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Types of Fiber

- 1. Glass fiber
- 2. Carbon Fiber
- 3. Kevlar fiber
- 4. Boron fiber
- 5. Natural fiber
- 6. Hybrid fibers



FIBER SELECTION

Factors to consider when choosing glass type include thermal properties; fiber cost, type of manufacturing process being used, and forms of reinforcement

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Introduction

- The dominant forms that fibers are sold include:
 - Many fibers or filaments stranded together in a bundle, wound in a spool or reel)
 - woven fabrics (flattened strands of filaments woven in a variety of weaves to a type of fabric or cloth)
 - unidirectional (strands laid side by side and stitched or held together by other means, forming a kind of fabric that bares reinforcement only in the fill direction)
 - multiaxials (unidirectional woven fabrics stitched together in a combination of orientations)
 - and chopped strand mat (chopped strands held together with some kind of glue or "binder" in the form of a nonwoven fabric.)



Glass Fiber

The types of glass used are as follows:

- E-Glass the most popular and inexpensive. The designation letter "E" means "electrical implies that it is an electrical insulator". The composition of E-glass ranges from 52-56% SiO₂, 12-16% A1₂O₃, 16-25% CaO, and 8-13% B₂O₃
- **S-Glass** stronger than E-Glass fibers (the letter "S" means strength). High-strength glass is generally known as S-type glass in the United States, R-glass in Europe and T-glass in Japan. S-Glass is used in military applications and in aerospace. S-Glass consists of silica (SiO₂), magnesia (MgO), alumina (Al_2O_3).
- C-Glass corrosion and chemical resistant glass fibers. To protect against water erosion, a moisture-resistant coating such as a silane compound is coated onto the fibers during manufacturing. Adding resin during composite formation provides additional protection. C-Glass fibers are used for manufacturing storage tanks, pipes and other chemical resistant equipment.

Glass Fiber

- Glass fibers are manufactured from molten glass, from which glass monofilaments are drawn and then gathered to strands. The strands are used for preparation of different glass fiber products (yarns, rovings, woven fabrics, mats).
- The most popular matrix materials for manufacturing fiberglasses are Thermosets such as unsaturated polyesters (UP), epoxies (EP) and Thermoplastics such as nylon (polyamide), polycarbonate (PC), polystyrene (PS), polyvinylchloride (PVC)
- Fiberflass materials usually have laminate structure with different fibers orientations in the reinforcing glass layers. Various glass fibers orientations result in anisotropy of the material properties in the plane parallel to the laminates. Concentration of glass fibers in fiberglass is normally about 40% - 70%.



Production of Glass Fibers

- Produced by drawing monofilaments from a furnace and ٠ gathering them to form a strand.
- Strands are held together with resinous binder.
- **Properties:** Density and strength are lower than carbon and aramid fibers.
- Higher elongation.
- Low cost and hence commonly used.



After M.M. Schwartz, "Composite Materials Handbook," McGraw-Hill, 1984, pp. 2-24.

C Bay Deep	E-glass (%)	S-glass (%)	AR-glass (%)
SiQ 2	54	65	64 3
TiO ₂ ZiO ₂	14	25	13 1
MgO3 MgO CaO	9 5 18	10	5 14
Na ₂ O Modulus (GPa)	70	80	75
Strength (MPa)	2200	2600	1700
Density (Mg/m ³)	2.54	2,49	2.70

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Glass Fiber

- Fiberglasses (Glass fibers reinforced polymer matrix composites) are characterized by the following properties:
- High strength-to-weight ratio;
- High modulus of elasticity-to-weight ratio;
- Good corrosion resistance;
- Good insulating properties;
- Low thermal resistance (as compared to metals and ceramics).
- Fiberglass materials are used for manufacturing: boat hulls and marine structures, automobile and truck body panels, pressure vessels, aircraft wings and fuselage sections, housings for radar mems, swimming pools, welding helmets, roofs, pipes.

