NEW TRENDS IN COMPOSITE MATERIALS

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PART I

Introduction to Composite Materials

Composite Materials

- These are materials made up from, or composed of, a combination of different materials **to take overall advantage of their different properties**.

- Composite material consist of **strengthening phase** embedded in **matrix.**

Relative importance of Engineering Materials as a function of time.

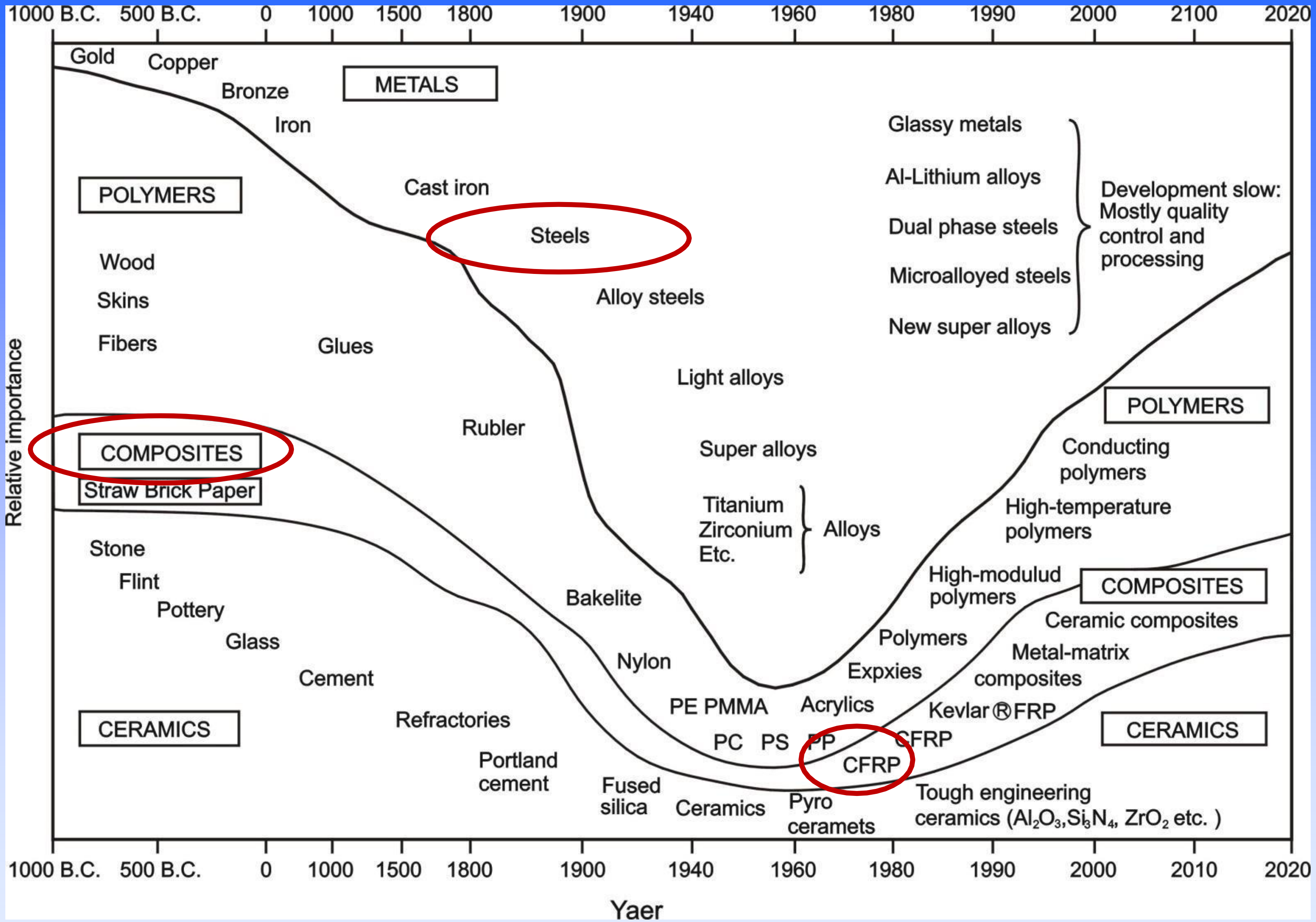


Fig. The relative importance of metals, polymers, composites and ceramics as a function of time.(Ashby 1987)

Introduction

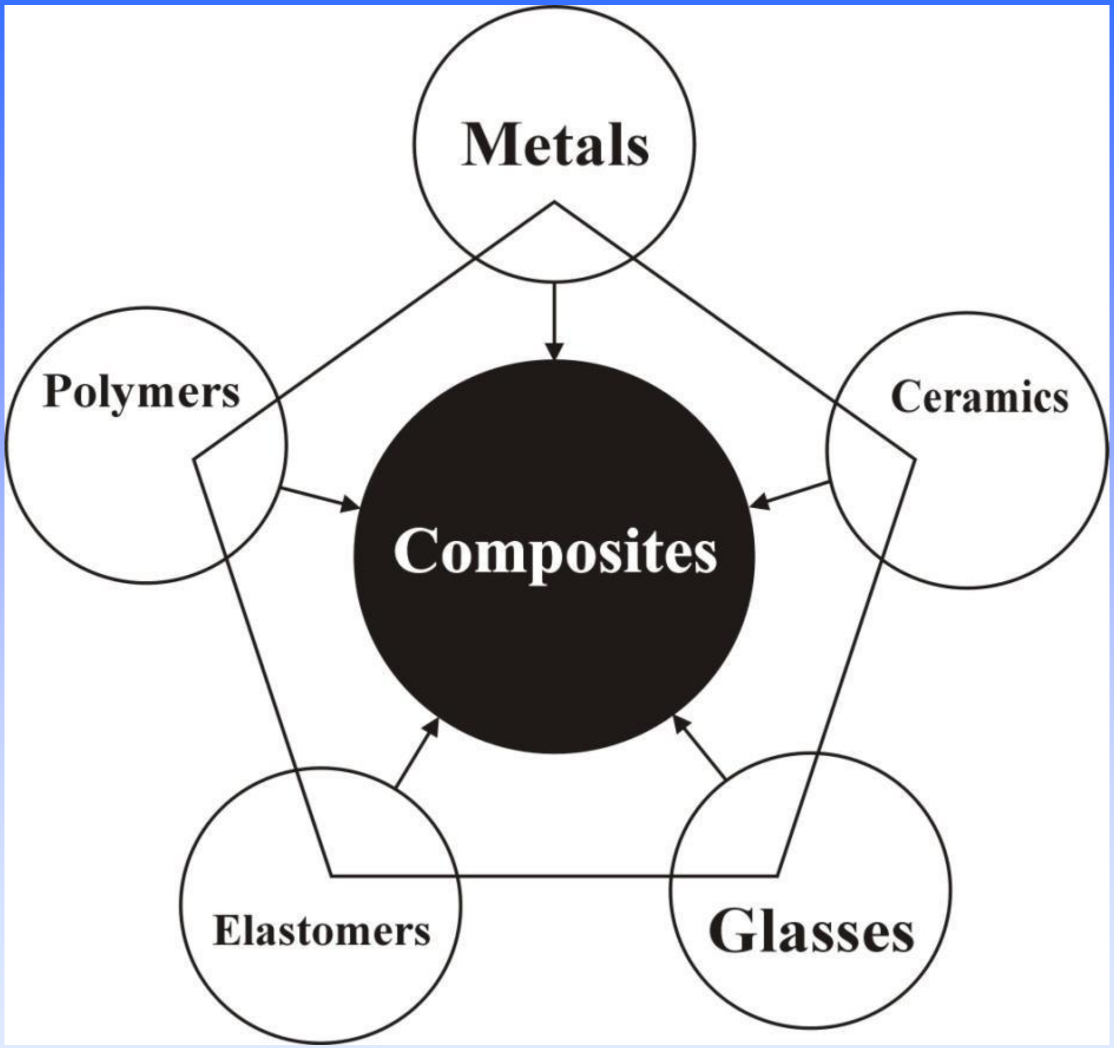


Fig. The material classes from which composites are made.

Classifications of Composite Materials

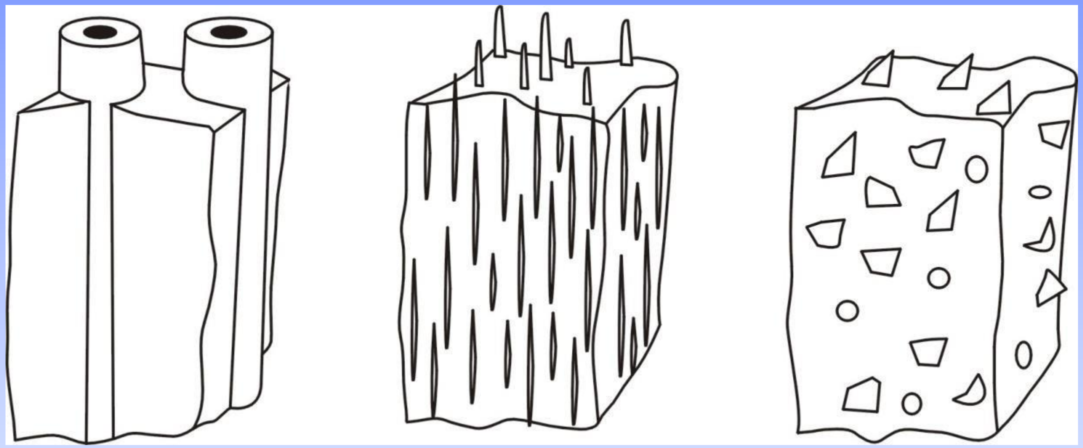
1. With respect to the matrix

- **Organic Matrix Composites (<u>O</u>MC)**
  - -Polymer Matrix Composites (<u>P</u>MCs)
  - - Carbon Matrix Composites (<u>C</u>MCs)
- **Metal Matrix Composites (<u>M</u>MC)**
- **Ceramic Matrix Composites (<u>C</u>MC)**

- **The matrix is usually a <u>low density metal</u>.**
  - Aluminum
  - Aluminum - lithium
  - Magnesium
  - Copper
  - Titanium

Classifications of Composite Materials

2. With respect to the reinforcement



Monofilaments Whiskers/Staple Particulate

Composites may contain:

- continuous fibres
- whiskers or short fibres
- particles

<u>Special Features of Composites</u>

- **Composite materials provide capabilities for part integration. Several metallic components can be replaced by a single composite component.**

- **Composite structures provide in-service monitoring or online process monitoring with the help of embedded sensors.(Materials with embedded sensors are known as "<u>smart" materials</u>) This feature is used to monitor fatigue damage in aircraft structures**

- **Composite materials have a high <u>specific stiffness</u> (stiffness-to-density ratio), Composites offer the *<u>stiffness of steel at one fifth the weight</u>* and equal the *<u>stiffness of aluminum at one half the weight.</u>***

- **High specific strength**

- **The fatigue strength (endurance limit) is much higher for composite materials.**

- **Composite materials offer increased amounts of design flexibility. For example, the coefficient of thermal expansion (CTE) of composite structures can be made zero by selecting suitable materials and lay-up sequence. Because the CTE for composites is much lower than for metals, composite structures provide good dimensional stability.**

- **Net-shape or near-net-shape parts can be produced with composite materials.**

- **Composites offer good impact properties**

- **The cost of tooling required for composites processing is much lower than that for metals processing because of lower pressure and temperature requirements.**

Drawbacks of Composites

- The materials cost for composite materials is very high compared to that of steel and aluminum.
- The lack of high-volume production methods limits the widespread use of composite materials.
- Designing parts with composites lacks machinery and design handbooks because of the lack of a database.
- The temperature resistance and chemicals resistance of composite parts depends on the temperature resistance of the matrix materials. Its big problem with polymers base matrix composites.
- Composites may absorb moisture, which affects the properties and dimensional stability of the composites.

