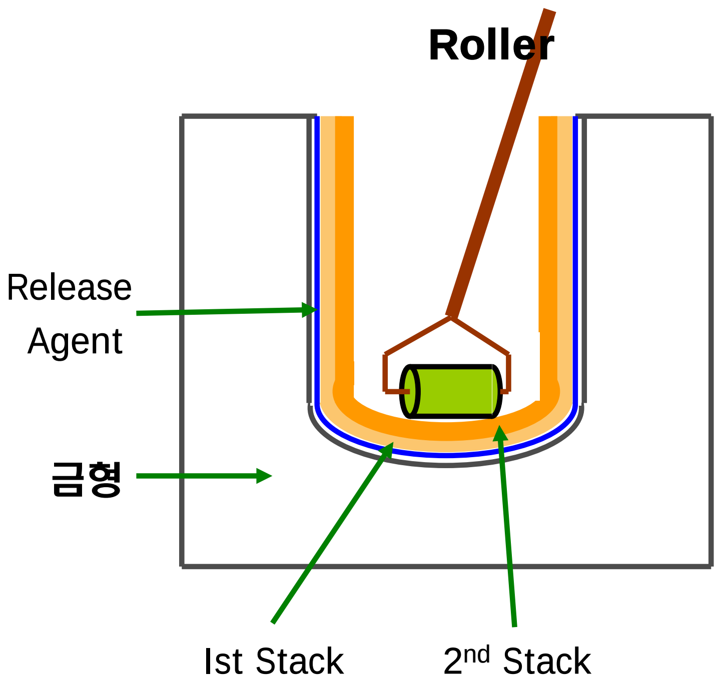
Prepreg (prepreg) production

- **Process features**
- Purpose --- Manufacture of one-way fiber reinforced tape with resin semi-cured
- characteristics
  - Reinforcing material uses long fiber roving Secured the desired length by cutting
  - Both heat curable and thermoplastic resins can be used
  - The thermosetting resin prepreg is stored at room temperature.
  - Thermoplastic prepreg is stored at low temperature
  - Easy control of mixing ratio of resin and fiber and quality control
  - **applications**
  - After individual sheets or lamination of the finished sheet, vacuum bag molding and actual product completion through RTM
  - Used for aircraft's thin exterior plate (1 ~ 2mm)

프리프레그

Hand Lay-up (핸드 레이업)

- Process Schematic



- The number of laminations depends on the thickness

- Process Order

Product shape

Mold processing

↓

Mold surface

Release agent coating

↓

After prepreg

lamination Resin

↓

After sticking with a roller

High temperature molding

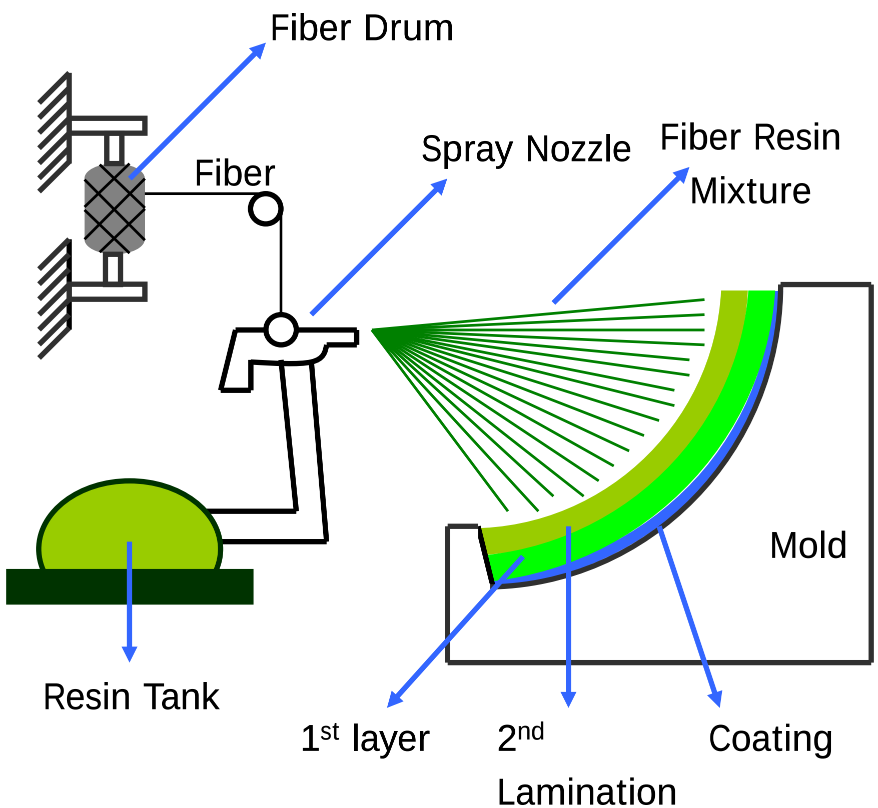
Hand Lay-up (핸드 레이업)