Carbon Fiber

- A carbon fiber is a long, thin strand of material about 0.0002-0.0004 in (0.005-0.010 mm) in diameter and composed mostly of carbon atoms.
- The carbon atoms are bonded together in microscopic crystals that are more or less aligned parallel to the long axis of the fiber.
- The crystal alignment makes the fiber incredibly strong for its size. Several thousand carbon fibers are twisted together to form a yarn, which may be used by itself or woven into a fabric.
- The yarn or fabric is combined with epoxy and wound or molded into shape to form various composite materials.
- Carbon fiber-reinforced composite materials are used to make aircraft and spacecraft parts, racing car bodies, golf club shafts, bicycle frames, fishing rods, automobile springs, sailboat masts, and many other components where light weight and high strength are needed.

Carbon Fiber

- The types of carbon fibers are as follows:
- UHM (ultra high modulus). Modulus of elasticity > 65400 ksi (450GPa).
- HM (high modulus). Modulus of elasticity is in the range 51000-65400 ksi (350-450GPa).
- IM (intermediate modulus). Modulus of elasticity is in the range 29000-51000 ksi (200-350GPa).
- HT (high tensile, low modulus). Tensile strength > 436 ksi (3 GPa), modulus of elasticity < 14500 ksi (100 GPa).

(super high tensile). Tensile strength > 650 ksi (4.5GPa).

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Carbon Fiber: Raw Materials

 The raw material used to make carbon fiber is called the precursor. About 90% of the carbon fibers produced are made from polyacrylonitrile. The remaining 10% are made from rayon or petroleum pitch.



Carbon Fiber

- Carbon fibers are also classified according to the manufacturing method:
- 1. PAN-based carbon fibers (the most popular type of carbon fibers).
- In this method carbon fibers are produced by conversion of polyacrylonitrile (PAN) precursor through the following stages:
- Stretching filaments from polyacrylonitrile precursor and their thermal oxidation at 400°F (200°C). The filaments are held in tension.
- Carbonization in Nitrogen atmosphere at a temperature about 2200 °F (1200°C) for several hours. During this stage noncarbon elements (O,N,H) volatilize resulting in enrichment of the fibers with carbon.
- Graphitization at about 4500 °F (2500°C).
- 2. Pitch-based carbon fibers.
- Carbon fibers of this type are manufactured from pitch:
- Filaments are spun from coal tar or petroleum asphalt (pitch).
- The fibers are cured at 600°F (315°C).
 - Carbonization in nitrogen atmosphere at a temperature about 2200 °F (1200°C).

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Carbon Fiber

- Carbon Fiber Reinforced Polymers (CFRP) are characterized by the following properties:
- Light weight;
- High strength-to-weight ratio;
- Very High modulus elasticity-to-weight ratio;
- High Fatigue strength;
- Good corrosion resistance;
- Very low coefficient of thermal expansion;
- Low impact resistance;
- High electric conductivity;
- High cost.
- Carbon Fiber Reinforced Polymers (CFRP) are used for manufacturing: automotive marine and aerospace parts, sport goods (golf clubs, skis, tennis racquets, fishing rods), bicycle frames.

Kevlar Fiber

- Kevlar is the trade name (registered by DuPont Co.) of aramid (poly-para-phenylene terephthalamide) fibers.
- Groundbreaking research by DuPont scientists in the field of liquid crystalline polymer solutions in 1965 formed the basis for the commercial preparation of the Kevlar® aramid fiber.
- It was about 25 years ago that the first generation of Kevlar® fibers under the name of Kevlar® 29 was used in US ballistic vests for the first time.
- Kevlar fibers were originally developed as a replacement of steel in automotive tires.
- Kevlar filaments are produced by extrusion of the precursor through a spinnert. Extrusion imparts anisotropy (increased strength in the lengthwise direction) to the filaments.
- Kevlar may protect carbon fibers and improve their

very high tensile strength with high impact and abrasion resistance.

Kevlar Fiber

- Kevlar fibers possess the following properties:
- High tensile strength (five times stronger per weight unite than steel);
- High modulus of elasticity;
- Very low elongation up to breaking point;
- Low weight;
- High chemical inertness;
- Very low coefficient of thermal expansion;
- High Fracture Toughness (impact resistance);
- High cut resistance;
- Textile processibility;
- Flame resistance.
- The disadvantages of Kevlar are: ability to absorb moisture (making Kevlar composites more sensitive to the environment), difficulties in cutting (Toughness makes fabrics difficult to cut with conventional methods), low compressive strength.

