دانشکده فنی و مهندسی
گروه مهندسی عمران

مکانیک مواد مرکب

(Mechanics of Composite Materials)

دکتر مهرداد حجازی

۱۳۹۰

فصل اول

ویژگی های عمومی مواد مرکب

(General Features)

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Composite Material

Two inherently different materials that when combined together produce a material with properties that exceed the constituent materials.

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Composites Offer

- High Strength
- Light Weight
- Design Flexibility
- Consolidation of Parts
- Net Shape Manufacturing

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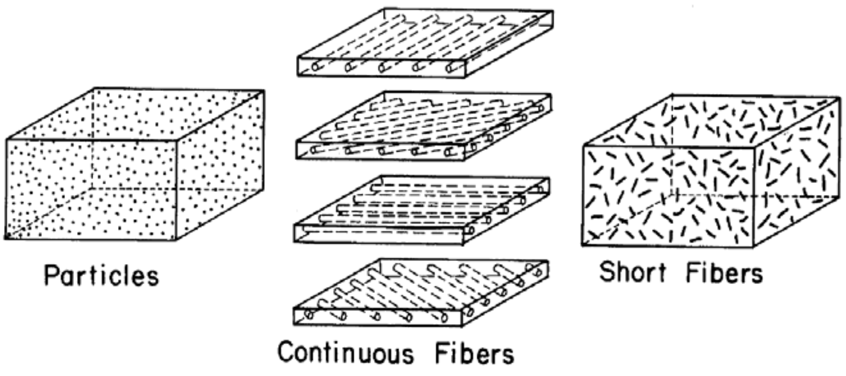
- Microstructure of a composite = matrix + reinforcement



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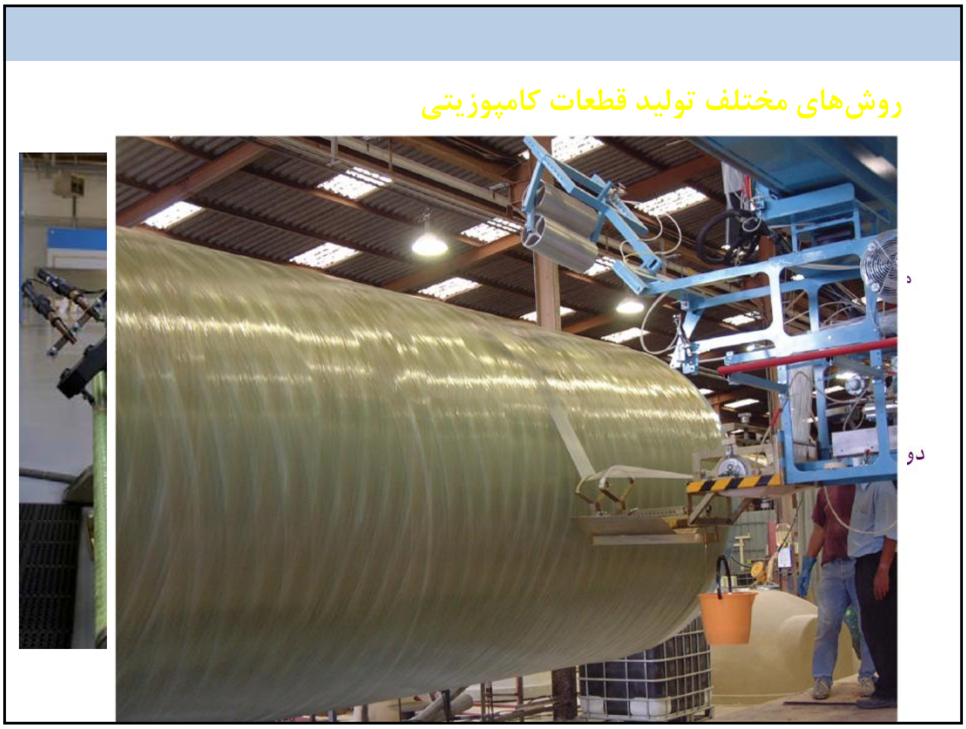
روش‌های مختلف تولید قطعات کامپوزیتی

کاربردهای مواد مرکب (کامپوزیتها)

- صنایع دریایی
- صنعت هوا فضا
- صنعت نفت ، گاز و پتروشیمی
- صنعت راه و ساختمان
- صنایع دفاعی
- صنایع خودرو سازی
- صنایع انرژی
- صنایع ورزشی و تفریحی
- صنایع پزشکی
- و ...

کاربرد: **صنایع دریایی**

- **با توجه به پایداری بسیار زیاد کامپوزیتهای بستر پلیمری و مقاومت بسیار خوب آنها در محیطهای خورنده، این کامپوزیتها، کاربردهای وسیعی در صنایع دریایی پیدا کرده اند که از آن جمله می توان به ساخت بدنه قایقها و کشتیها و تاسیسات فراساحلی اشاره داشت.**

استفاده از کامپوزیتها در این صنعت، حدود 60% صرفه جویی اقتصادی داشته است .

کاربرد: صنعت هوا فضا

- ساخت بدنه هواپیما، پره های هلیکوپتر و پوشش رادار هواپیما و حتی در تهیه لباس فضا نوردان از کاربردهای کامپوزیت در صنعت هوا فضا است.

کاربرد: صنعت نفت ، گاز و پتروشیمی

- این مواد در صنعت نفت وگاز نیز به منظور ترمیم و تقویت سازه های فرسوده و ترمیم لوله های فرسوده نفت و گاز به کار میروند (لوله هاي انتقال گاز غالباً دچار مشکل خوردگي مي گردند).
- امروزه يكي از روشهاي مناسب تعمير در دنيا، استفاده از كامپوزيت ها مي باشد.

کاربرد: **صنایع انرژی**

- **کامپوزیت ها با توجه به ساختار شبکه ای و طولی ای که دارند گرما را فقط در جهت طولی منتقل می کنند و نه عرضی**

بنابراین به عنوان عایق گرما برای دیواره توربین ها مناسب می باشند.