- **Process Features**
- Purpose --- Simple shape product manufacturing
- characteristics
    - Oldest way
    - Any type of fiber can be used
    - Determination of product thickness with the number of stacked sheets
    - Possibility to disturb the direction of the fiber when squeezing with a roller
    - Disadvantage for mass production
    - **Application**
    - Simple and low-volume applications
    - Boat shell, small pool, special paper production

핸드 레이업 작업 모습

Spray-up (스프레이-업)

- Process Schematic



- Process order

Product shape

Mold processing

↓

Mold surface release

Agent coating

↓

Of fibers and

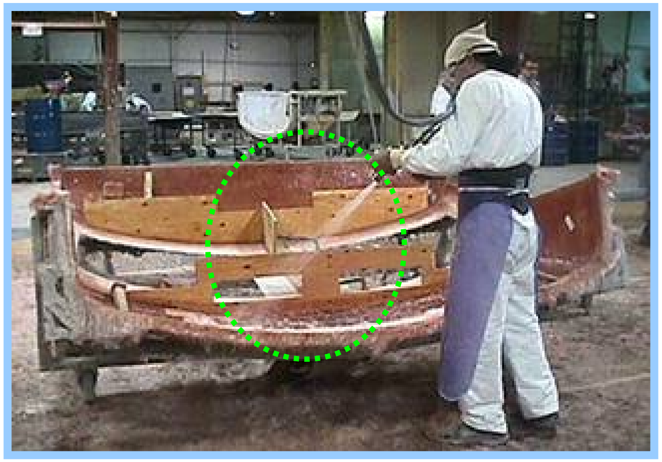
resins Mixing spray

↓

High temperature molding

Spray-up (스프레이-업)

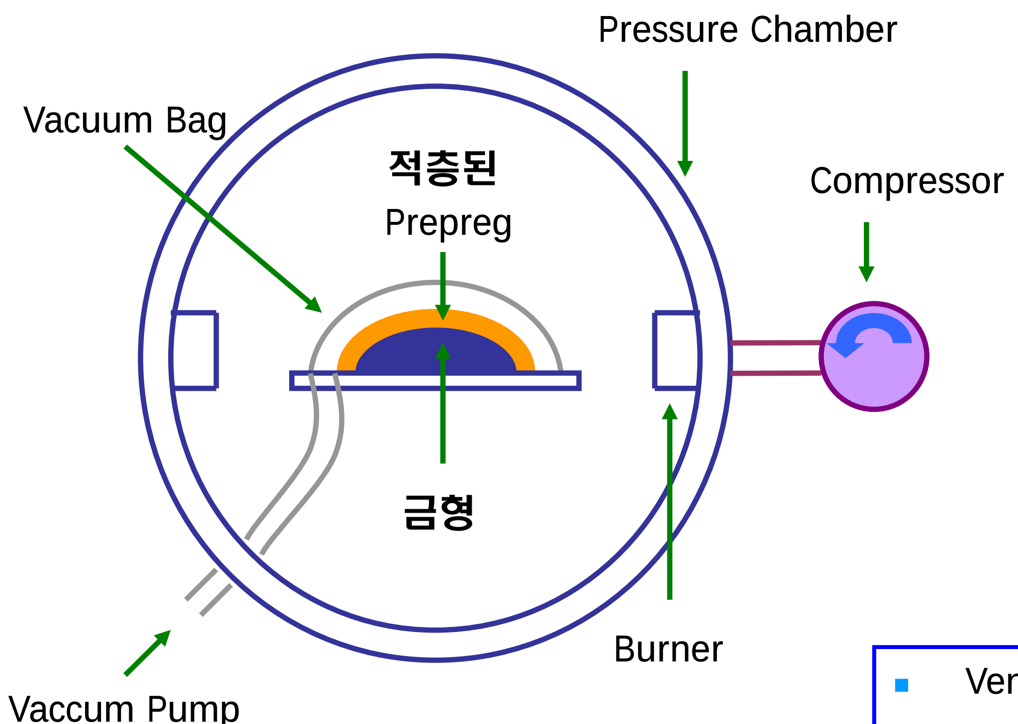
- Process features
- Purpose --- Manufacturing more complex shapes than hand layup
- Characteristic
- Automated hand layup method
- Reinforcing materials are available only for short fibers --- 10 ~ 30 mm
- Similar to hand layup
- Disadvantage for mass production
- Applications
- Products manufactured by hand layup
- Boat shell, swimming pool, large cover, tank container