Kevlar Fiber

- Aramids can be hot-drawn, i.e. Kevlar 29, is drawn at a temperature over 400° C (750° F) to produce Kevlar 49 (a fiber with nearly double the stiffness compared to Kevlar 29)
- There are several modifications of Kevlar, developed for various applications:
- **Kevlar 29** high strength, low density fibers used for manufacturing bulletproof vests, composite armor reinforcement, helmets, ropes, cables, asbestos replacing parts.
- Kevlar 49 high modulus, high strength, low density fibers used in aerospace, automotive and marine applications.
- Kevlar 149 ultra high modulus, high strength, low density, highly crystalline fibers used as reinforcing dispersed phase for composite aircraft components.

Grade	Density g/cm^3	Tensile Modulus GPa	Tensile Strength GPa	Tensile Elongation %
29	1.44	83	3.6	4.0
49	1.44	131	3.64.1	2.8
149	1.47	186	3.4	2.0



Kevlar 149 is the most crystalline while Kevlar 29 is the least crystalline

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(c) Figure 2.4 The molecular structure of: (a) nylon; (b) aramid; (c) polyethylene.

The close packing of the aromatic polymer chains produced a strong, tough, stiff, high-melting fiber, good for radial tires, heat- or flameresistant fabrics, bulletproof clothing, and fiber-reinforced composite materials



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Kevlar Fabric for Protection

- The superior toughness of aramid is an outcome of the energy consuming failure mechanism of its fibers. This energy absorbing failure mechanism makes it ideal for use in armor, military and ballistic applications, like helmets and bullet-proof vests.
- The type of Kevlar fiber used for protective applications is Kevlar 29.
- Kevlar fabric for protective applications is used primarily by the military and law enforcement agencies for bullet resistant vests and helmets.
- The military has found that helmets reinforced with Kevlar offer 25-40% better fragmentation resistance than comparable steel helmets while providing better fit and greater comfort.
- Bullet resistant vests using Kevlar cloth have saved thousands of police officers and military personnel in the line of duty. Kevlar fabric also offers excellent thermal protection in items such as gloves and boots since it can withstand extreme heat and is inherently flame resistant.



Boron fibers

- Are five times as strong and twice as stiff as steel.
- They are made by a chemical vapor-deposition process in which boron vapors are deposited onto a fine tungsten or carbon filament.
- Boron provides strength, stiffness and light weight, and possesses excellent compressive properties and buckling resistance.
- Uses for boron composites range from sporting goods, such as fishing rods, golf club shafts, skis and bicycle frames, to aerospace applications as varied as aircraft empennage skins, space shuttle truss members and prefabricated aircraft repair patches

NATURAL FIBERS

- abaca, coconut, flax, hemp, jute, kenaf and sisal are the most common — are derived from the bast or outer stem of certain plants.
- They have the lowest density of any structural fiber but possess sufficient stiffness and strength for some applications.
- The automotive industry, in particular, is using these fibers in traditionally unreinforced plastic parts and even employs them as an alternative to glass fibers. European fabricators hold the lead in use of these materials, in part because regulations require automobile components to be recyclable.

Types of Natural Fiber



Sugarcane-Bagasse Fiber







Jute Fiber





Kenaf Fiber fextilestudypoin Hermp Fiber



Natural fiber composites vs.					
synthetic fiber composites					
Study	Materials	Application	Performance		
Schmidt & Meyer (1998)	Hemp-EPDM-PP vs. GF-EPDM- PP	Auto Insulation component (Ford car)	Hemp fibers are able to replace glass fibers		
Diener & Siehler (1999)	GF-PP vs. Flax- PP	Auto car panel (Mercedes A car)	Successfully passed all test		
Wotzel et al. (1999)	Hemp – Epoxy vs. ABS	Auto side panel	Do not discuss the performance		
Corbiere-Nicollier et al. (2001)	China reed-PP vs. Glass-PP	Transport pallet	Satisfying service requirement		
Source : Joshi et al. (2003) http://textilestudypoint.blogspot.com					