- **همچنین در تهیه انواع قابهای لامپ روشنایی استفاده می شوند.**

کاربرد: **صنعت راه و ساختمان**

- **سطح کامپوزيتي، 6 تا 7 برابر سطح بتون آرمه ظرفيت تحمل بار را دارد و اين در حالي است كه تنها 20 درصد وزن آنرا داراست.**
- **طول عمر آنها نسبت به مشابه فولادي و بتني چندين برابر است.**
- **كامپوزيت ها در طول دوره سرما منقبض نمي شوند**

و مانند آهن در محيط مرطوب زنگ نمي زنند
و در محيط دريا دچار خوردگي نمي شوند

- **توانايي استفاده از كامپوزيت ها در ساخت سازه هاي پيش ساخته و سبک وزن باعث مي شود كه هزينه بناي سازه بشدت كاهش يابد**
- **كامپوزيت ها مي توانند با مقاومت بالايي كه در برابر خوردگي و خستگي از خود نشان مي دهند، هزينه هاي مربوط به تعمير و نگه داري خود را به حداقل برسانند.**

کاربرد کامپوزیتها در راه سازی

ساخت تراورس (چوبهاي عرضي كه در زير ريل راه آهن قرار مي گيرند)

- **قيمتي معادل قيمت بهترين نوع چوبي آن**
- **سهولت كاربرد**
- **عمر طولاني تر**
- **مواد اوليه ارزان قيمت (از ضايعات كارخانجات ديگر مثل ضايعات رزيني آسياب شده، لاستيك خرد شده از تايرهاي بازيافتي و ضايعات فيلم هاي پلي اتيلني با دانسيته بالا(HDPE))**
- **برخلاف چوب اين تراورس ها**
  - **نمي شكنند**
  - **ترك بر نمي دارند**
  - **مستعد پوسيدگي نيستند**
  - **حشرات نمي توانند به آنها آسيبي بزنند**

به علت عدم پوسيدگي، استفاده از اين تراورس ها در مناطق مرطوب به صرفه تر از نوع چوبي آن است.

در كشور ما ساليانه مقادير بسيار زيادي تراورس راه آهن تعويض يا بهسازي مي گردد و اين جداي از هزينة هنگفت بستن خط و تغيير ريل ها و زيرسازي هاي لازم است. اما اگر همين تراورس ها با كامپوزيت تقويت شوند عمر 7 ساله تراورس ها را تا 30 سال مي توان افزايش داد و در ازاي پرداخت هزينة اوليه دو يا سه برابر، هزينة تعمير و تعويض تا 4 برابر كاهش مي يابد و در نهايت صرفة اقتصادي دارد .

کاربرد کامپوزیتها در پل سازی

پل هاي كامپوزيتي حاصل، در مقايسه با پل هاي مشابه از جنس بتن و فولاد،

- **سبكي،**
- **طول عمر مفيد بيشتر،**
- **سرعت نصب بيشتر،**
- **هزينة نصب و نگهداري كمتري دارند.**

سطوح پل هاي كامپوزيتي نيز از پانل هاي كامپوزيتي ساخته مي شوند .

اين پانل ها از روش هايي همچون لايه چيني دستي و پالتروژن ساخته مي شوند و با طول عمر بالا و استحكام بيشتر، جايگزين ايده آلي براي مشابه فولادي خود هستند.

اين قطعات متناسب با احتياج مصرف كننده مي تواند در سايزهاي مختلفي بريده شود تا با ابعاد پل موردنظر سازگار باشند.

کاربرد کامپوزیتها در صنایع ساختمان

1. تعمير و تقويت خارجي سازه ها
2. ساخت سازه هاي تمام كامپوزيت

در كشورهايي همچون مالزي، ساخت سازه هاي تمام كامپوزيت از قبيل گنبدها آغاز شده است. در ايران نيز سازه هاي گنبدي شكل وجود دارند كه وزن بتن مورد نياز براي ساخت آنها بالغ بر 70 هزار تن خواهد گرديد و اگر آنها را از كامپوزيت بسازيم وزن آنها تا يك سوم تقليل مي يابد.

3. تعمير و تقويت داخلي سازه ها

در مناطق جنوب و شمال كشور، به دليل زياد بودن رطوبت و ساير مواد خورنده، آرماتورهاي فلزي بتن، دچار پوسيدگي زودهنگام مي شوند كه اين خود باعث كاهش مقاومت آرماتور و ترك برداشتن و گسيختن بتن دراثر ازدياد حجم آرماتورهاي پوسيده ميگردد. در چنين شرايطي آرماتور هاي كامپوزيتي توليد شده توسط فرايند پالتروژن مي توانند پاسخگوي مناسبي به اين مسئله باشد.

Composite Bicycle

Laminated Fiberglass Bow

Graphite Snowboard

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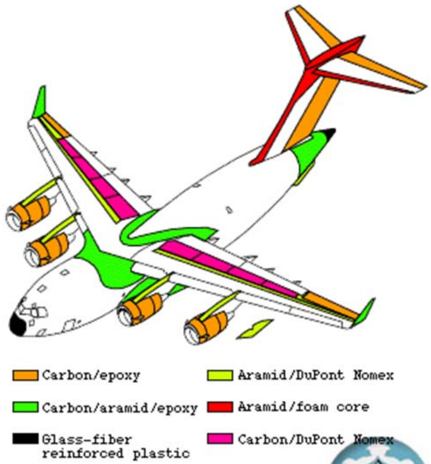
Dodge Viper

Front grill of an Automobile



Different part of an airplane

Fiber Reinforced Polymer Matrix

Matrix

- Transfer Load to Reinforcement
- Temperature Resistance
- Chemical Resistance

Reinforcement

- Tensile Properties
- Stiffness
- Impact Resistance

Design Objective

- Performance: Strength, Temperature, Stiffness
- Manufacturing Techniques
- Life Cycle Considerations
- Cost

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Matrix Considerations

- End Use Temperature
- Toughness
- Cosmetic Issues
- Flame Retardant
- Processing Method
- Adhesion Requirements

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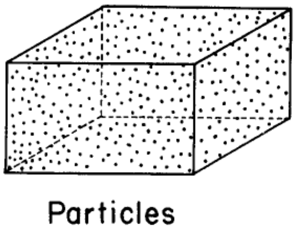
Classification of Composites

- On basis of matrix:
  - **Polymer** matrix composites (**P**MCs)
  - **Metal** matrix composites (**M**MCs)
  - **Ceramic** matrix composites (**C**MCs)

- Purpose of reinforcement
  - PMC: increase stiffness (E), yield strength, tensile strength, and creep resistance
  - MMC: increase yield strength, tensile strength, and creep resistance
  - CMC: increase fracture toughness (K_c)

Classification of Composites

- On basis of reinforcement
  - Particle reinforced composites
    - Natural
      - Ex., precipitates
    - Artificial
      - Addition of immiscible phases



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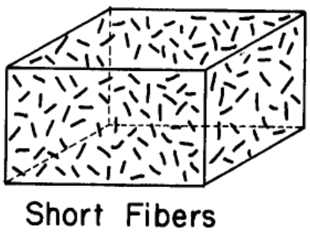
- Short fiber or whisker reinforced composites
  - Artificial