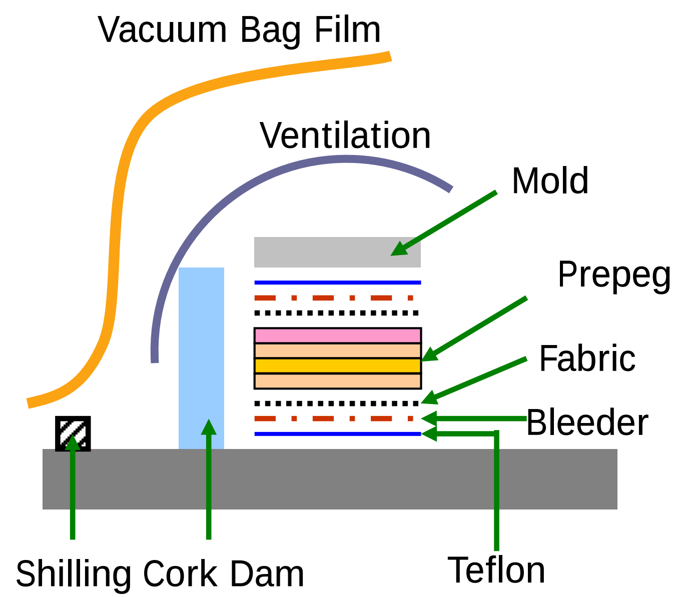
Spray Up Work

Vacuum Bag Molding (진공백 성형)

- Process Schematic



- Lamination Part Enlargement



- Ventilation plate: Gas removal during molding
- Fabric: easy to demold
- Bleeder: Resin leaks to induce proper ratio
- Sealing: secure vacuum

Vacuum Bag Molding (진공백 성형)

- **Process features**
- Purpose --- Manufacturing 3D molded products
- **Characteristic**
- Use of preforms laminated with prepregs
- Complex shapes can be manufactured
- Disadvantage for mass production
- **Applications**
- Laminate molding
- Complex shape and low quantity products

- Process order

Laminate preparation

↓

Demolition fabric, bleeder,

Lamination of Teflon film and preform

↓

Border sealing

↓

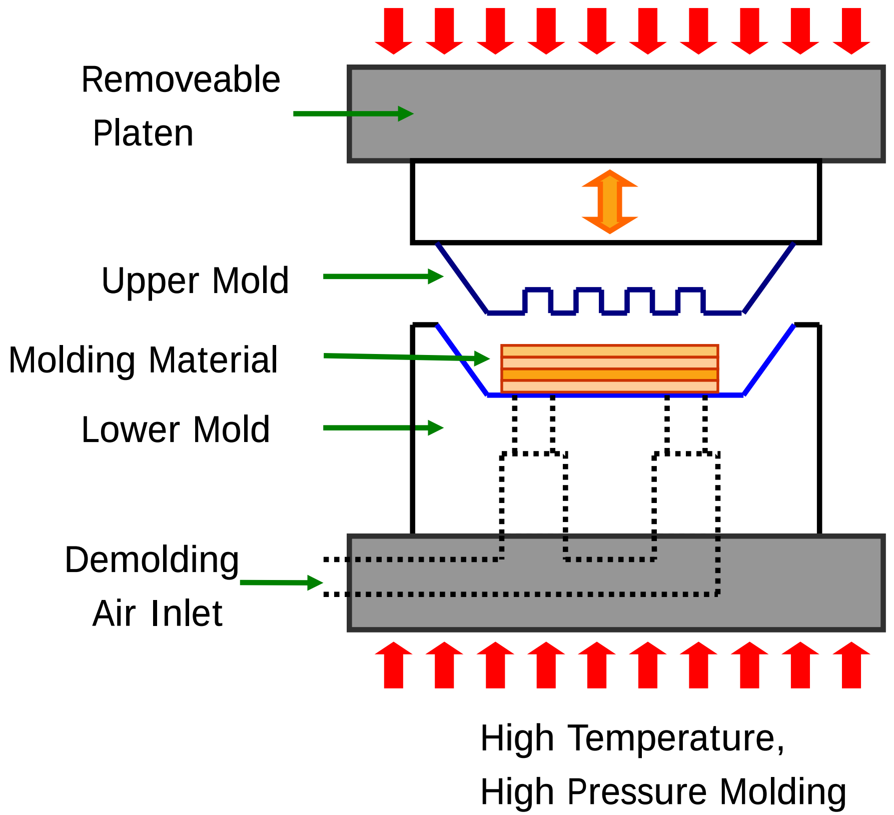
Vaccum pressure operation

↓

High temperature, high pressure molding

Compression Molding (압축 성형법)