Weight Reduction

Component Study NFRP Base component component 1125 g (ABS) Wotzel et al. 820 g (hemp-Auto side panel epoxy) 3.5 kg (GF-PP) 2.6 kg (hemp-Schmidt & Auto insulation Meyer (1998) PP) 11.77 kg (China 15 kg (GF – PP) Transport-Pallet Corbierereed – PP) Nicollier et al. (2001)

Source : Joshi et al. (2003) http://textilestudypoint.blogspot.com

2. Recreation and Leisure

Patio furniture

Railing

Decking product

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WWWWW

3. Insulated Roofing

Roof sandwich with foam core

Roof sandwich structure with bamboo core

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Fiber hybrids

- Fiber hybrids capitalize on the best properties of various fiber types, and may reduce raw material costs.
- Hybrid composites that combine carbon/aramid or carbon/glass fibers have been used successfully in ribbed aircraft engine thrust reversers, telescope mirrors, driveshafts for ground transportation and infrastructure columnwrapping systems.





Reinforcement

- 1. Fiber
- 2. Whiskers
- 3. Flake
- 4. Particle

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Material	Specific Gravity	Tensile Strength [GPa (10 ⁶ psi)]	Specific Strength (GPa)	Modulus of Elasticity [GPa (10 ⁶ psi)]	Specific Modulus (GPa)
		Whiskers			
Graphite	2.2	20	9.1	700	318
		(3)		(100)	
Silicon nitride	3.2	5-7	1.56-2.2	350-380	109-118
		(0.75 - 1.0)		(50-55)	
Aluminum oxide	4.0	10-20	2.5 - 5.0	700-1500	175-375
		(1-3)		(100-220)	
Silicon carbide	3.2	20	6.25	480	150
		(3)		(70)	
		Fibers			
Aluminum oxide	3.95	1.38	0.35	379	96
		(0.2)		(55)	
Aramid (Kevlar 49)	1.44	3.6-4.1	2.5-2.85	131	91
		(0.525 - 0.600)		(19)	
Carbon ^a	1.78-2.15	1.5-4.8	0.70-2.70	228-724	106-407
		(0.22 - 0.70)		(32 - 100)	
E-Glass	2.58	3.45	1.34	72.5	28.1
		(0.5)		(10.5)	
Boron	2.57	3.6	1.40	400	156
		(0.52)		(60)	
Silicon carbide	3.0	3.9	1.30	400	133
		(0.57)		(60)	
UHMWPE (Spectra 900)	0.97	2.6	2.68	117	121
		(0.38)		(17)	
		Metallic Wires			
High-strength steel	7.9	2.39	0.30	210	26.6
0 0		(0.35)	1922/06/271	(30)	
Molybdenum	10.2	2.2	0.22	324	31.8
		(0.32)		(47)	
Tungsten	19.3	2.89	0.15	407	21.1
	12/2020	(0.42)	8000800	(59)	8003599330

"The term "carbon" instead of "graphite" is used to denote these fibers, since they are composed of crystalline graphite regions, and also of noncrystalline material and areas of crystal misalignment. http://textilestudypoint.blogspot.com/



Table 15.5 Properties of Continuous and Aligned Glass-, Carbon-, and Aramid-fiber Reinforced Epoxy-matrix Composites in Longitudinal and Transverse Directions. In All Cases the Fiber Volume Fraction is 0.60

Property	Glass (E-glass)	Carbon (High Strength)	Aramid (Kevlar 49)
Specific gravity	2.1	1.6	1.4
Tensile modulus			
Longitudinal [GPa (10 ⁶ psi)]	45 (6.5)	145 (21)	76(11)
Transverse [GPa (10 ⁶ psi)]	12 (1.8)	10 (1.5)	5.5 (0.8)
Tensile strength			
Longitudinal [MPa (ksi)]	1020 (150)	1240 (180)	1380 (200)
Transverse [MPa (ksi)]	40 (5.8)	41 (6)	30 (4.3)
Ultimate tensile strain			. ,
Longitudinal	2.3	0.9	1.8
Transverse	0.4	0.4	0.5

Source: Adapted from R. F. Floral and S. T. Peters, "Composite Structures and Technologies," tutorial notes, 1989.