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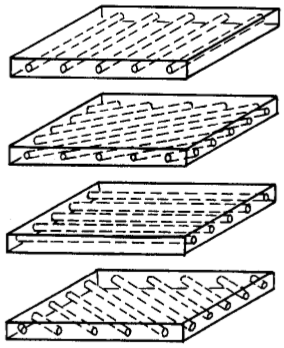
- Continuous fiber or sheet reinforced MMCs
  - Natural ("sort of")
    - Ex., DS eutectics
  - Artificial



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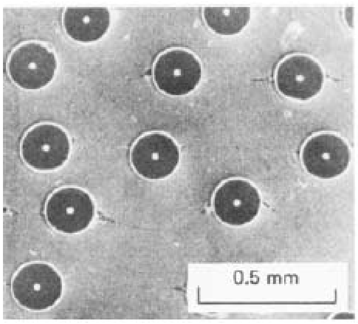
What can composites look like?

MMC

Fiber reinforced



Transverse section of a boron fiber reinforced aluminum composite. $V_f = 10\%$.

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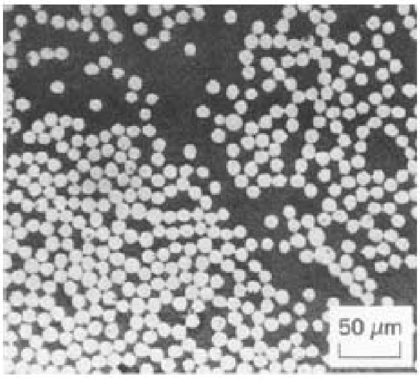

PMC

Fiber reinforced

Transverse section of a carbon fiber reinforced polyester resin. V_f = 50% (Optical).

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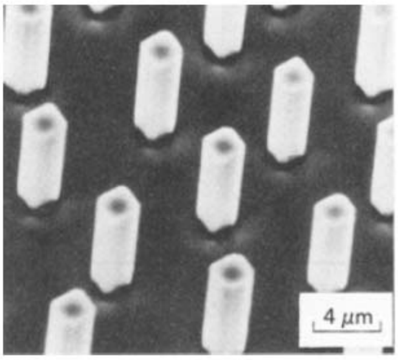
MMC

Fiber reinforced (eutectic)



Deeply etched transverse section of a eutectic composite showing NbC fibers in a Ni-Cr matrix.

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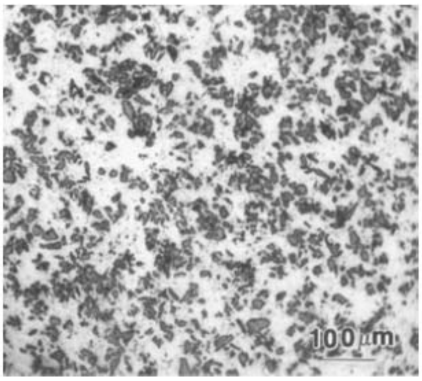

MMC

Particle reinforced

SiC particles in an Al alloy matrix (SEM). $V_f = 17\%$.

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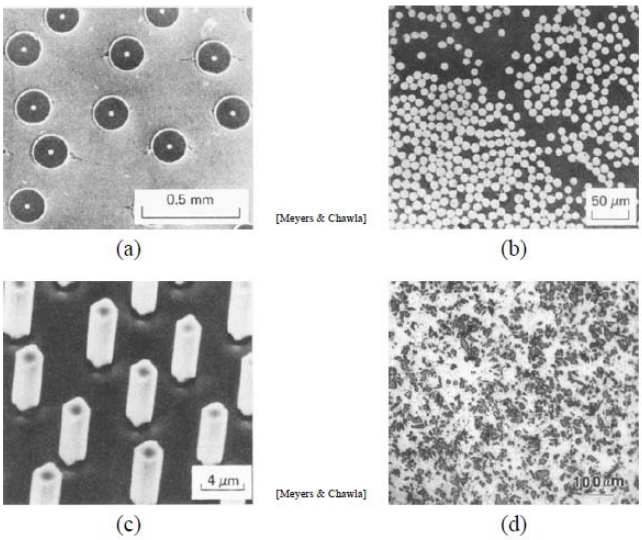
MMC
Fiber reinforced

PMC
Fiber reinforced

MMC
Fiber reinforced (eutectic)

MMC
Particle reinforced



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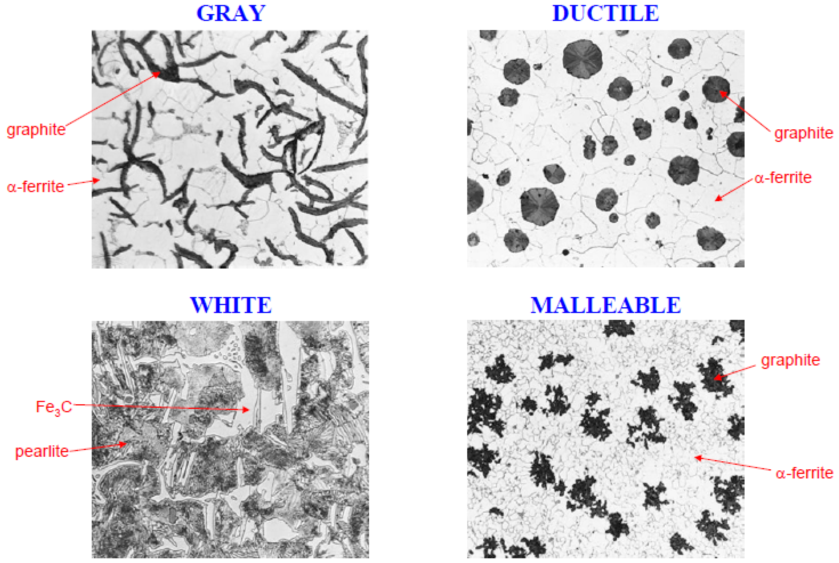
Cast Iron: another good example of a composite

Particle reinforced MMCs



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What do properties depend upon?

- Matrix type
  - Structure and intrinsic properties
- Reinforcement:
  - Concentration
  - Shape
  - Size
  - Distribution
  - Orientation
  - Matrix/reinforcement interface

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Matrix Types

Polyester

Polyesters have good mechanical properties, electrical properties and chemical resistance. Polyesters are amenable to multiple fabrication techniques and are low cost.

Vinyl Esters

Vinyl Esters are similar to polyester in performance. Vinyl esters have increased resistance to corrosive environments as well as a high degree of moisture resistance.