- Process Schematic



- Process Order

Forming material preparation

↓

Mounting of material on the lower mold

↓

High temperature high pressure molding

↓

demolding

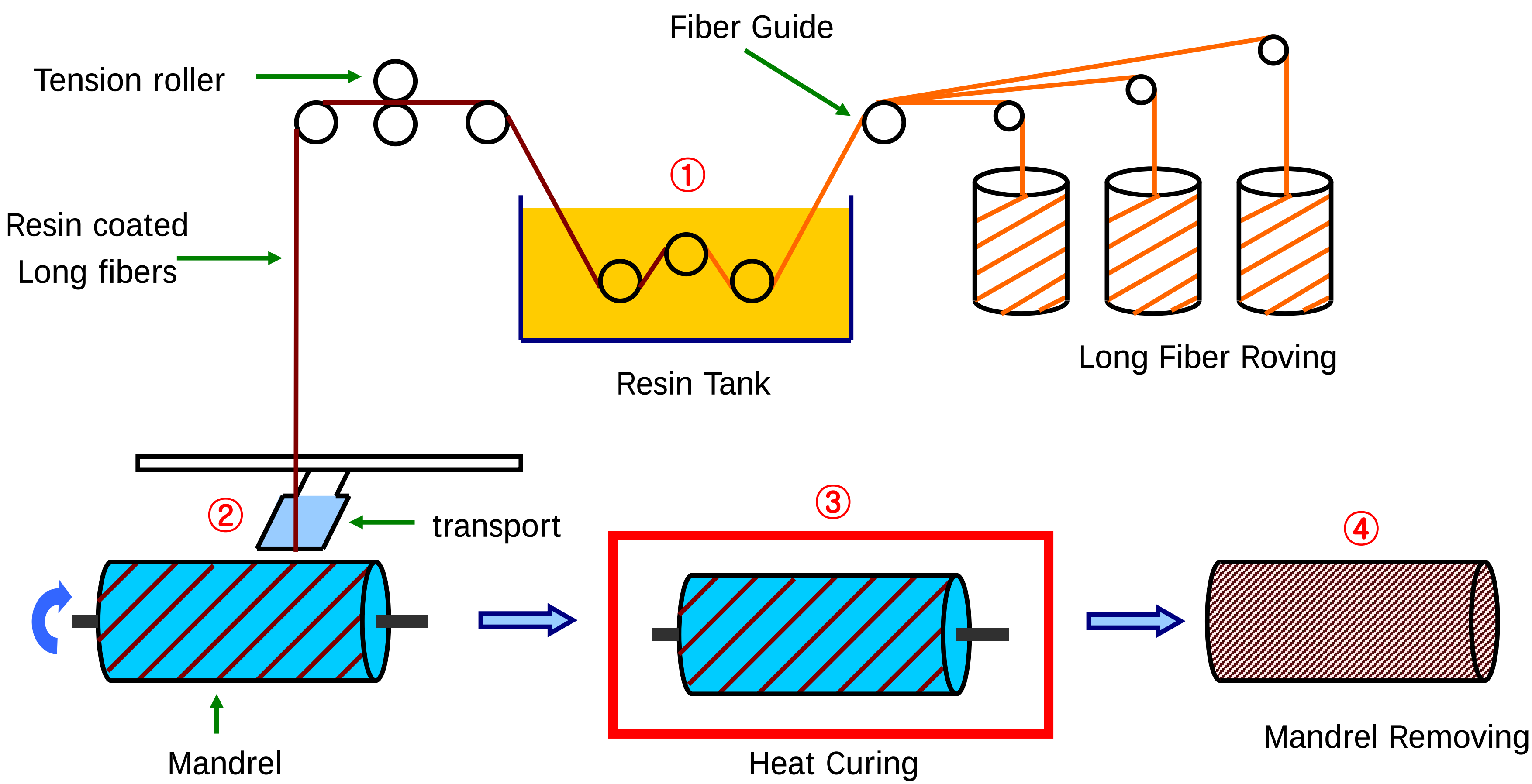
Compression Molding (압축 성형법)

- **Process features**
- Purpose --- Manufacturing almost two-dimensional products
- **Characteristic**
- Short time forming process
- Securing the optimal molding process is very important
- Easily create complex 2D shapes
- Cannot produce 3D products
- Advantageous for mass production
- **Applications**
- Various 2D products
- Laminate production

Hot Press

Filament Winding (필라멘트 와인딩)

- Process Schematic



Filament Winding (필라멘트 와인딩)

- **Process Features**
- Purpose --- Making strong pressure vessels of cylinder or spherical shape

- **Characteristic**
- Produced by winding long continuous fibers
- Carbon and Kevlar fibers are used as aircraft materials.