Table 15.6 Elastic Modulus, Density, and Cost Data for Glass and Various Carbon Fibers, and Epoxy Resin

Material	Elastic Modulus (GPa)	Density (g/cm ³)	Cost (\$/kg)
Glass fibers	72.5	2.58	2.50
Carbon fibers (standard modulus)	230	1.80	35.00
Carbon fibers (intermediate modulus)	285	1.80	70.00
Carbon fibers (high modulus)	400	1.80	175.00
Epoxy resin	2.4	1.14	9.00



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Properties of Fiber

T T



Table 11.3 Fiberglass polyester	Woven clo	Cł th r	10pped oving	Sheet-molding compound	
Tensile strength, ksi (MPa)	30–50 (206–344) (1	15–30 03–206)	8–20 (55–138)	
Tensile modulus of elasticity, Msi (GPa)	1.5-4.5 (103-310) (80–2.0 55–138)		
Impact strength notched bar, Izod ft · lb/in, (J/m) of notch	5.0–30 (267–160	2 0) (10	2.0–20.0 07–1070)	7.0–22.0 (374–1175)	
Density (g/cm ³)	1.5-2.1	1.3	35-2.30	1.65–2.0	
Table 11.4 Properties (Carbon fibers an	d epoxy) I	ongitudina	l (0°)	Transverse (90°)	
ensile strength, ksi (MPa)		270 (1860))	9.4 (65)	
ensile modulus of elasticity, Msi (GPa)		21 (145)	C	1.36 (9.4)	
ltimate tensile strain (%)		1.2		0.70	



Reinforcement: Whiskers

- Single crystals grown with nearly zero defects a re termed whiskers
- They are usually discontinuous and short fibers made from several materials like graphite, silicon carbide, copper, iron, etc.
- Whiskers differ from particles where whiskers have a definite length to width ratio greater than one
- Whiskers can have extraordinary strengths upto 7000 MPa

- Metal-whisker combination, strengthening the system at high temperature
- Ceramic-whisker combinations, have high moduli, useful strength and low density, resist temperature and resistant to mechanical and oxidation more than metallic whiskers



Reinforcement: Flake

- Flake
 Often used in place of fibers as they can be densely packed
- Flakes are not expensive to produce and usually cost less than fibers
- Metal flakes that are in close contact with each other in polymer matrices can conduct electricity and heat
- Flakes tend to have notches or cracks around the edges, which weaken the final product.
- They are also resistant to be lined up parallel to each other in a matrix, causing many ven strength

Reinforcement: Partikel

 The composite's strength of particulate reinforced composites depends on the diameter of the particles, the interparticle spacing, volume fraction of the reinforcement, size and shape of the particles.





Continuous and Aligned Fiber Composites a) Stress-strain behavior for fiber and matrix phases



-Consider the matrix is ductile and the fiber is brittle -Fracture strength for fiber is σ^*_{f} and for the matrix is σ_{m}^{*} - Fracture strain for fiber is ε^*_{f} and for the matrix is ϵ^*_{m} $(\epsilon_{m}^{*} > \epsilon_{f}^{*})$



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b) Stress-strain behavior for a fiber reinforced composites



-Stage I-the curve is linear, the matrix and resin deform elastically -For the composites, the matrix yield and deform plastically (at ε*_{vm}) -The fiber continue to stretch elastically, in as much as the tensile strength of the fiber is significantly higher than the yield strength of the matrix



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Elastic Behavior a) Longitudinal Loading

- Consider the elastic behavior of a continuous and oriented fibrous composites and loaded in the direction of fiber alignment
- Assumption: the interfacial bonding is good, thus deformation of both matrix and fibers is the same (an isostrain condition)

Equation for Elastic Modulus of Lamellar Composite



• Isostrain condition: Stress on composite cause all composite layers.