Wetting between matrix and reinforcement material

$$\gamma sv = \gamma sl + \gamma lv \ \ \text{Cos}\ \theta$$ → **Young's Eq.**

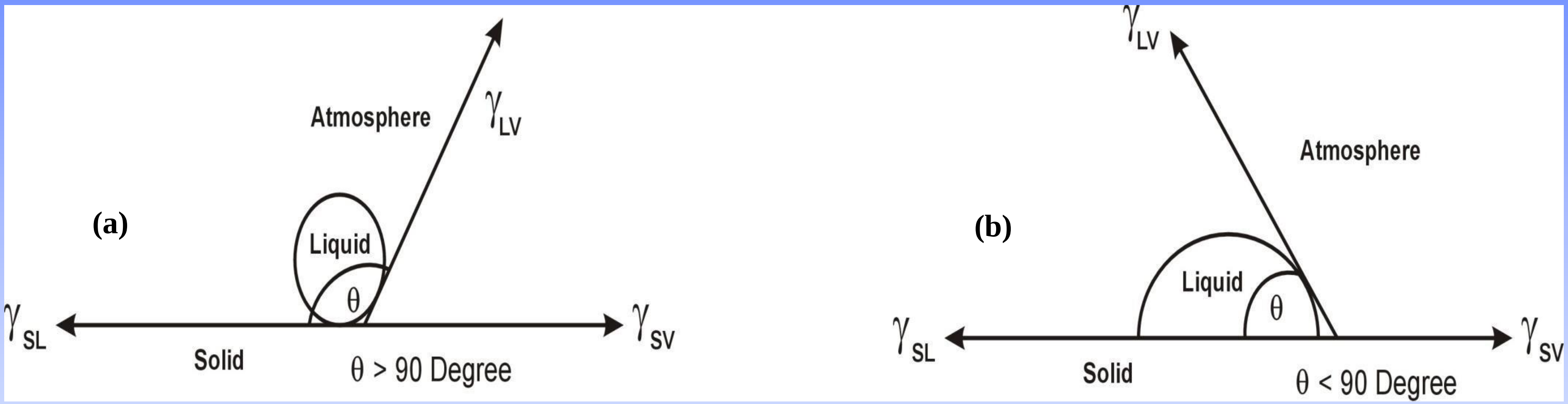


Fig. Schematic illustration of contact angle in a (a) non-wetting system, and (b) wetting system.

Fig. Bad wetting between as cast Al base matrix and SiC particles.

Some defects in as cast MMCs

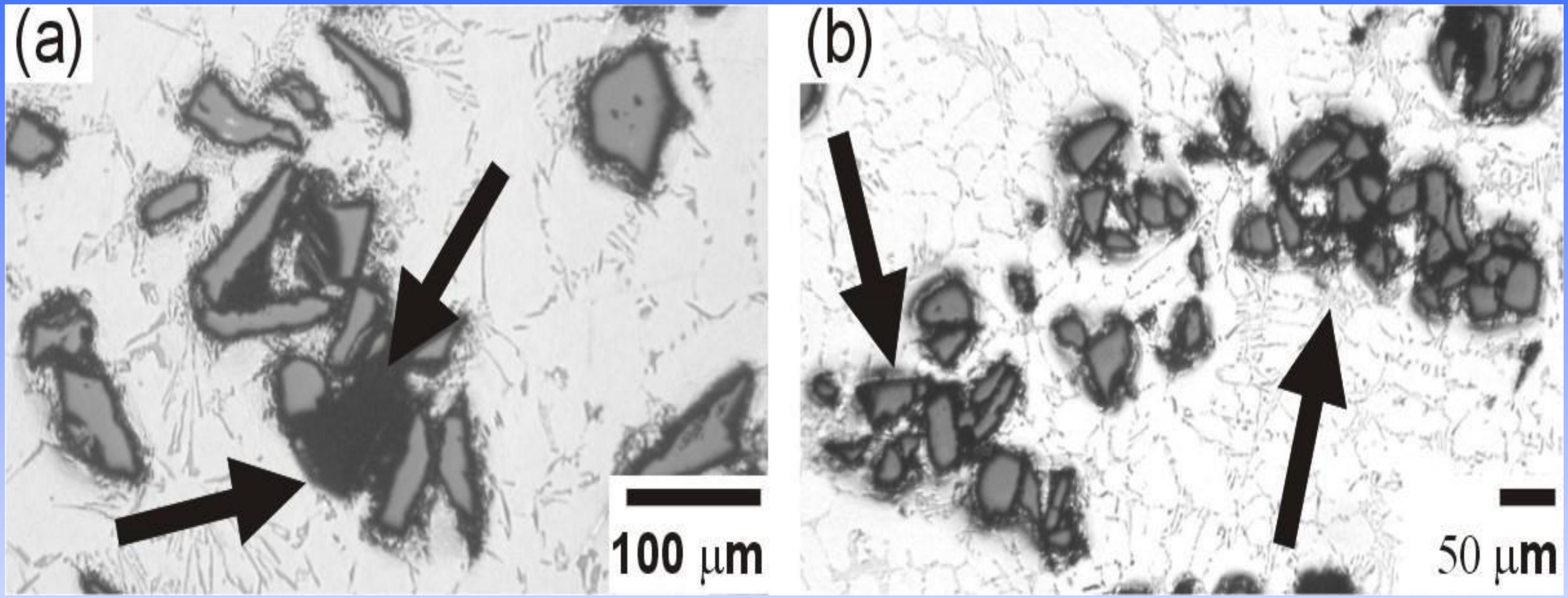


Fig. Optical micrograph of A356-25 vol.% SiC composite in as-cast conditions (a) gas porosity and (b) particle porosity clusters.

Improvement of the Wettability Between Solid-Liquid Matrix

1. **Use of metal coating**

   i-cementation technique

   ii- electroless deposation technique

2. **Addition of elements onto the liquid metal**

   i- reduction of the surface tension of the melt

   ii- reduction of the solid-liquid interfacial energy of the melt

   iii- inducing the chemical reaction at the interface

3. **Heat treatment of ceramic particulates**

Pre-treatment of reinforcement

82%

96%

900°C for 3 hr.

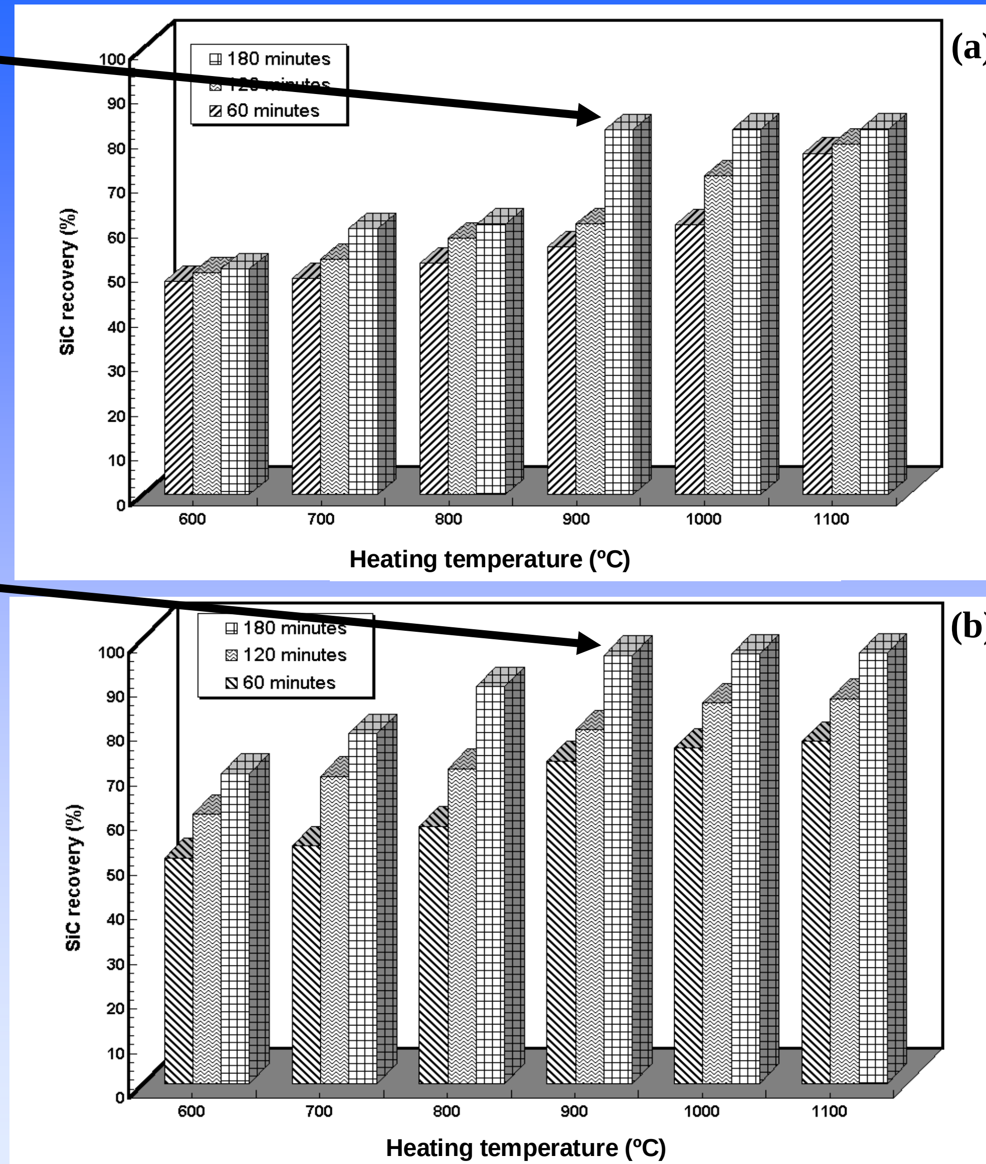


Fig. Effect of heating temperature on SiC recovery in Al matrix composite when applying (a) stir casting and (b) compocasting techniques.

Processing Routes

1- Solid-phase techniques

- Powder metallurgy
- High rate, High energy process, (Mechanical alloying)
- Diffusion Bonding

2- Two phase processes

- Osprey Deposition
- Compocasting / Rheocasting

3- Liquid phase processes

- Liquid Metal-Ceramic Particulate Mixing
- Melt Infiltration
- Melt Oxidation Processes
- Squeeze Casting or Pressure Infiltration

Powder metallurgy

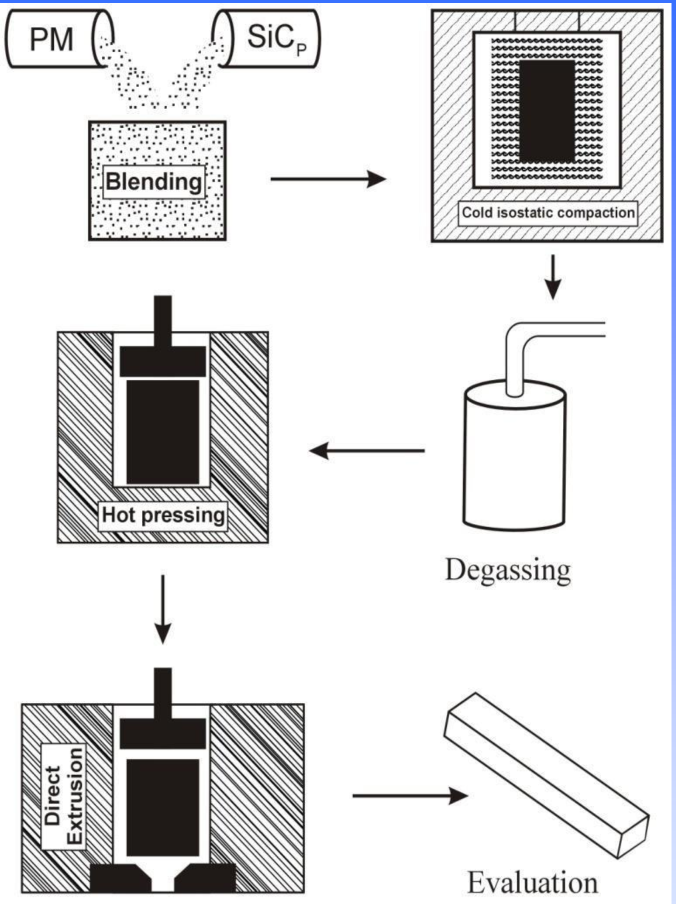


Fig. Schematic interpretation of the processing route for P/M Al/SiC_p composites.