- Glass fiber is used for munitions
- Design of physical properties according to winding tension, winding angle, and fiber type
- Small winding angle makes molding difficult
- Product shape is monotonous

- **Applications**
- Pipe, tube, pressure tank

- Process order

Production of winding mandrel

↓

Resin on fiber ①

↓

Winding the fiber around the mandrel ②

↓

Resin curing ③

↓

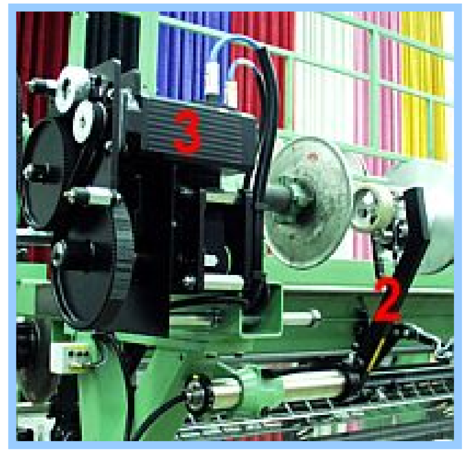
Mandrel removal ④

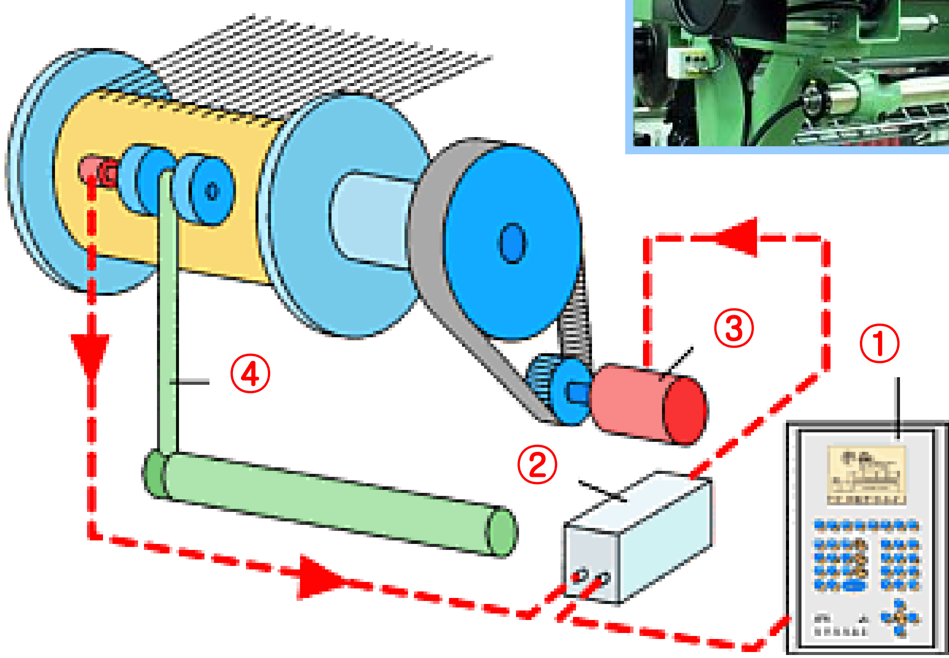
↓

Further processing

EB Filament Winding (전자 빔 와인딩)