 $\sigma = P/A$ $\sigma_c A_c = \sigma_f A_f + \sigma_m A_m$

 $P_c = P_f + P_m$

Pc = Load on composite Pf = Load on fibers Pm = load on matrix

Figure 11.14

Since length of layers are equal

 $E_{f} = E_{f}V_{f} + E_{m}V_{m}$

 $\sigma_c V_c = \sigma_f V_f + \sigma_m V_m$ Where V_c , V_f and V_m are volume fractions ($V_c = 1$) Since strains $\varepsilon_c = \varepsilon_f = \varepsilon_m$,

$$\frac{\sigma_{c}}{\varepsilon_{c}} = \frac{\sigma_{f} V_{f}}{\varepsilon_{f}} + \frac{\sigma_{m} V_{m}}{\varepsilon_{m}}$$

Rule of mixture of binary composites

Exercise

 A continuous and aligned glassreinforced composite consists of 40% of glass fibers having a modulus of elasticity of 69 GPa and 60% vol. of a polyester resin that when hardened, displays a modulus of 3.4 GPa



- a) Compute the modulus of elasticity of this composite in the longitudinal direction
- b) If the cross-sectional area is 250 mm² and a stress of 50 MPa is applied in this direction, compute the magnitude of the load carried by each of the fiber and matrix phases
- c) Determine the strain that is sustained by each phase when the stress in part (b) is applied



b) Transverse loading

- A continuous and oriented fiber composites may be loaded in transverse direction, load is applied at a 90° angle to the direction of fiber alignment
- In this case, the stresses of the composite, matrix and reinforcement are the same.



Loads on Fiber and Matrix Regions

• Since $\sigma = \mathcal{E}\varepsilon$ and $\varepsilon_{f} = \varepsilon_{m}$ $\frac{P_{f}}{P_{m}} = \frac{\sigma_{f}A_{f}}{\sigma_{m}A_{m}} = \frac{E_{f}\varepsilon_{f}A_{f}}{E_{m}\varepsilon_{m}A_{m}} = \frac{E_{f}V_{f}}{E_{m}A_{m}} = \frac{E_{f}V_{f}}{E_{m}V_{m}}$



Isostress Condition

Fiber layer

Matrix layer

Eigure 11.15

 Stress on the composite structure p equal stress condition on all the layer

$$\sigma_{c} = \sigma_{f} + \sigma_{m}$$
$$\varepsilon_{c} = \varepsilon_{f} + \varepsilon_{m}$$

Assuming no change in area and assuming unit length of the composite σ $\varepsilon_{c} = \varepsilon_{f}V_{f} + \varepsilon_{m}V_{m}$ But $\frac{\sigma}{E_{c}} = \frac{\sigma}{E_{f}} + \frac{\sigma}{E_{m}}$

> Therefore http://textilestudypoint.blogspot.com



Indicate whether the statements are TRUE of FALSE

- 1) Usually the matrix has a lower Young's Modulus than the reinforcement
- 2) The main objective in reinforcing a metal is to lower the Young's Modulus
- 3)The properties of a composite are essentially isotropic when the reinforcement is randomly oriented, equiaxed particles

Mark the correct answers

The matrix

- a) Is always fibrous
- b) Transfers the load to the reinforcement
- c) Separates and protects the surface of the reinforcement
- d) Is usually stronger than the reinforcement

💷s never a ceramic

- The specific modulus
- a) Is given by 1/E where E is Young's modulus
- b) Is given by Ep where p is density
- c) Is given by E/ρ
- d) Is generally low for polymer matrix composites
- e) Is generally low for metallic materials



- Hybrids
- a) Are composites with two matrix materials
- b) Are composites with mixed fibers
- c) Always have a metallic constituents
- d) Are also known as bidirectional woven composites
- e) Are usually multilayered composites



- Compared with a ceramic, a polymer normally has a
- a) Greater strength
- b) Lower stiffness
- c) Lower density
- d) Better high temperature performance
- e) Lower hardness



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