The powder metallurgy route has several attractive features:

✓It allows essentially any alloy to be used as the matrix

✓It also allows any type of reinforcement to be used because reaction between the matrix and reinforcement can be minimized by using solid state processing

✓High volume fraction of reinforcement are possible, thus maximising the modulus and minimizing the coefficient of thermal expansion of the composite.

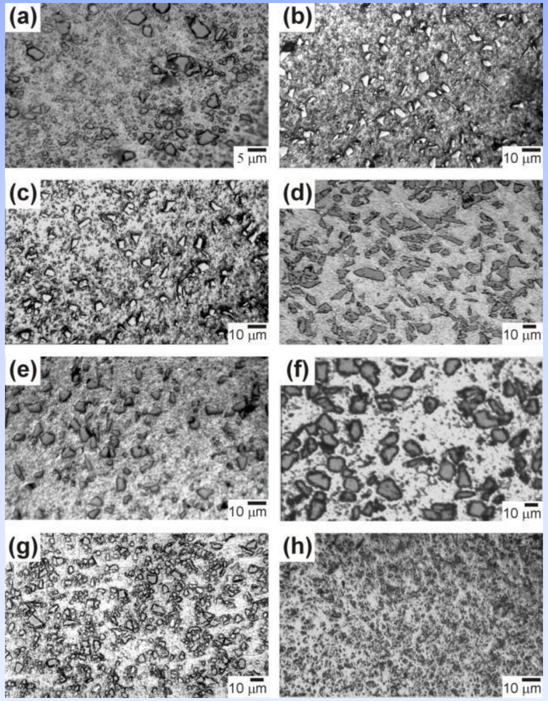


Fig. Optical micrograph of Al/SiC composites with 5 µm SiC particles, a) 5 vol.%, b) 10 vol.%, c) 15 vol.%, d) 20 vol.%, e) 25 vol.%, f) 30 vol.%, g) 35 vol.% and h) **40 vol.%** produced by hot-press technique.

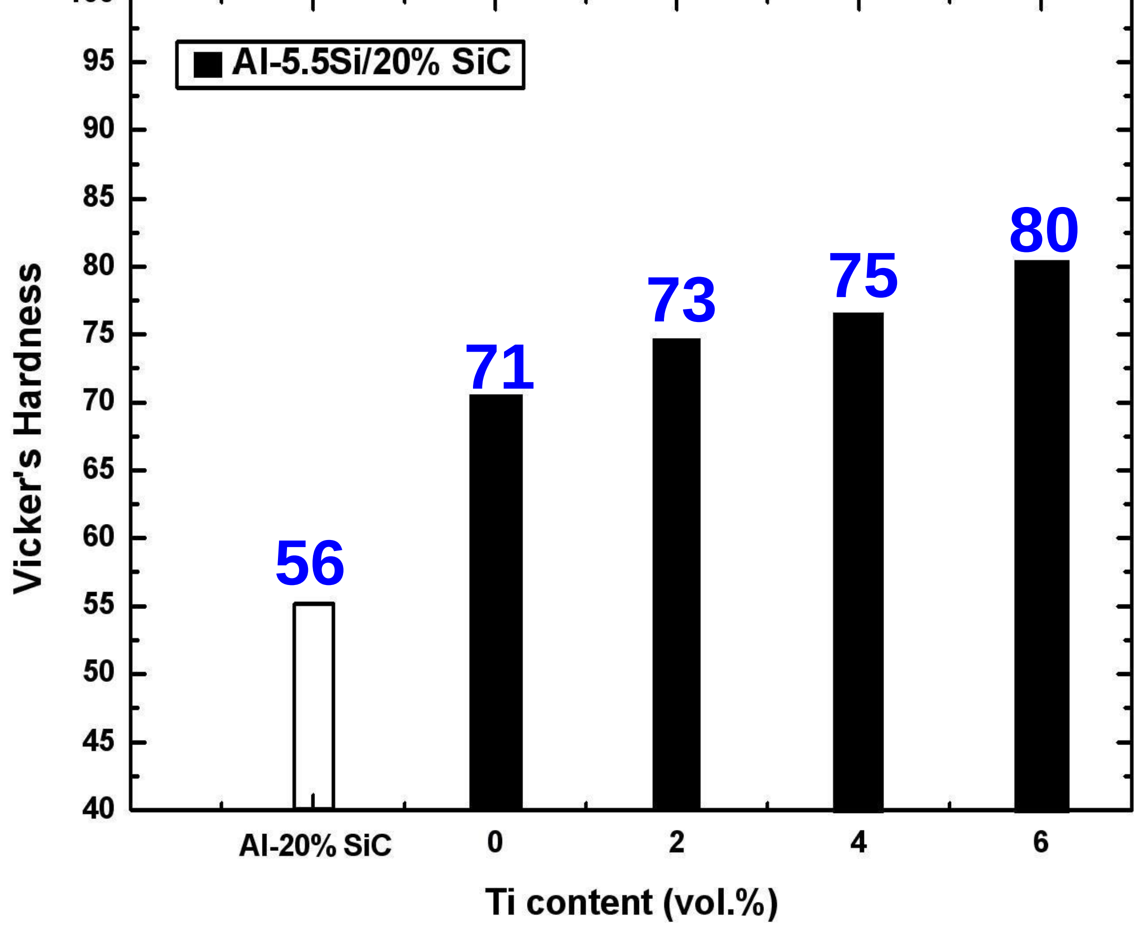


Fig. Effect of Ti addition on the hardness of hot-pressed Al-5.5Si/20%SiC composite.

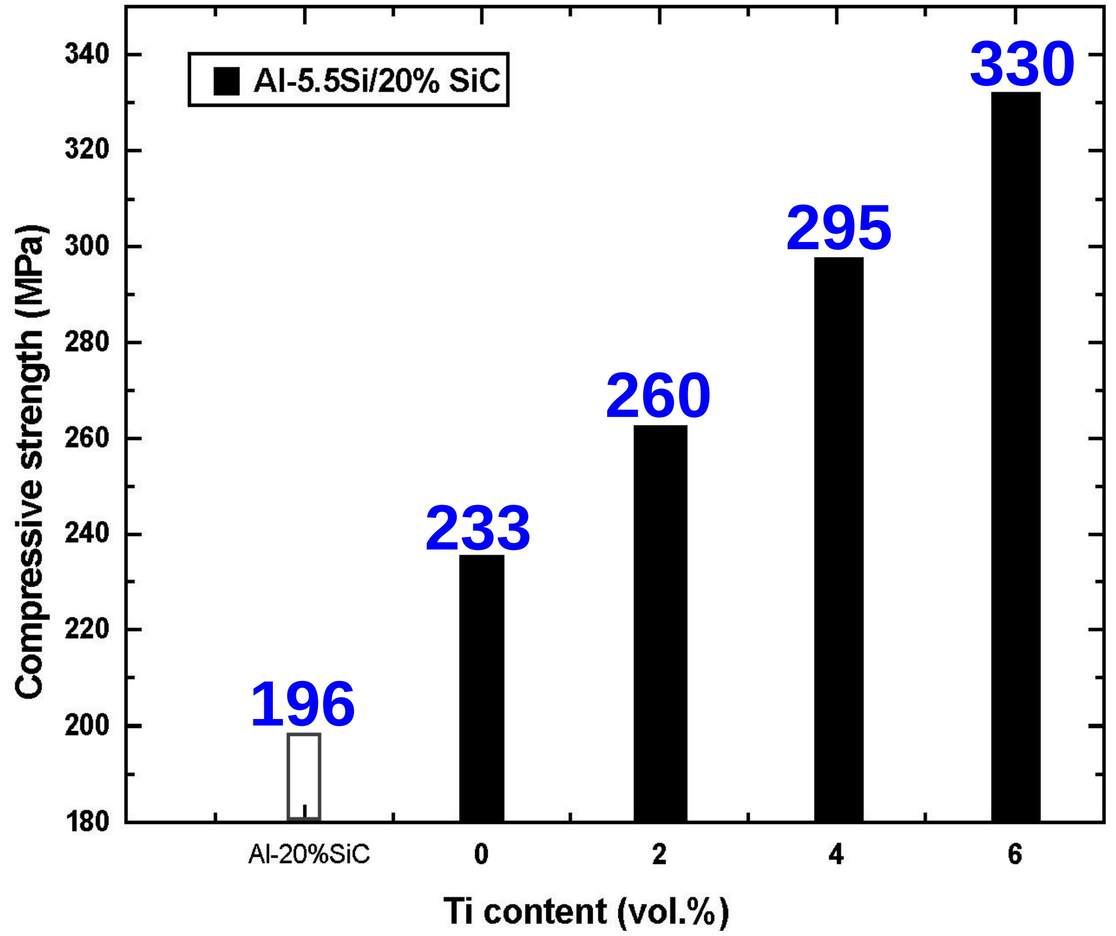


Fig. Effect of Ti addition on compressive strength of hot-pressed Al-5.5Si/20%SiC composite.

Diffusion Bonding

Diffusion bonding is a common **solid-state welding technique** for joining similar and dissimilar metals at an elevated temperature .

The major advantages of this technique are

- **Ability to process a wide variety of matrix metals.**
- **Control of fiber orientation and volume fractions.**

Among Some disadvantages are

- **Processing times of several hours.**
- **Cost of high processing temperatures and pressures.**
- **Ability to produce objects of only limited size.**

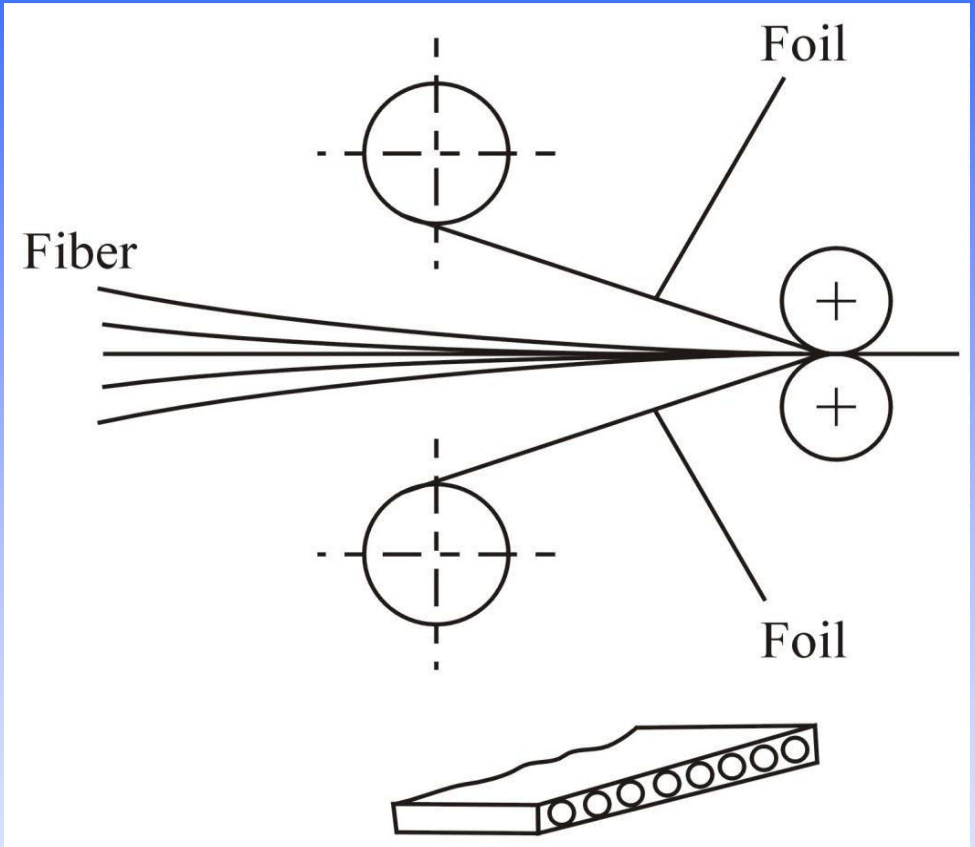


Fig. Schematic depiction of Hot-Roll diffusion bonding process.