Epoxy

Epoxies have improved strength and stiffness properties over polyesters. Epoxies offer excellent corrosion resistance and resistance to solvents and alkalis. Cure cycles are usually longer than polyesters, however no by-products are produced.

Flexibility and improved performance is also achieved by the utilization of additives and fillers.

Reinforcement

Fiber Type

- Fiberglass
- Carbon
- Aramid

Textile Structure

- Unidirectional
- Woven
- Braid

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Fiberglass

E-glass: Alumina-calcium-borosilicate glass (electrical applications)

S-2 glass: Magnesuim aluminosilicate glass (reinforcements)

Glass offers good mechanical, electrical, and thermal properties at a relatively low cost.

	E-glass	S-2 glass
Density	2.56 g/cc	2.46 g/cc
Tensile Strength	390 ksi	620 ksi
Tensile Modulus	10.5 msi	13 msi
Elongation	4.8%	5.3%

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Aramid

Kevlar™ & Twaron™

Para aramid fiber characterized by high tensile strength and modulus

Excellent Impact Resistance

Good Temperature Resistance

Density	1.44 g/cc
Tensile Strength	400 ksi
Tensile Modulus	18 Msi
Elongation	2.5%

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Carbon Fiber

PAN: Fiber made from Polyacrylonitrile precursor fiber

High strength and stiffness

Large variety of fiber types available

	Standard Modulus	Intermediate Modulus
Density	1.79 g/cc	1.79 g/cc
Tensile Strength	600 ksi	800 ksi
Tensile Modulus	33 Msi	42 Msi
Elongation	1.8 %	1.8 %

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Weight Considerations

Aramid fibers are the lightest
1.3-1.4 g/cc

Carbon
1.79 g/c

Fiberglass is the heaviest
2.4 g/cc

Strength Considerations

Carbon is the strongest (tensile strength)
600-800 ksi

Fiberglass
400-600 ksi

Aramids
400 ksi

Impact Resistance

Kevlar (Aramid) is the toughest

Fiberglass

Carbon

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Stiffness Considerations

Carbon is the stiffest (tensile mudulus)
30-40 msi

Aramids
14 msi

Fiberglass
10-13 msi

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Cost Considerations

Fiberglass is cost effective
$5.00-8.00/lb.

Aramids
$20.00/lb

Carbon
$30.00-$50.00/lb

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FRP = Fibre Reinforced Polymer (Plastic)
CFRP = Carbon Fibre Reinforced Polymer
GFRP = Glass Fibre Reinforced Polymer

CFRP vs. GFRP

CFRP	GFRP
Active loading	Passive/seismic loading
Damp/wet conditions	Dry conditions
Stiffness driven	Strength driven
Extreme alkaline conditions	Extreme acidic conditions
	Economical

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FRP Composite Applications for Infrastructure, Rehabilitation and Repairs

Steel vs. Composites

Steel	Composites
Low material cost	High material cost
High installed cost	Low installed cost
Corrosive	Non-corrosive
Heavy	Lightweight
Fabrication required	No fabrication required
High maintenance	Low maintenance

Fabric Structures

Woven: Series of Interlaced yarns at 90° to each other

Knit: Series of Interlooped Yarns

Braided: Series of Intertwined, Spiral Yarns

Nonwoven: Oriented fibers either mechanically, chemically, or thermally bonded

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Woven Fabrics

Basic woven fabrics consists of two systems of yarns interlaced at right angles to create a single layer with isotropic or biaxial properties.

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Physical Properties

- Construction (ends & picks)
- Weight
- Thickness
- Weave Type

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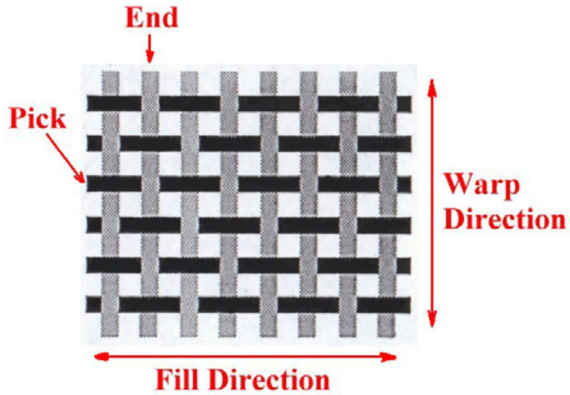
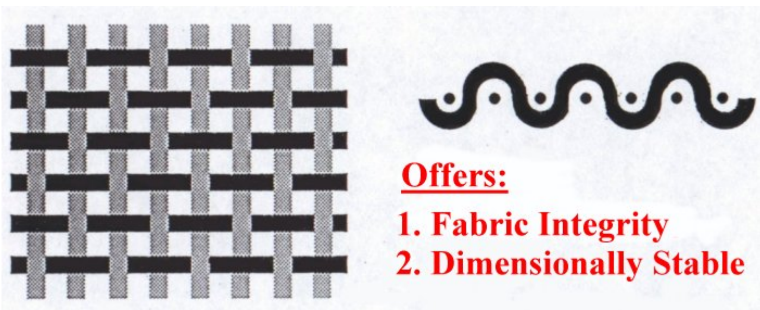
Components of a Woven Fabric