Process Schematic





- Process Order

① Winding process programming

② With microprocessor Servo motor control

③ Via servo motor Mandrel rotation

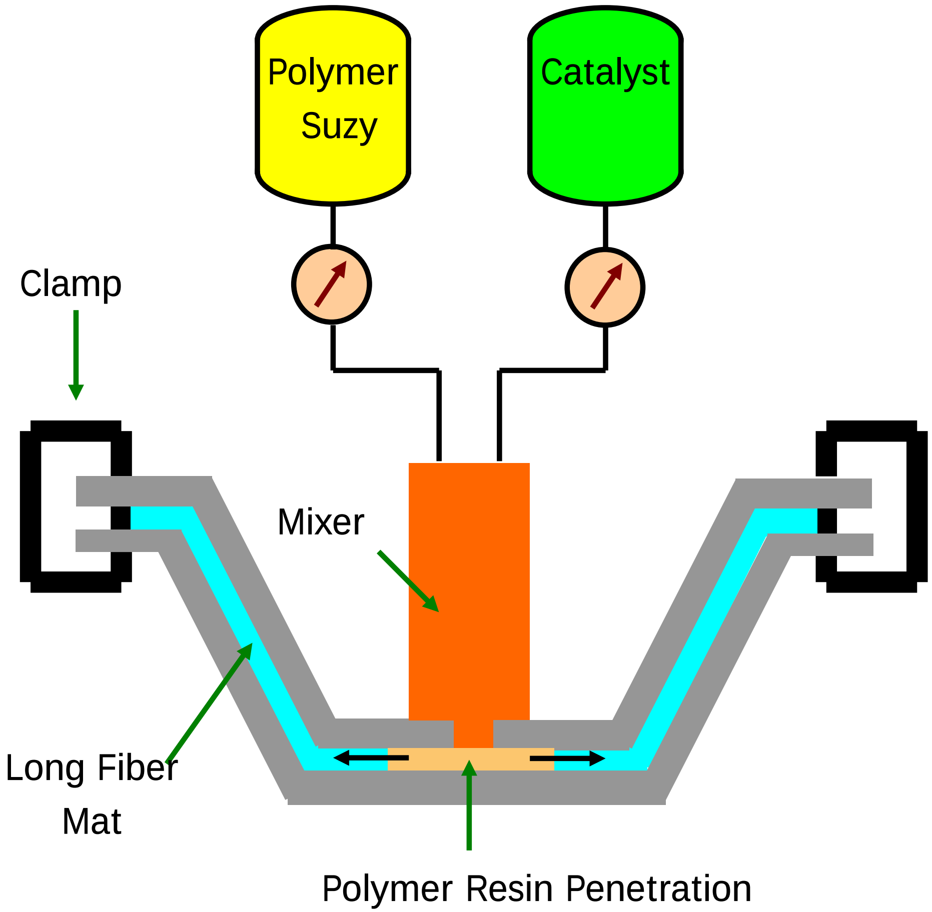
④ With roller arm EB Quick curing

EB Filament Winding (전자 빔 와인딩)

- **Process features**
- Purpose --- Automatic production of strong pressure vessels
- **Characteristic**
- Produced by winding long continuous fibers
- Similar to general Filament Winding
- Rapid curing induction by using Electric Beam System
- Automated product molding
- **Applications**
- Molding of filament winding products requiring mass production

Resin Transfer Molding (RTM)