Osprey Deposition

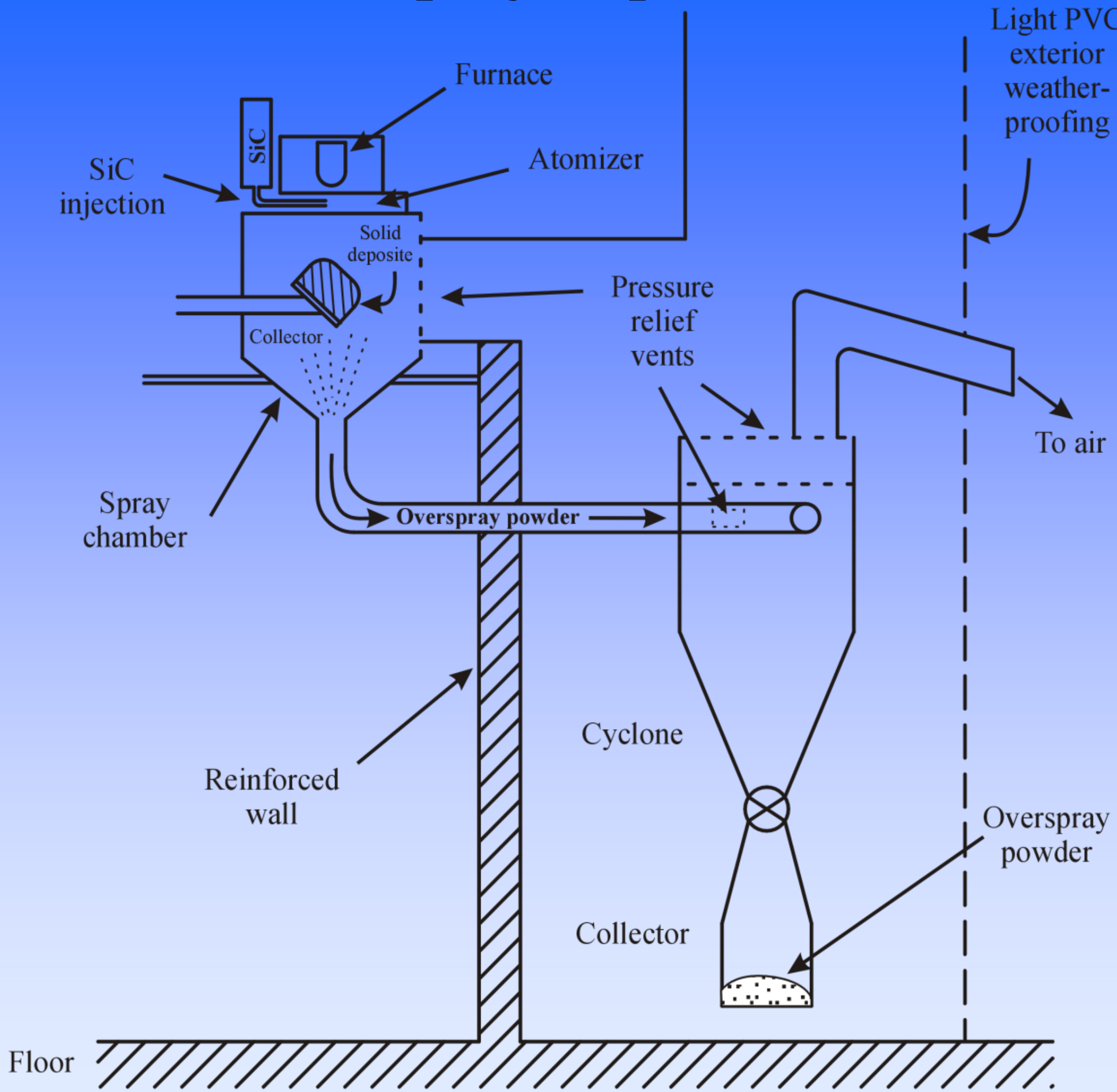


Fig. Schematic diagram of the modified Osprey technique.

Pressure infiltration (squeeze casting)

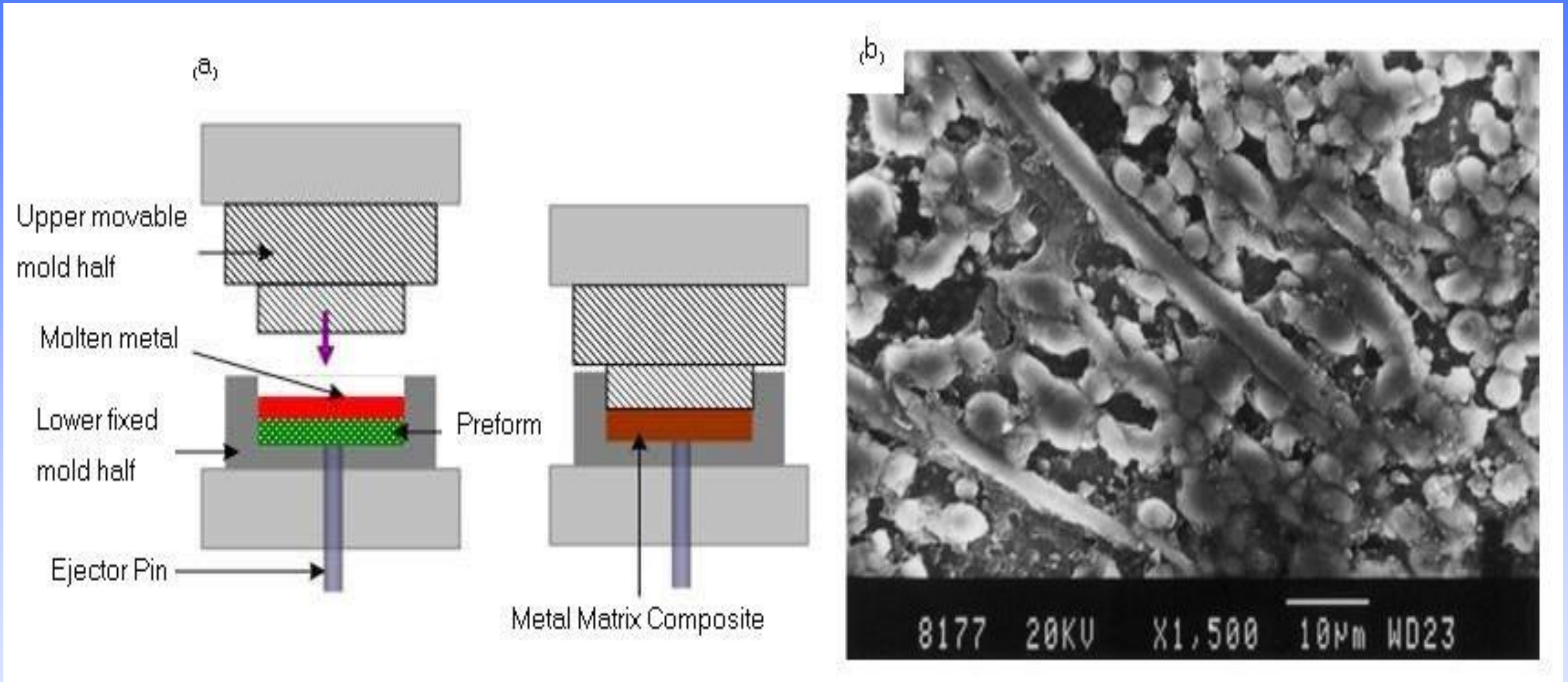


Fig. Illustrates (a) the process of the squeeze casting of a magnesium matrix composite, and (b) scanning electron micrograph of AM100 composite (20% Vf)

PART II

New Trends in Composite Materials

Introduction

Composite materials that traditionally incorporate **micron scale reinforcements** in a bulk matrix offer opportunities to **tailor material properties** such as hardness, tensile strength, ductility, density, thermal and electrical conductivity, and wear resistance.

Metallic composites containing **nanoparticles** or **carbon nanotubes** could offer distinct advantages over polymeric composites due to the inherent **high temperature stability**, **high strength**, high modulus, wear resistance, and thermal and electrical conductivity of the metal matrix.

1- Metal Matrix nanocomposites

(MMCs)

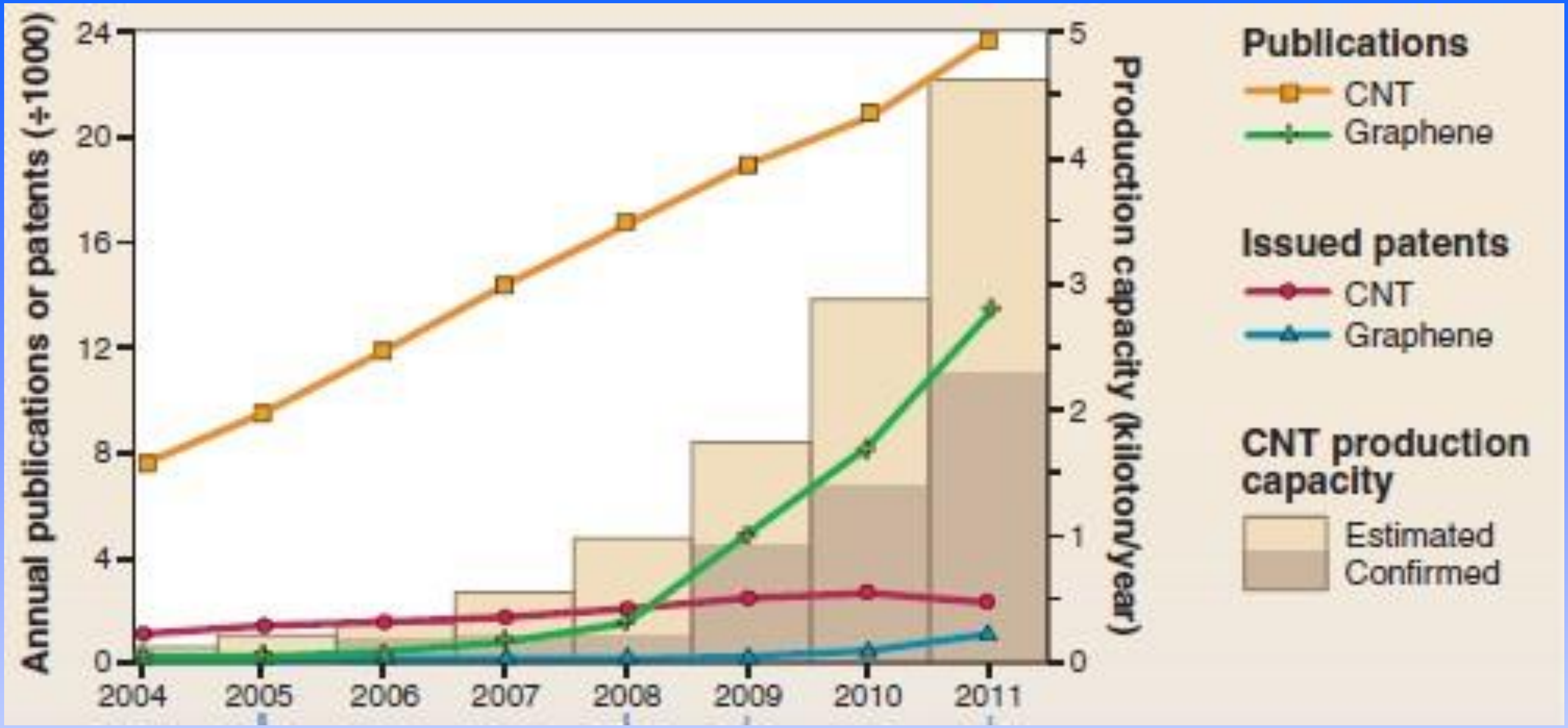


Fig. Number of publications on different metal matrix-CNT composites and production capacity

http://www.sciencemag.org.lib-ezproxy.tamu.edu:2048/content/339/6119/535.full.pdf