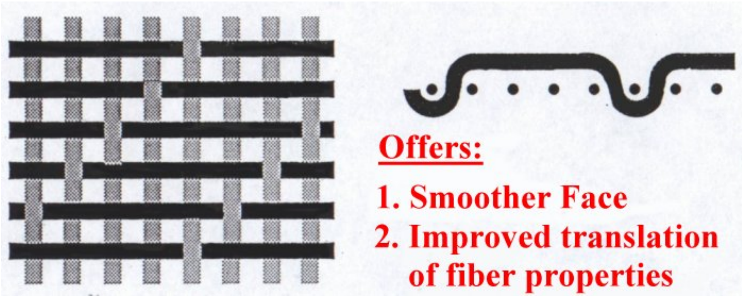


Basic Weave Types

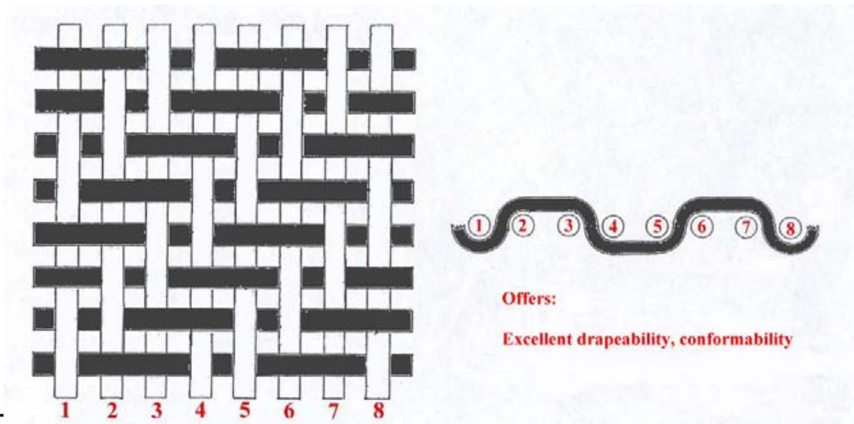
Plain Weave



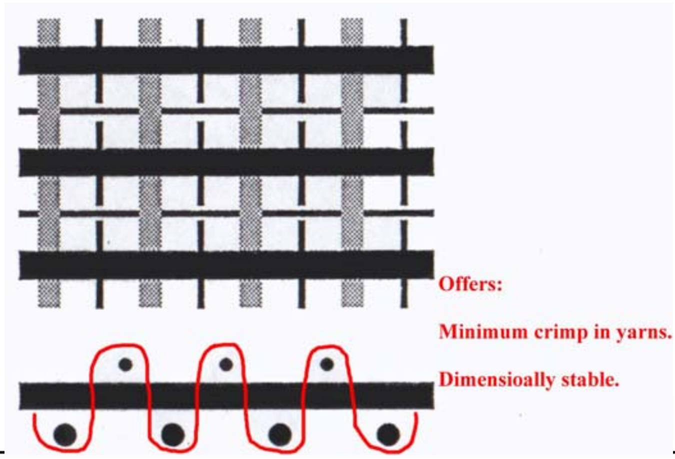
Satin 5HS



2 x 2 Twill



Non-Crimp



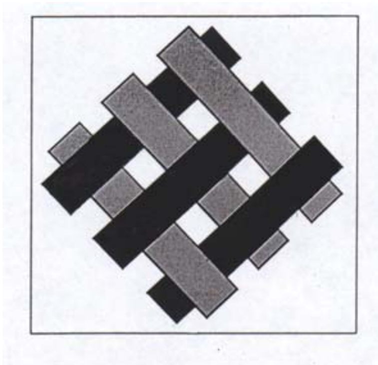
Braiding

A braid consists of two sets of yarns, which are helically intertwined.

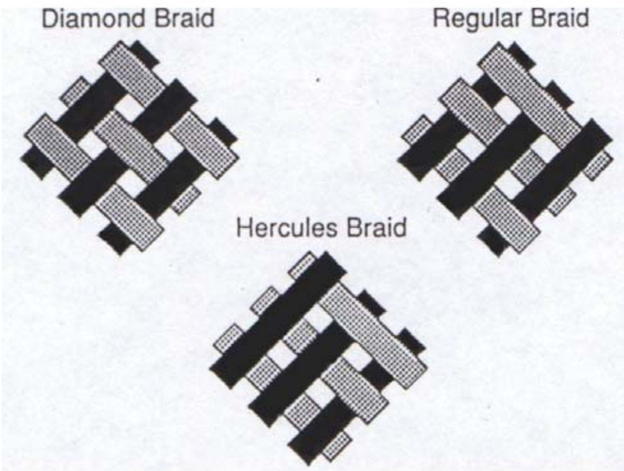
The resulting structure is oriented to the longitudinal axis of the braid.

This structure is imparted with a high level of conformability, relative low cost and ease of manufacture.

Braid Structure



Types of Braids

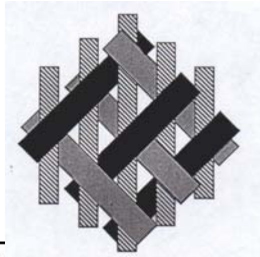


Triaxial Yarns

A system of longitudinal yarns can be introduced which are held in place by the braiding yarns

These yarns will add dimensional stability, improve tensile properties, stiffness and compressive strength.

Yarns can also be added to the core of the braid to form a solid braid.



FRP Composite Applications for Infrastructure, Rehabilitation and Repairs

FRP = Fibre Reinforced Polymer (Plastic)

FRP Composite Applications for Infrastructure, Rehabilitation and Repairs

FRP Products

- Bridge Deck Replacement
  - All-FRP, full deck replacement
  - All-FRP, low-profile deck replacement
- Concrete Reinforcement
  - Deck replacement – Top mat
  - Traffic barriers
  - Parapets
- External Reinforcement Systems
  - Strengthening
  - Seismic Upgrade

FRP Composite Benefits for Construction Applications

- Faster construction could reduce traffic delays
- Reliability of pre-engineered systems
- Enhanced durability and fatigue characteristics as proven in related applications from other industries
- Products and systems enable value engineering that result in innovative and efficient installations

FRP Composite Applications for Infrastructure, Rehabilitation and Repairs

Estimated Installations to Date Worldwide (Bridges)

▪ All-FRP Deck	200
▪ FRP Reinforced Concrete	200
▪ Seismic Upgrade - Strengthening	15,000+

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FRP Composite Applications for Infrastructure, Rehabilitation and Repairs

FRP Bridge Decks

FRP Composite Applications for Infrastructure, Rehabilitation and Repairs

FRP Bridge Decks

Bentley Creek Bridge
Elmira, NY

Route 418
Schroon River Bridge
Warrensburg, NY

FRP Composite Applications for Infrastructure, Rehabilitation and Repairs

FRP Rebar

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FRP Composite Applications for Infrastructure, Rehabilitation and Repairs

External Reinforcement

- Steel
  - Plates
  - Jackets

- CFRP
  - Strips
  - Fabrics
  - Brackets

- GFRP
  - Fabrics

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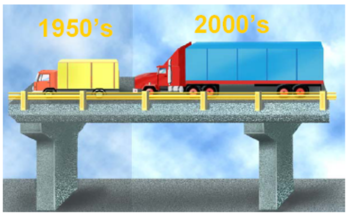
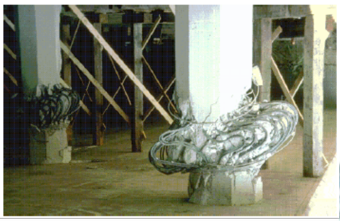
Why Do Structures Need Strengthening?