Process Schematic



- Process Order

Spray body preparation

↓

Clamp the mold

↓

Resin injection

↓

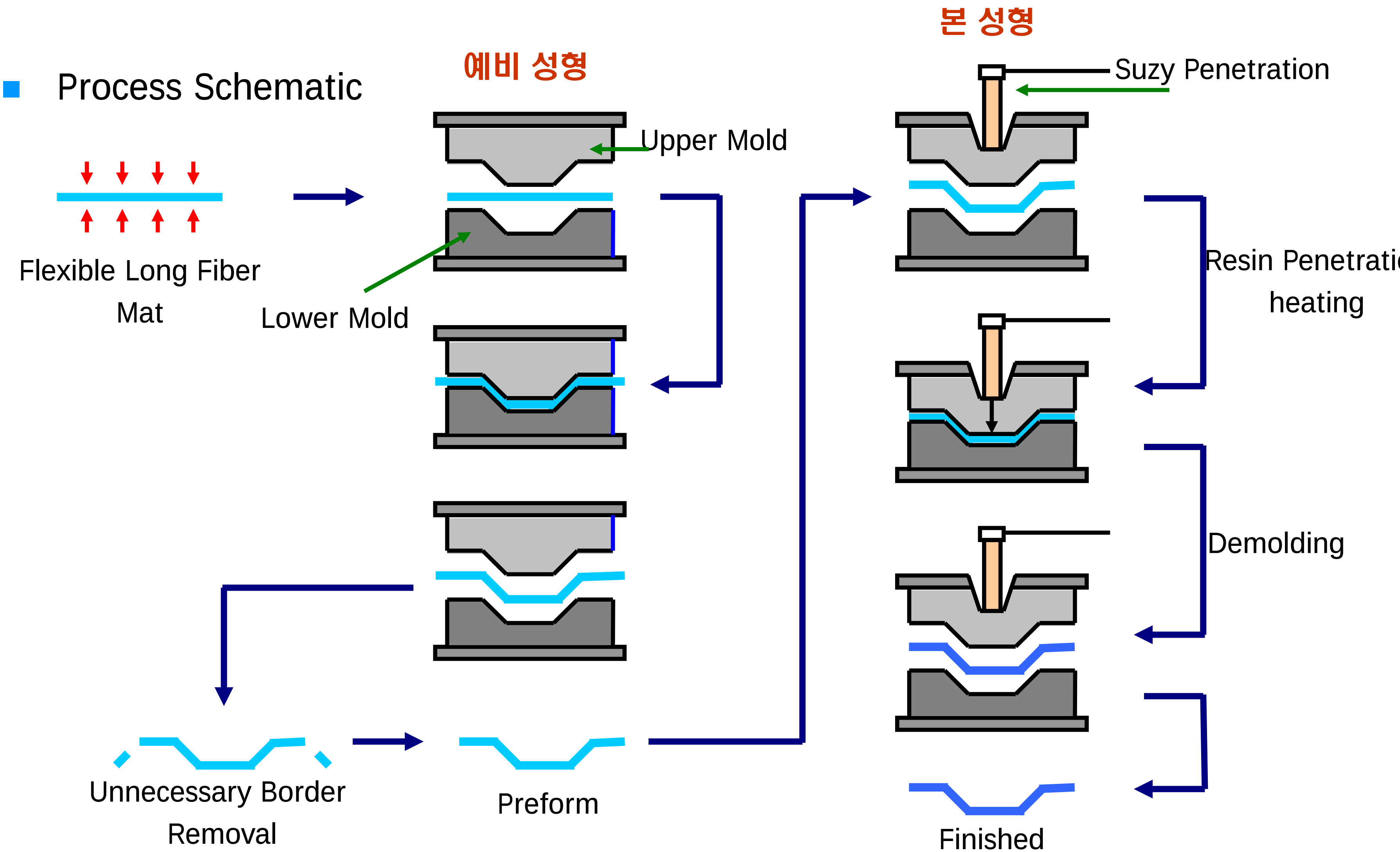
High temperature curing

↓

demolding

Preforming & RTM

- Process Schematic



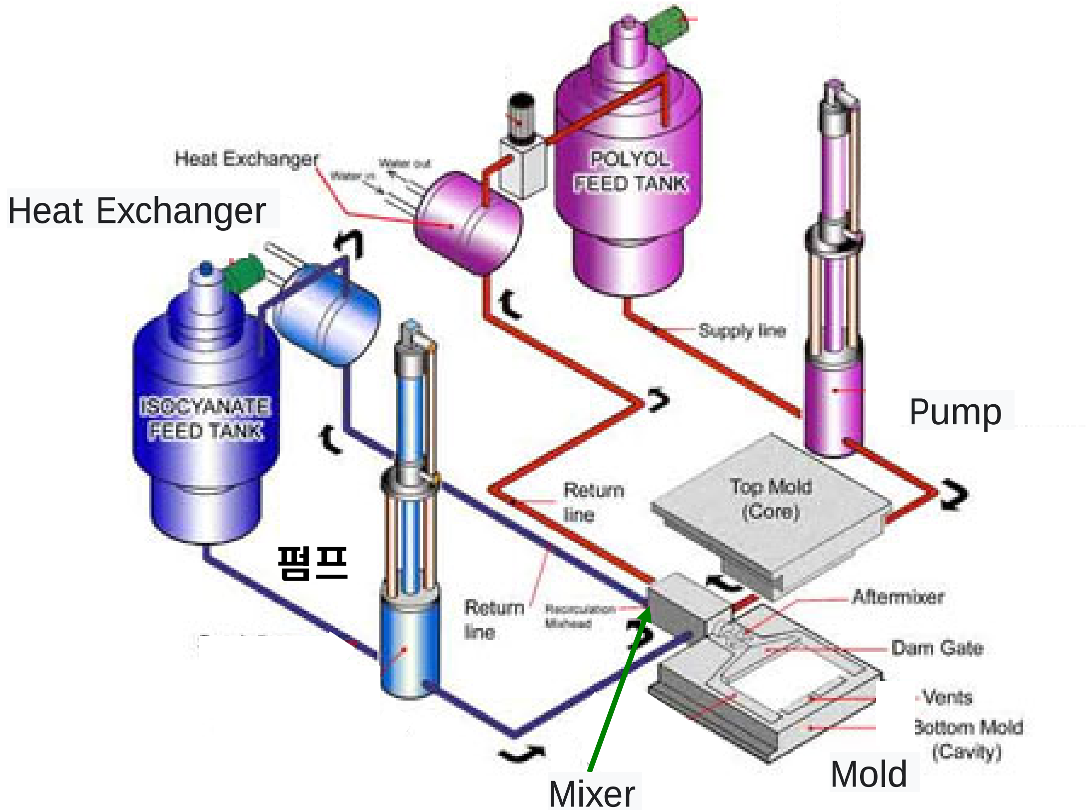
Resin Transfer Molding (RTM)

- **Process features**
- Purpose Production of products with a wide and complex shape
- **Characteristic**
- Reinforcing materials use strand mat or woven roving
- Depending on the choice of catalyst, room temperature curing is possible
- Large dimensional deviations require finishing after molding
- Disadvantage for mass production
- Use of preforms such as holes and ribs
- Advantageous for manufacturing complex shapes
- **Applications**
- Vehicle parts, cabinet, chair, bathtub, boat

RTM **제품**

Reaction Injection Molding (RIM)

- Process Schematic



- Process Order

Prepare two liquids Fiber on one side

↓

Pump the two liquids Transfer to mixer

↓

Inject mixture into mold

↓

Low temperature low pressure molding

↓

demolding

Reaction Injection Molding (RIM)