Coal

Carbon, FCC

Allotrope of carbon

1- Graphite

Graphite is the most stable form of carbon, electrical conductor, **Hexagonal**

2- Diamond

One well known allotrope of carbon.

Diamond is less stable than graphite, but the conversion rate from diamond to graphite is negligible at standard conditions

3- Carbon nanotubes

Are cylindrical Carbone molecules with novel properties that make them potentially useful in a wide variety of applications (e.g., nano-electronics, optics, materials applications, etc.)., **Hexagonal**

4- Graphene

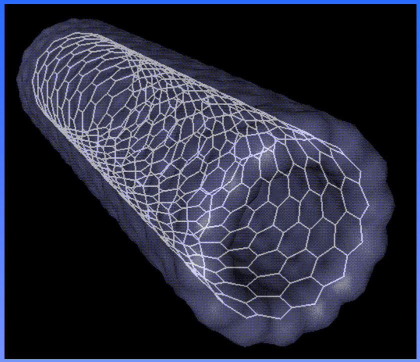
A single layer of graphite, has extraordinary electrical, thermal, and physical properties

What are Carbon nanotubes?

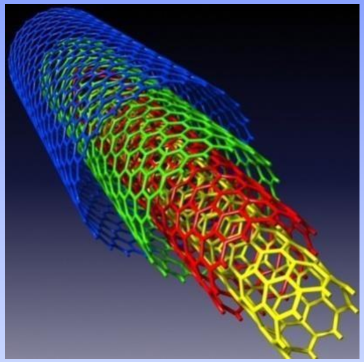
Carbon nanotubes

- layers of carbon bonded in hexagonal lattices
- form large sheets of graphene
- when sheets are rolled up they form tubes which are existent at a nanometer scale

	Single Walled CNT	Multi Walled CNT
Length	Less than **100nm** up to **several cm**	
Diameter	0.8-2nm	5-20nm
L/D	100- 4x10^7	20-2x10^6
Thermal Conductivity	3500 W/mK (>diamond)	-
Tensile Strength	-	100 Gpa



http://4.bp.blogspot.com/JT5P-RJi06I/TF-IJcmNGmI/AAAAAAAAAFQ/ulIUwi-8IMc/s1600/CNT.gif



http://journalclubscienceblog.files.wordpress.com/2012/07/multiwall-carbon-nanotube.jpg

Two types of CNTs

1- multi walled, make incredibly strong fibers

2- single walled, well suited for electrical and thermal conduction

❖ the strength of a MWNT is ten times higher than any other known fiber!

How CNTs are made?

- **Arc discharge**
  - CNTs Can be found in the carbon soot of graphite electrodes during an arc discharge involving high current.
  - This process yields CNTs with lengths up to 50 microns.
- **Laser Ablation**
  - In the laser ablation process, a pulsed laser vaporizes a graphite target in a high-temperature reactor while an inert gas is inserted into the reactor.
  - Nanotubes develop on the cooler surfaces of the reactor as the vaporized carbon condenses.
- **Other methods where CNTs are created**
  - Chemical Vapor Decomposition
  - Natural, incidental, and controlled flame environments

Currently, CNT’s are used in specialty applications such as bikes, boats, and race cars because of <u>CNT’s very light weight compared to competing high strength materials.</u>

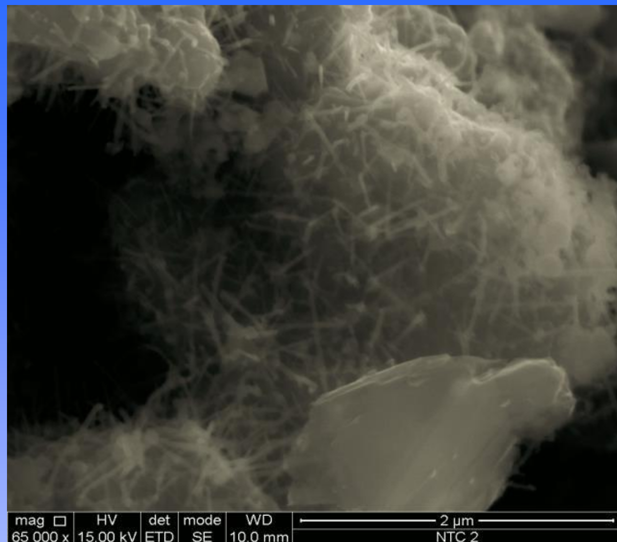
Most recently CNT’s have been used in <u>batteries, transistors,</u> and even as a <u>shield against space debris for NASA’s Juno spacecraft</u>.

The increasing demand for CNT’s is driving advances in CNT synthesis, purification, and chemical modification technology.

The advances in production are beginning to create new applications for CNT’s that go beyond the incorporation of bulk powders.

The most promising areas of research are <u>microelectronics, biotechnology, water purification, and composite materials.</u>

1-1 Metal Matrix CNT Composites



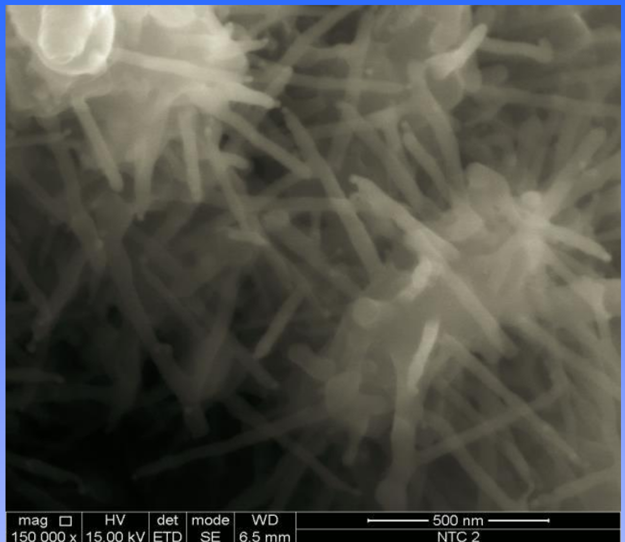
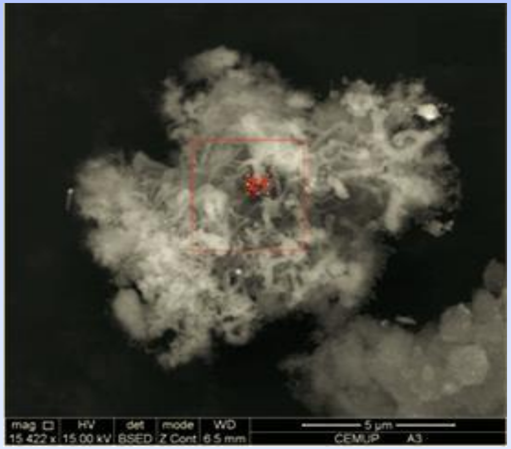


Fig. SEM images of CNT-Al particles agglomerates (a) CNT dispersion around the aluminum particles and (b) higher magnification SEM image.



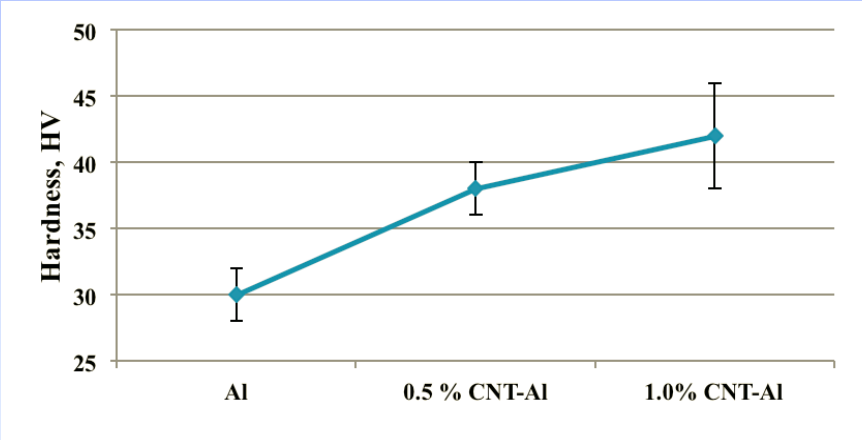


Fig. (a)SEM image of CNT-Al particles agglomerates, (b) Hardness evolution of the aluminum matrix composites with CNT-Al agglomerates concentration.