- Insufficient reinforcement
- Corrosion damage
- Change in use
- Structural damage
- Seismic upgrade





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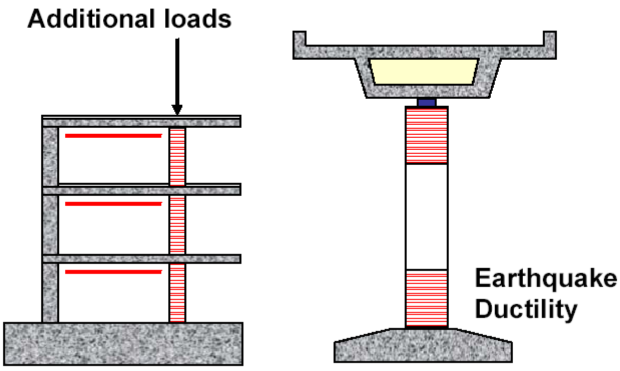
Structures



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Typical Applications

Bridges

- Girder Strengthening
- Column Wrapping
- Pier Upgrades
- Deck Stiffening

FRP Composite Applications for Infrastructure, Rehabilitation and Repairs

FRP Fabrics

- Available in carbon or glass
- Conforms to all shapes & sizes
- Effective on concrete and masonry

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Saturating the Fabric

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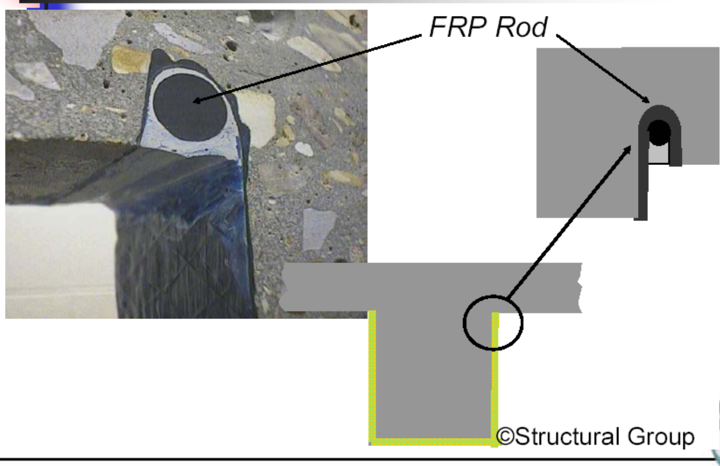
Shear Strengthening
Anchorage Details



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FRP Composite Applications for Infrastructure, Rehabilitation and Repairs

Cold Weather Installations

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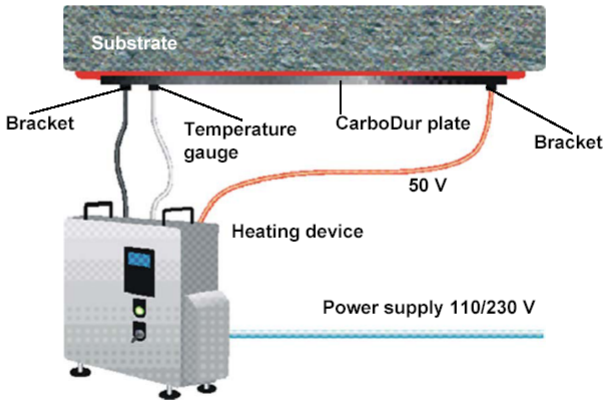
Fast curing of the adhesive

How it works



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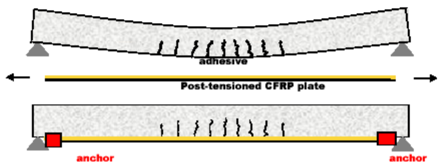
Wooden Bridge

FRP Composite Applications for Infrastructure, Rehabilitation and Repairs

Post-tensioning with CFRP

- Optimal use of Carbon Fiber Plates
- Reduces tensile strain in existing steel reinforcement
- Increases live load capacity of member
- Non-corrosive material



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Post-tensioning with CFRP

Dead End

Live End

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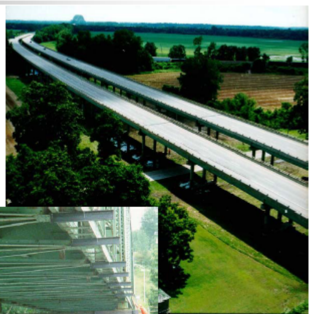
Case Studies



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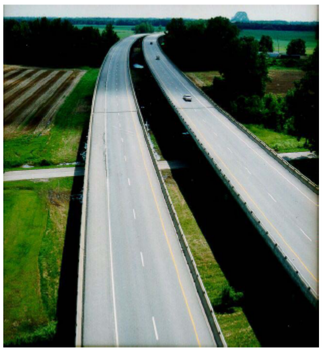
I-57 Bridge Column Seismic Upgrade Cairo, Illinois

- Owner:
  Illinois DOT
- 150 mile New Madrid Fault crosses 5 state lines
- New Madrid earthquake of 1811-12 included 3 main tremors > 8.0 on Richter scale
- Illinois DOT has undertaken program to seismically strengthen bridges
- 50 Piers and 158 columns were part of this contract



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I-57 Bridge Column Upgrade

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I-80 Salt Lake City

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I-580 Reno, NV

- Seismic strengthening project
- Flared column geometry

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Bible Christian Bridge Cornwall County, UK

- Owner: UK - Department of Transport
- General Contractor: Cornwall County
- Subcontractor: Makers, Ltd.

Bible Christian Bridge

- Located 250 miles (400 km) from London
- A30 Highway (4 lanes total)
- Guard rails protect columns from cars
- Columns strengthened for protection against trucks (impact loading)

Bible Christian Bridge

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Switzerland Bridge

- Top side reinforcement
- Carbon fiber plates installed
- Hot applied asphalt placed over carbon fiber

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Route 278 over Bennetts Creek
Steuben County

- First Composite Bridge in New York
- Superstructure Replacement
- Span Length – 26 Feet
- Supplier - Hardcore Composites
- Construction and Erection - NYSDOT Maintenance
- Opened to traffic – October 1998

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Route 367 over Bentley Creek Chemung County

- Deck Replacement
- 140 foot truss Span
- Existing concrete deck weighed 150psf , new FRP deck weighs 22 psf
- Removed 14 ton load Posting
- Winner of Civil Engineering Research Foundation's Charles H. Pankow Award for Innovation

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Route 223 over Cayuta Creek Chemung County

- Deck replacement
- 140 foot truss Span

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Route 418 over Schroon River Warren County

- Deck Replacement
- 160′ Thru Truss Span
- ADT 3500
- Supplier – Martin Marietta Composites
- Removed Load Restriction thru use of FRP Deck