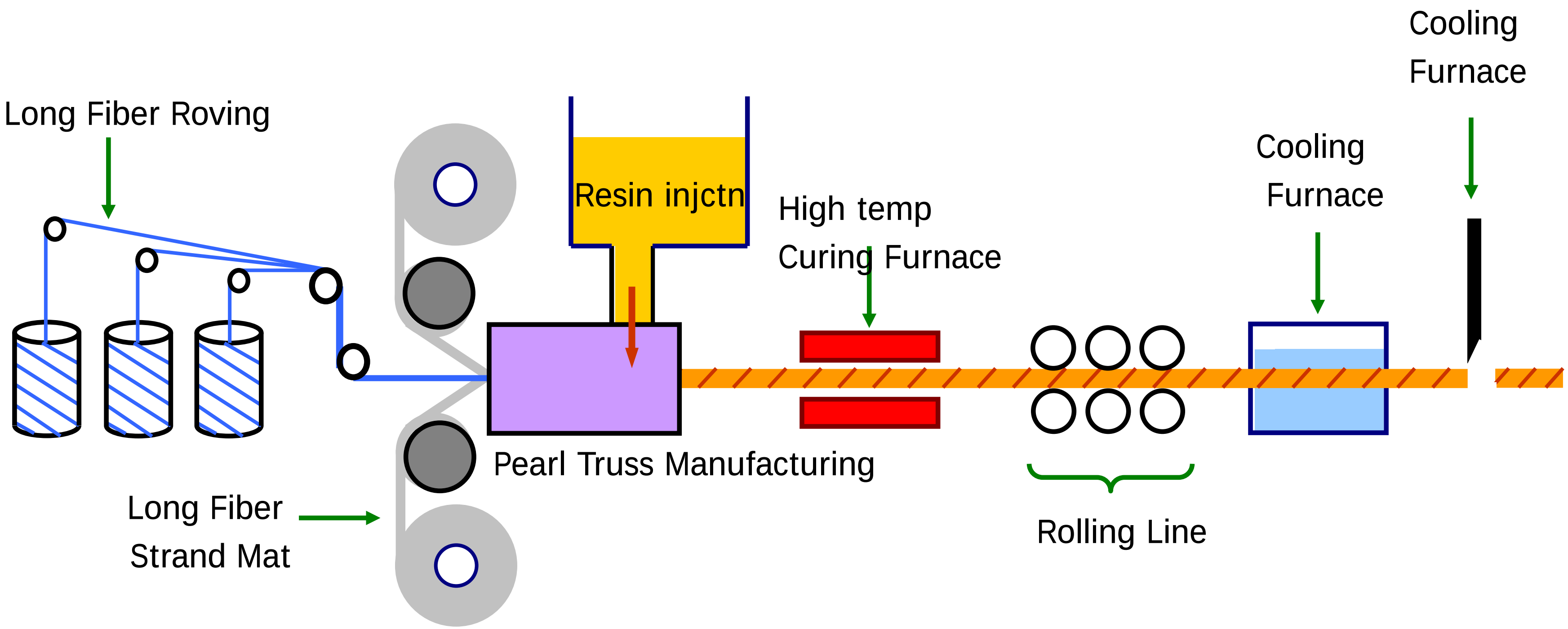
- **Process features**
- Purpose Quick injection molding of complex shaped products
- **Characteristic**
- Uses two liquids that are cured by chemical reaction polyol + isocyanate-> polyurethane
- Reinforcing materials use short strands
- Molding at low temperature and low pressure --- Shortening molding time
- **Applications**
- Car spoiler, car panel

Camera Housing

Product Cover

Pultrusion (인발 성형)

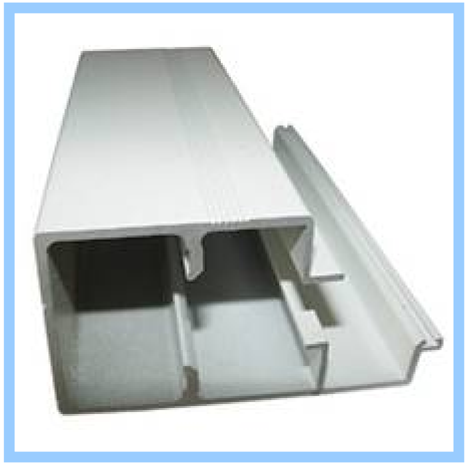
- Schematic Diagram



Pultrusion (인발 성형)

- **Process features**
- Purpose --- Manufacturing long products with constant cross section
- **Characteristic**
- Reinforcing materials use long fibers
- High fiber ratio --- 30 ~ 70%
- The shape of the section is limited
- High price of process machine
- Production of exact dimensions
- Advantageous for mass production
- **Applications**
- Pipe, beam structure

Pearl Truss Machine



Window Frame

Thermoplastic Molding Process

- Schematic Process