Metal Matrix CNT nanocomposites

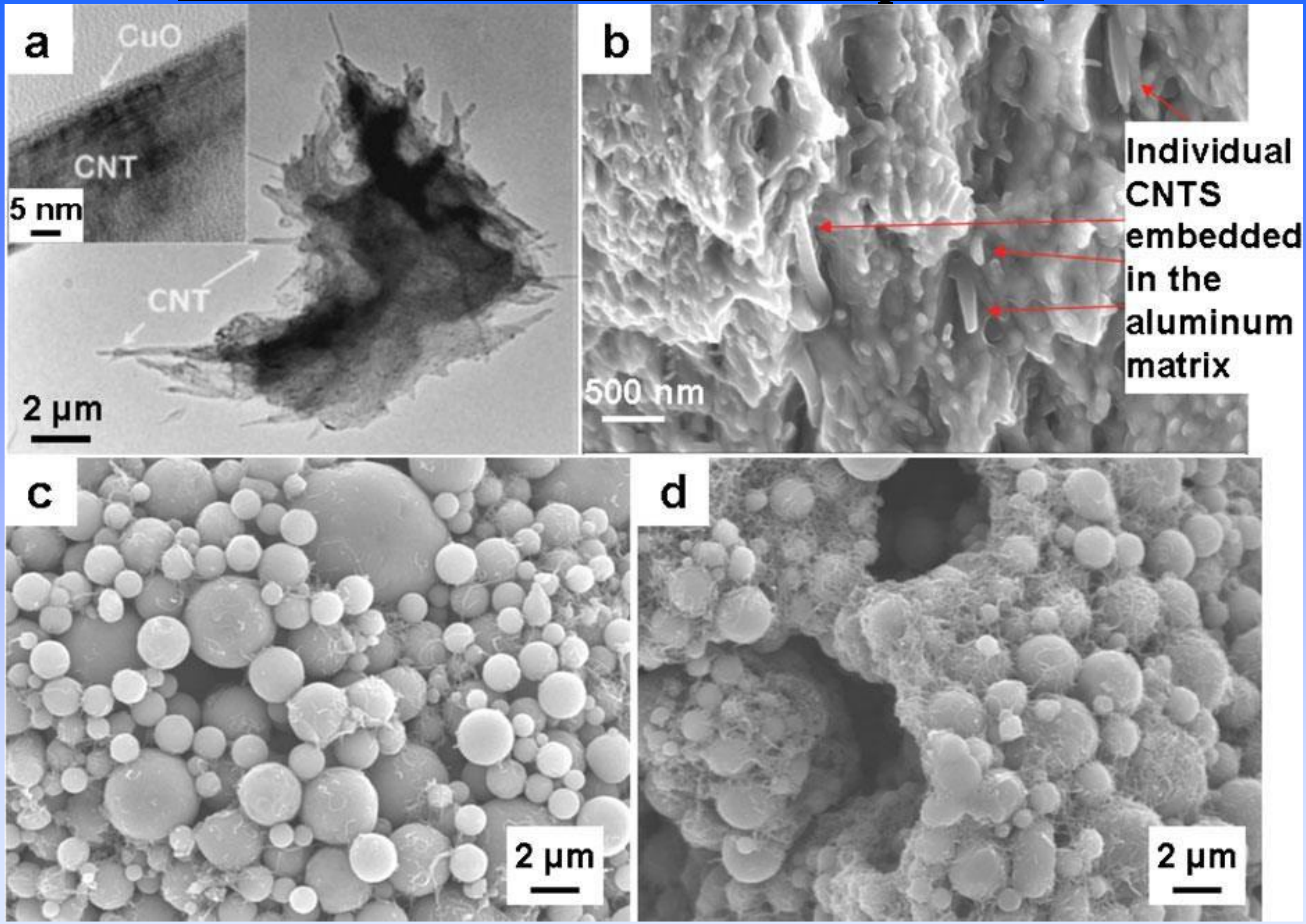


Fig. image (TEM) of CuO/CNT powder prepared by molecular level mixing method, b image (SEM) of the fracture surface of Al/CNT powder prepared by ball milling for 48 h, C image (SEM) of spray dried Al–Si agglomerates containing 5 wt-%CNT and d 10 wt-%CNT

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1-2 Ultrasonic Cavitation Process

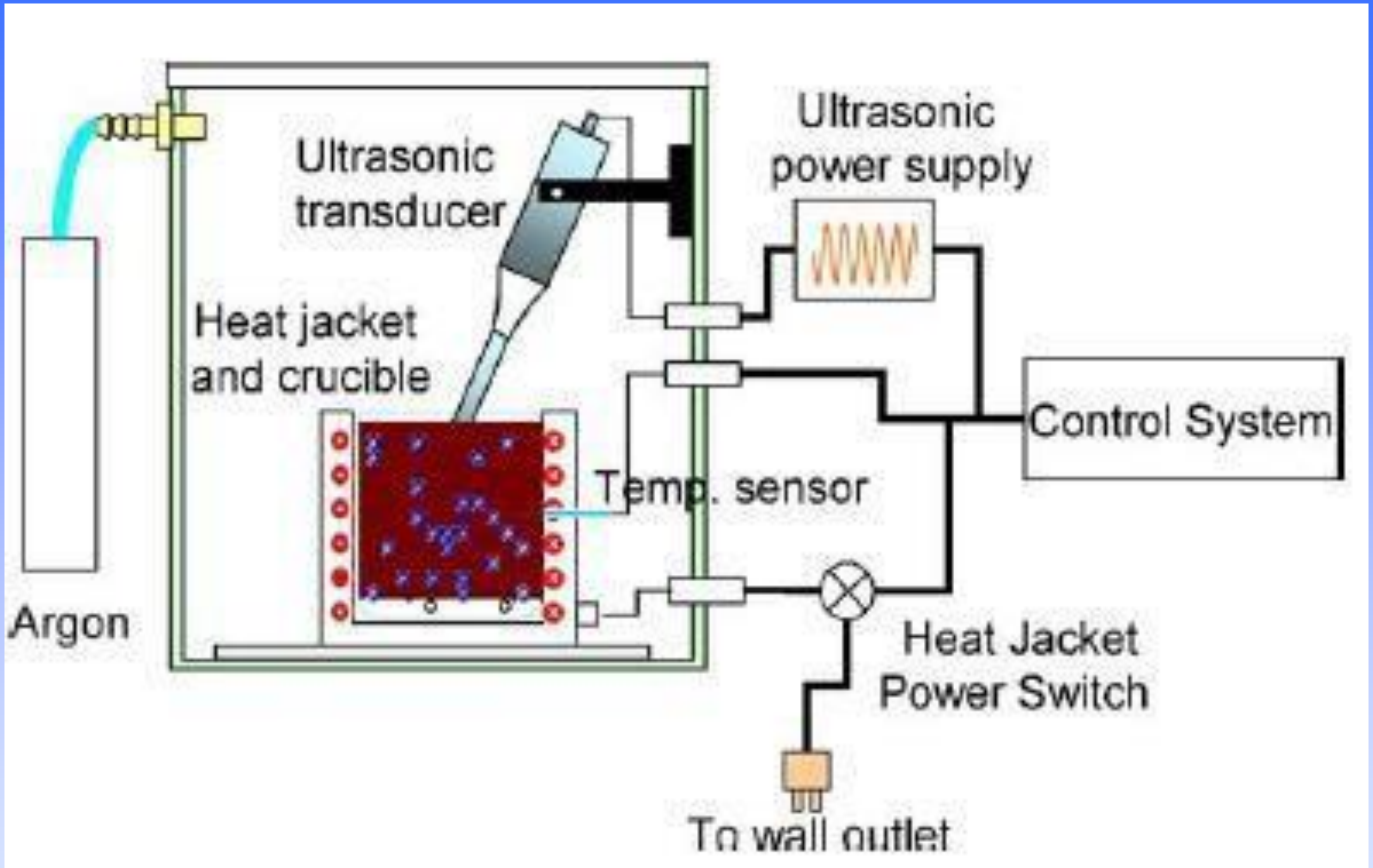


Fig. Schematic diagram showing the experimental setup of ultrasonic method

Ultrasonic cavitation process

Yang et al. fabrication bulk Al-based nanocomposites with nanosized SiC by the ultrasonic cavitation-based casting method.

They showed that nano-sized SiC particles are dispersed well in the matrix and the yield strength of A356 alloy was improved more than 50% with only 2.0 wt% of nano-sized SiC particles. With a 2.0 wt% SiC nano-particles, an approximately 20% hardness improvement was achieved

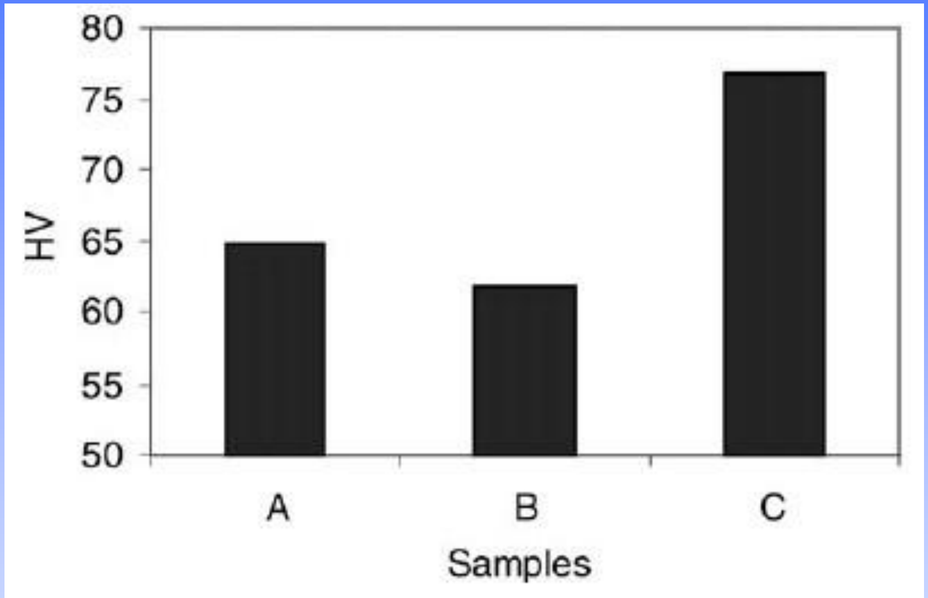


Fig. Hardness measurements:

(A) Aluminum alloy by regular casting,
(B) Aluminum alloy by ultrasonic-assisted casting, and
(C) Aluminum alloy matrix nano-composite by ultrasonic-assisted casting

1-3 Fraction Stir Processing (FSP)

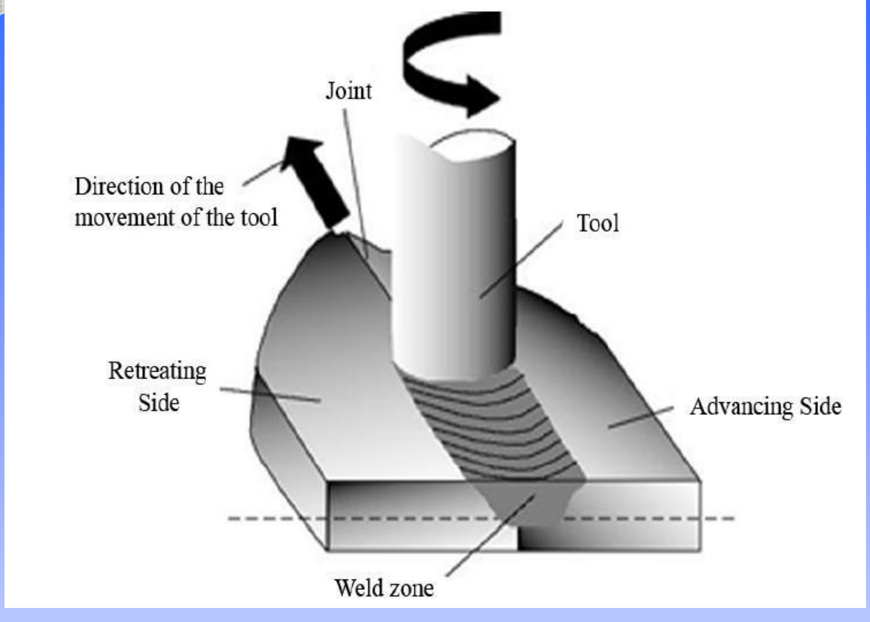


Fig.6. Schematic of FSW technique.