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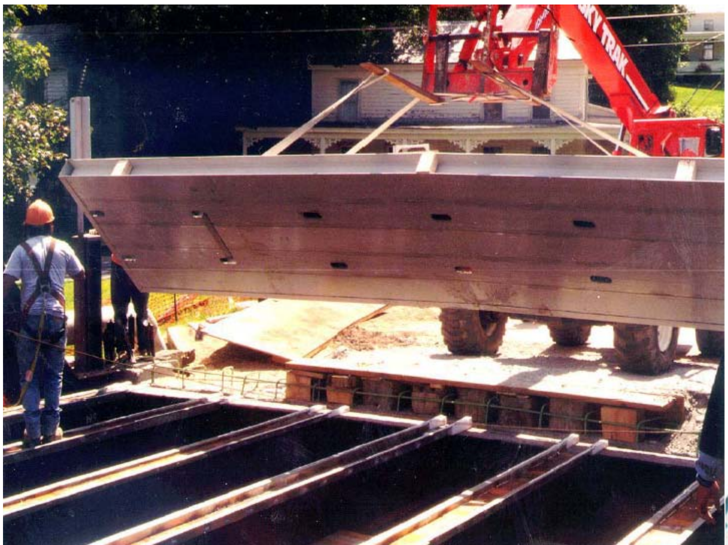

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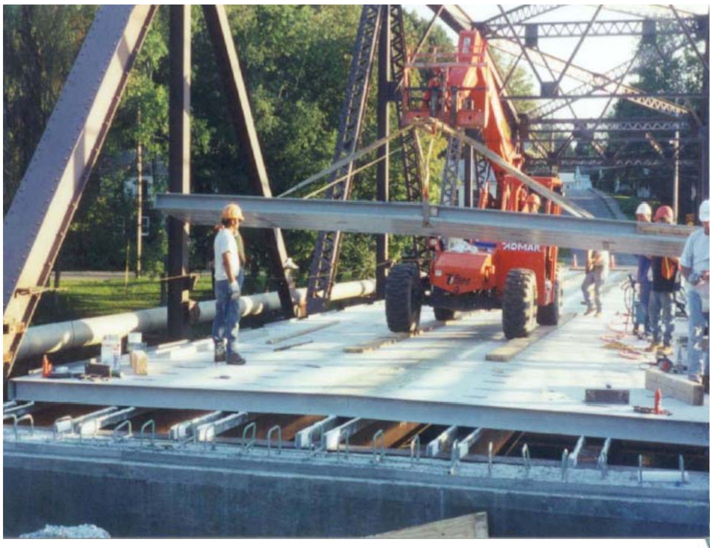

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Problems

- Wearing Surface
- Connections to Superstructure

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FRP Composite Applications for Infrastructure, Rehabilitation and Repairs

Concrete Repair & Strengthening

- Column Wrapping
- Pier Cap Beams
- Beam Strengthening
- Seismic Retrofitting

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FRP Composite Applications for Infrastructure, Rehabilitation and Repairs

FRP Advantages

- Durability
- High Strength to Weight Ratio
- Light Weight
- Speed of Installation
- Concrete Repair and Strengthening

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FRP Disadvantages

- Initial cost
- Lack of Accepted Design Codes and Specifications
- Thermal Expansion

Conclusions

•Composite materials offer endless design options.

•Matrix and Fibre are critical in the design process.

•Composite structures can be produced with specific properties to meet various requirements.

خلاصه

FRP : Fibre-reinforced plastic

FRP
- 1. short fibres (≤50mm) reinforced in a plastic matrix
- 2. continuous (long) fibres (>50mm) " " "

Continuous (long) fibre-reinforced composite materials are referred with these names:
- FRP composites
- advanced composites
- fibrous composites
- composite materials
- composites

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Fibrous Composites

Composite = consisting of two or more distinct parts.

Composites → Continuous medium = Matrix : the binding material
Composites → Discontinuous medium = Reinforcement

Composite materials →
1. Particulate composites
2. Fibrous composites
3. Laminate composites

Our Course:

Continuous Fibrous Composites in a Laminated Form
(Laminated Continuous FRP)

Fibres → 1. glass
→ 2. carbon (graphite)
→ 3. Kelvar (Armid)
(4. metallic fibre (boron) + metallic matrix (aluminium) ⇒ metal matrix composite) → F. / M.

FRP (Fibre-reinforced plastic)

Matrix → super polymer materials (plastics)

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Individual layers of the material → bonded together
→ an element of plate ⇒ laminated fibrous comp

Laminate : The constituent materials are the same in each layer. (with the same patt of fibre reinforceme
= play or lamina

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Hybrid Laminate:

→ The layers are of different constituent materials

↘ or of the same materials, but of different fibre reinforcing patte

FRP Constituents

Fibres
- 1. glass
  - 1. E(electrical)-glass → high strength
  - 2. S(silica)-glass → costly (higher strength)
- 2. carbon
  - 1. high modulus – low strength
  - 2. low modulus – high strength
  - → use intermediate
  - diameter ≃ 10 μm
- 3. Kelvar (organic: C, O, N, H) → for impact resistance applications (but poor com strength)
- (4. metal matrix composite (boron (metal), aluminium))

Matrix → Plastics (organic)

1. Thermosets (hardens irreversibly) : used extensively
2. Thermoplastics (softs when heated / hardens when cooled) : brittle and prone to in… dam…

Matrix → 1. Epoxy resins :
→ 2. Polyester resins :

: for high load bearing applications

: for low load bearing applications : aerospace applicatio…

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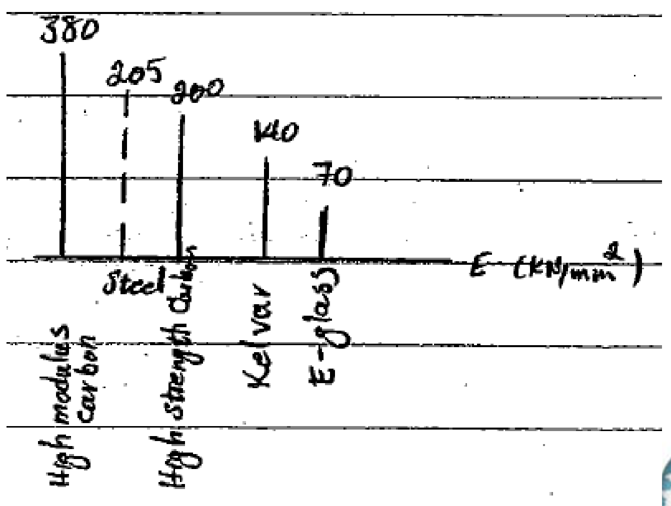
Volume of fibres ~ 60% composite



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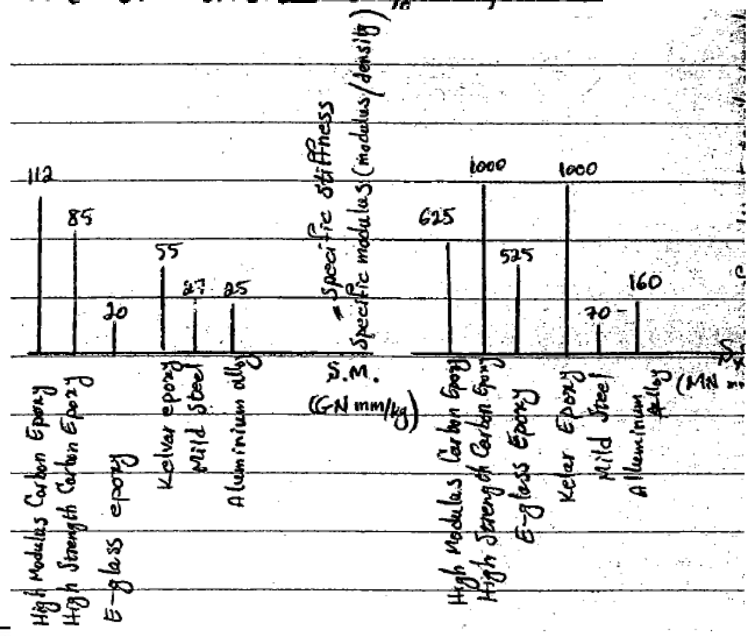
Volume of Fibres ≃ 60% composite



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Specific Strength (Ultimate tensile strength / density)

1. ~~Metal~~ Composites have great advantage over metallic materials.

(S.S. aluminium ≃ 2 × S.S. steel

S.S. H.S. Carbon Epoxy ≃ 15 S.S. steel

" ≃ 7 S.S. aluminium

{ " ≃ 2 S.S. E-glass epoxy

{ S.M. " ≃ 4 S.M. ⟹

use carbon rather than glass.

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Specific Modulus (Specific Stiffness) (Moludus/density)

S.M. H.S. Carbon Epoxy ≃ 4 × S.M. Steel

(S.M. Steel ≃ S.M. aluminium)

S.M. H.S. Carbon Epoxy ≃ 4 × S.M. E-glass Epoxy

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Types of Materials:

1. Homogenous: In a particular direction, material poropetics remain constant from point to point

2. Heterogenous: " , " don't "

3. Isotropic: At a point, the material propeties are the same in all directions.

4. Orthotropic: At a point, 1. the material has three different propeties in three mutually perpendicular directions, and
2. has only three mutually perpendicular planes of material property symmetry at a point in the body.

5. Anisotropic: At a point, has material propeties which are all different in all directions

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Study of C.M.:

1. Micromehanics: the constituent materials (fibres and resin) are looked at sperately. (heterogeneous)

✓ 2. Macromechanics: looks at the composite material as a whole. (homogeneous)

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خصوصیات الاستیک نمونه
(Typical Elastic Properties)

۱- مقادیر برای حرارت اتاق و شرایط خشک می باشد.

۲- حجم الیاف برای حالت یک جهته برابر ۶۰٪ و برای حالت دو جهته برابر ۵۰٪ می باشد.

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Unidirectional Prepregs: Typical Elastic Properties

	E_1 (kN/mm^2)	E_2 (kN/mm^2)	G_{12} (kN/mm^2)	ν_{12}
High strength carbon/epoxy	140	10	5	0·30
High modulus carbon/epoxy	180	8	5	0·30
E-glass/epoxy	40	8	4	0·25
Kevlar/epoxy	75	6	2	0·34

E_1 = Young's modulus in fibre direction.
E_2 = Young's modulus in transverse direction.
G_{12} = in-plane shear modulus.
ν_{12} = major Poisson's ratio.

برای فولاد: $E = 200\ kN/mm^2$

Prepreg= مواد مرکبی که در آنها همزمان الیاف و ماده مادر **(matrix)** به عمل می آیند، نه جدا جدا.
E(electrical)-glass

Woven Prepregs: Typical Elastic Properties

	E_1 (kN/mm^2)	E_2 (kN/mm^2)	G_{12} (kN/mm^2)	ν_{12}
High strength carbon/epoxy	70	70	5	0·10
High modulus carbon/epoxy	85	85	5	0·10
E-glass/epoxy	25	25	4	0·20
Kevlar/epoxy	30	30	5	0·20

E_1 = Young's modulus in fibre direction.
E_2 = Young's modulus in transverse direction.
G_{12} = in-plane shear modulus.
ν_{12} = major Poisson's ratio.

Woven= مواد مرکبی که در آنها الیاف دوجهته (عمود بر هم) هستند.

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مشخصات مقاومت نمونه
(Typical Strength Properties)

۱- مقادیر برای حرارت محیطی می باشد.

۲- حجم الیاف برای حالت یک جهته برابر ۶۰٪ و برای حالت دو جهته برابر ۵۰٪ می باشد.

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Unidirectional Prepregs: Typical Strength Properties (N/mm^2)

	X_t	X_c	Y_t	Y_c	S
High strength carbon/epoxy	1 500	1 200	50	250	70
High modulus carbon/epoxy	1 000	850	40	200	60
E-glass/epoxy	1 000	600	30	110	40
Kevlar/epoxy	1 300	280	30	140	60

X_t = longitudinal tensile strength.
X_c = longitudinal compressive strength.
Y_t = transverse tensile strength.
Y_c = transverse compressive strength.
S = in-plane shear strength.

Prepreg= مواد مرکبی که در آنها همزمان الیاف و ماده مادر (matrix) به عمل می آیند، نه جدا جدا.
E(electrical)-glass

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Woven Prepregs: Typical Strength Properties (N/mm²)

	X_t	X_c	Y_t	Y_c	S
High strength carbon/epoxy	600	570	600	570	90
High modulus carbon/epoxy	350	150	350	150	35
E-glass/epoxy	440	425	440	425	40
Kevlar/epoxy	480	190	480	190	50

X_t = longitudinal tensile strength.
X_c = longitudinal compressive strength.
Y_t = transverse tensile strength.
Y_c = transverse compressive strength.
S = in-plane shear strength.

Woven= مواد مرکبی که در آنها الیاف دوجهته (عمود بر هم) هستند.

Composite Materials

End