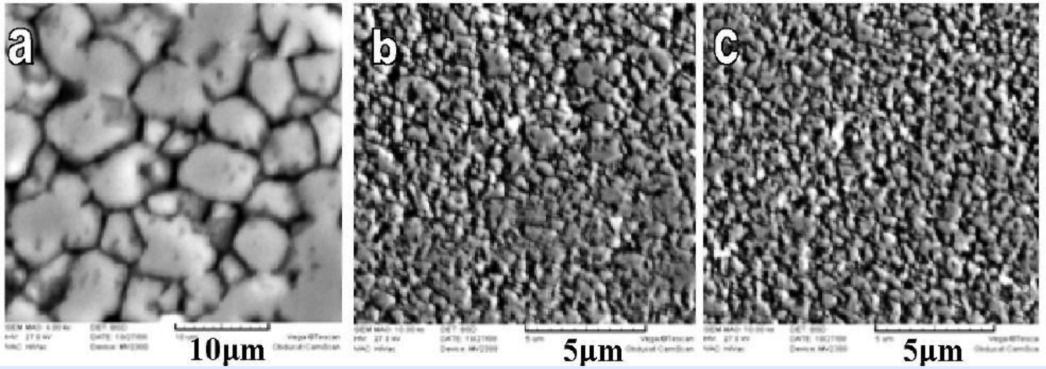


Fig. SEM micrographs showing the dispersion of B_4C particles after single pass (a), three passes (b), and four passes (c) at a rotating and advancing speeds of 1000 rpm and 85 mm/min, respectively

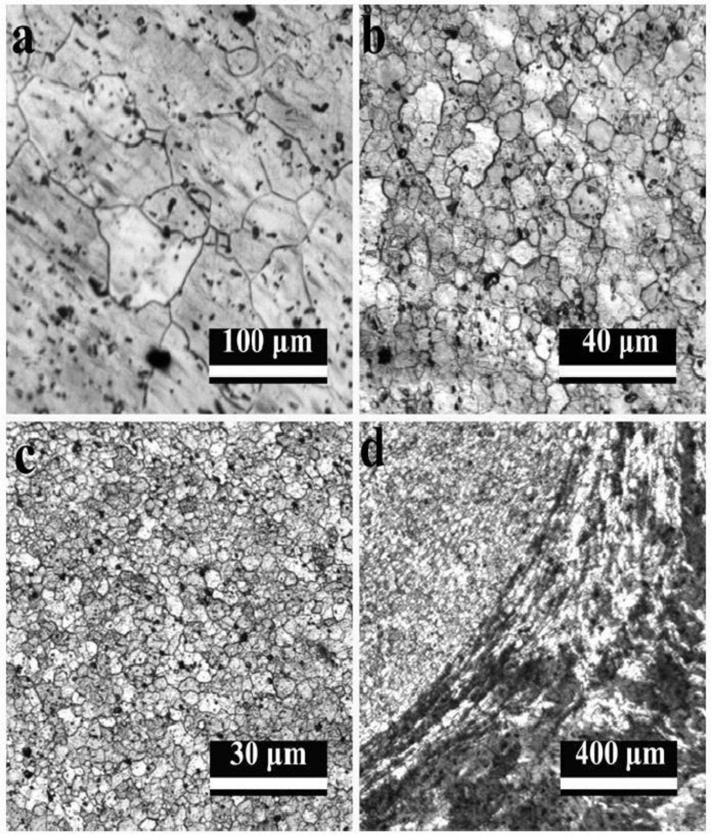
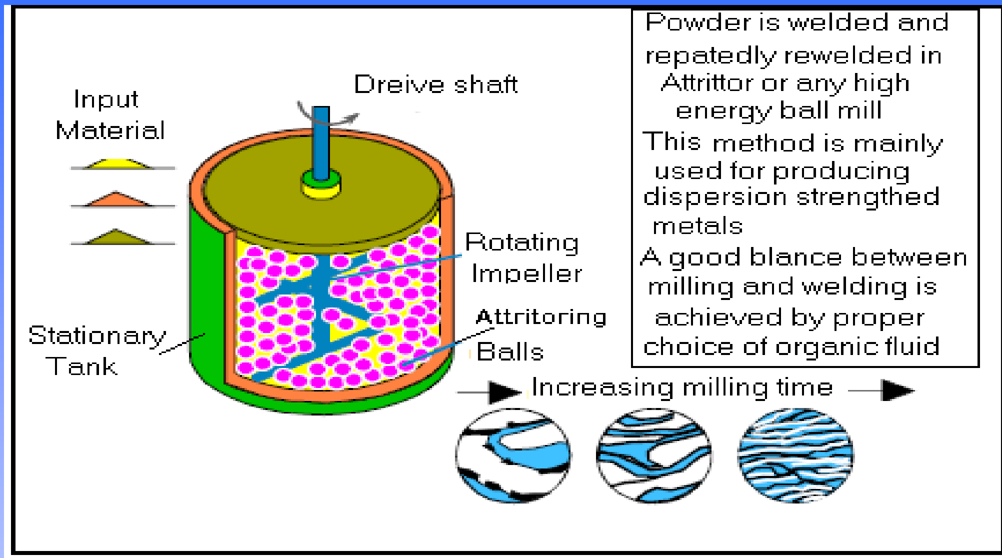
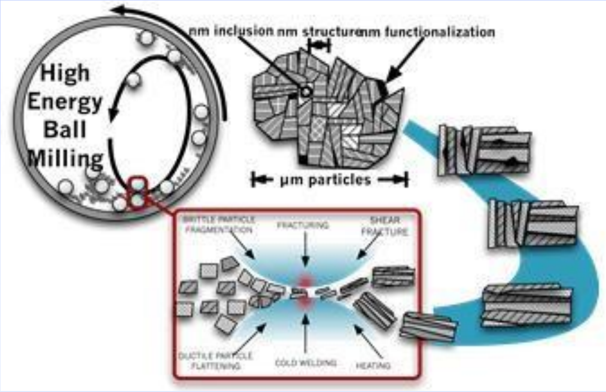


Fig. Optical micrographs showing grain structure of (a) Unaffected substrate material, (b) Friction stir processed zone of substrate after single pass (SP-Al), (c) Friction stir processed zone of the substrate inserted with Al_2O_3 powder (SP-Al/ Al_2O_3), and (d) transition zone of SP-Al/Al_2O_3.

1-4 Mechanical Alloying (MA)

Mechanical alloying (MA) method has been considered as a powerful and practical process for fabrication of several advanced materials with unique properties, in particular, for those materials that are difficult to obtain by the traditional method of liquid metallurgy. High thermal stable amorphous alloys, nanocrystalline and nanocomposite materials, and refractory hard materials, including metal nitrides, carbides, hydrides are examples of the advanced engineering materials that are prepared at room temperature.





Mechanical Alloying (MA)

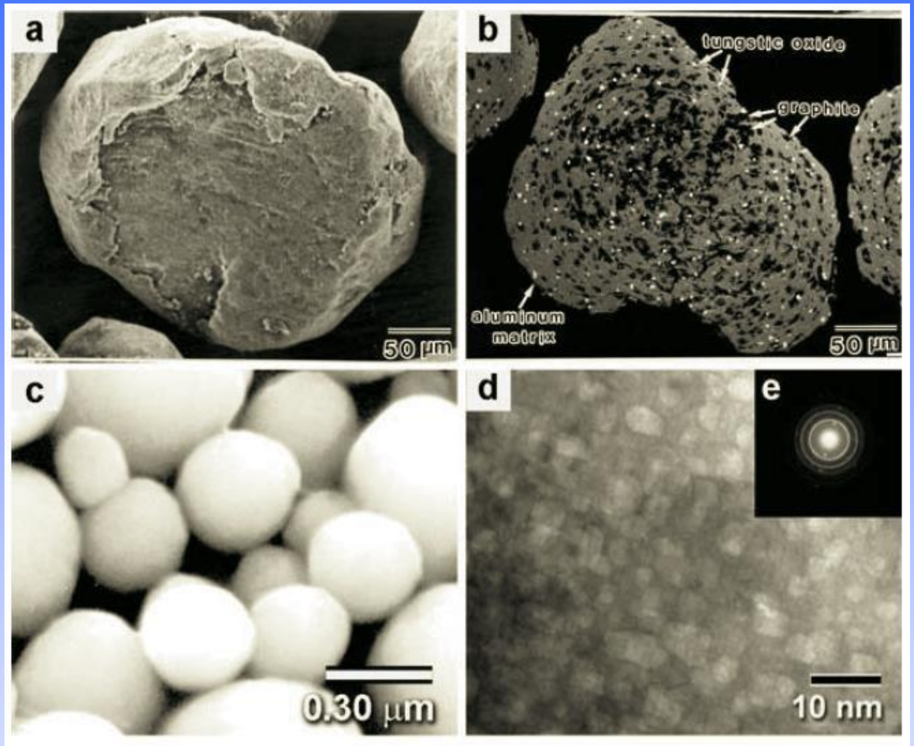


Fig. SEM micrographs of the ball-milled powders after, (a) 3.6 ks of the milling time (b) cross-sectional view of the samples (c) SEM (d) BFI micrographs (e) SADP of the powders after the final stage of milling

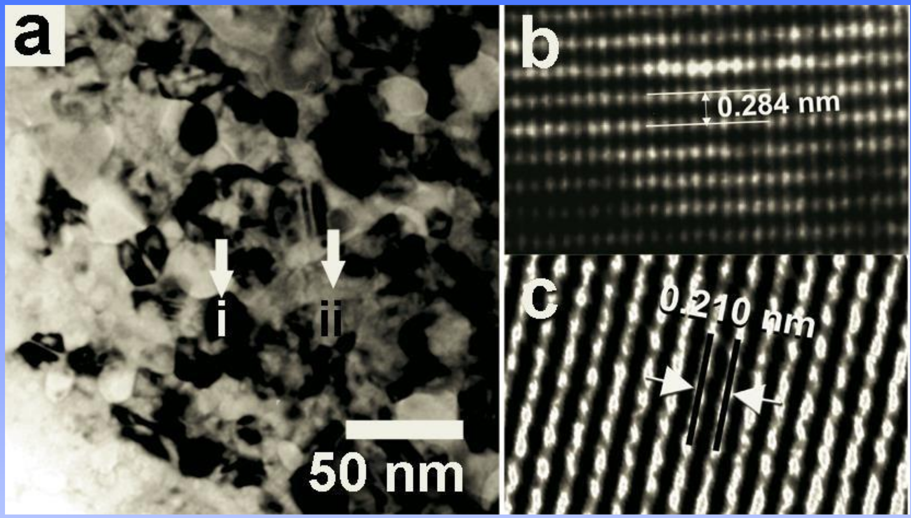


Fig. (a) BFI planner view of the end-product of nanocomposite WC/ Al_2O_3 after consolidation and the (b, c) HRTEM images of the indexed Regions I and II

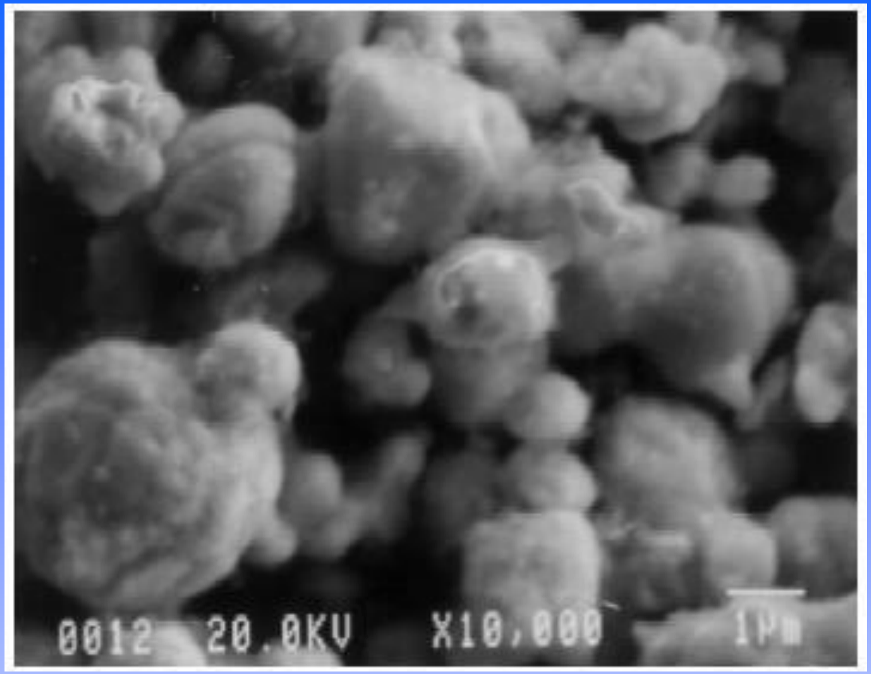


Fig. SEM micrograph of mechanically mixed $W_{50}\,C_{50}$ with metallic Co (14%. wt.%) powders after the ball milling time.

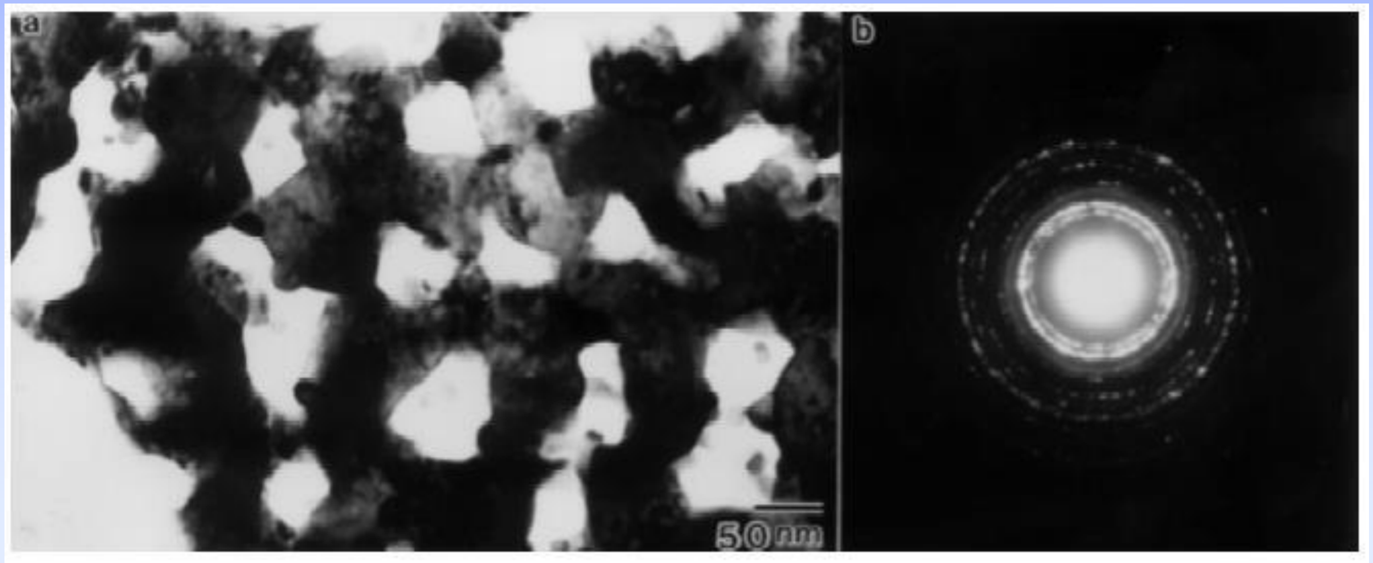


Fig. TEM micrograph of (a) BFI and (b) the corresponding SADP of as-consolidated mechanically solid state mixed WC–14 wt.% Co, ball-milled for 259 ks.

2- Laminated composite materials.

Laminated composite structures materials consist of a combination of materials (matrix and fibers) that are mixed together to achieve specific structural properties.

Fiber Forms

1- Roving 2-Unidirectional (Tape) 3-Bidirectional (Fabric) 4- Nonwoven (Knitted or Stitched)

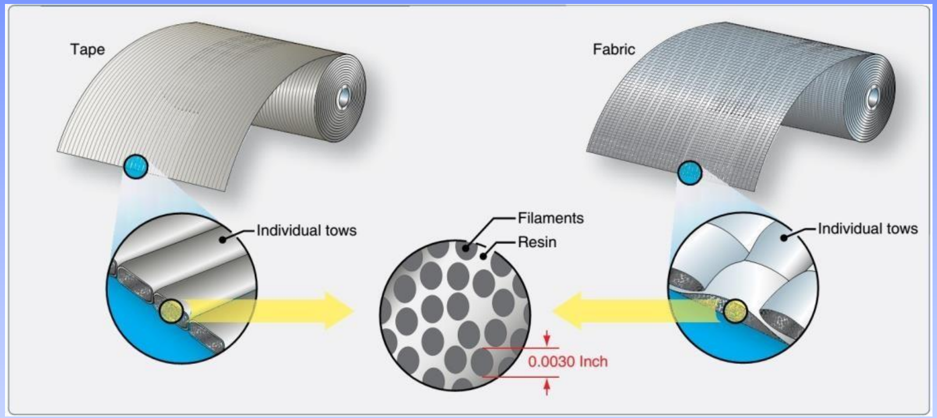


Fig. Tape and fabric products.

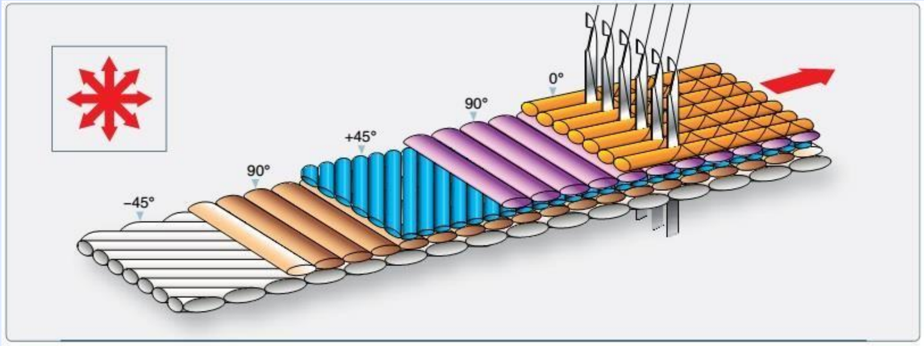


Fig. Nonwoven material (stitched).

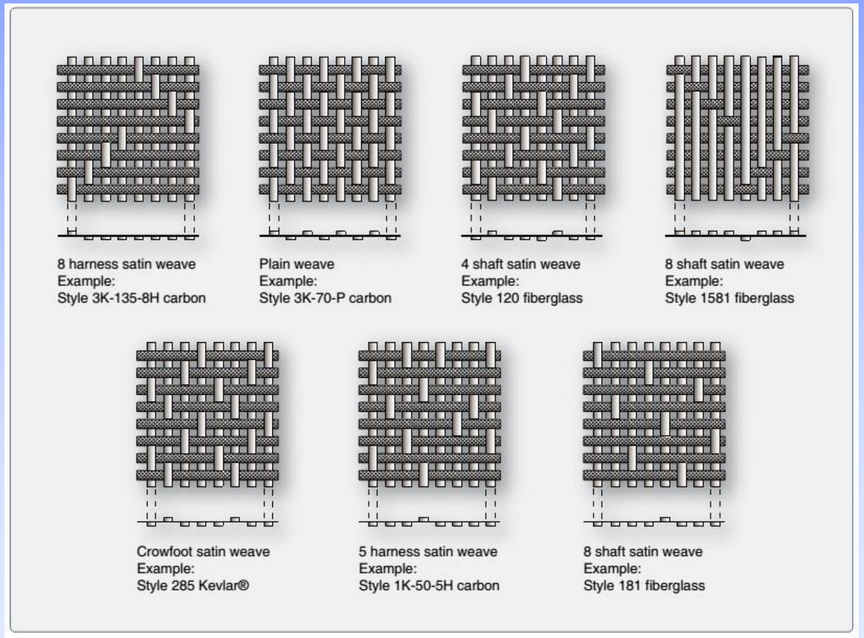


Fig. Typical fabric weave styles.

Types of Fiber

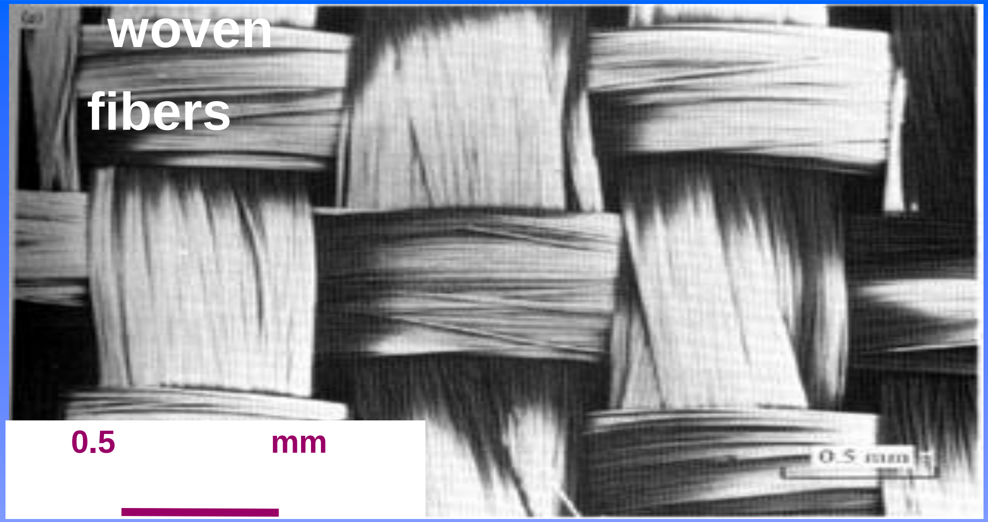
1. Fiberglass: is a type of fiber reinforced plastic where the reinforcement fiber is specifically glass fiber, The glass fiber may be randomly arranged but is commonly woven into a mat.

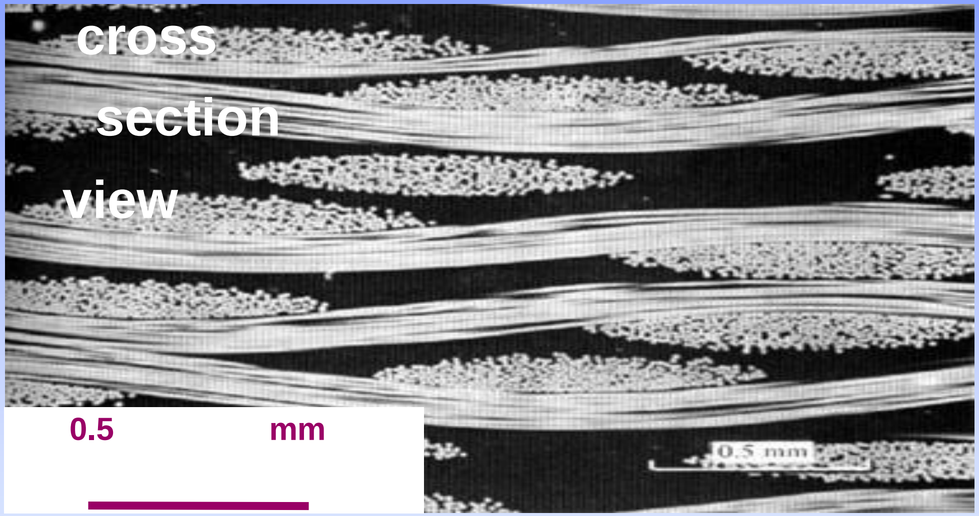
2. Kevlar®: is the registered trademark for a para-aramid synthetic fiber, a synthetic fiber of high tensile strength used especially as a reinforcing agent in the manufacture of tires and other rubber products and protective gear such as helmets and vests.

3. Carbon/Graphite: Carbon fibers are very stiff and strong, 3 to 10 times stiffer than glass fibers. Carbon fiber is used for structural aircraft applications, such as floor beams, stabilizers, flight controls, and primary fuselage and wing structure.

4. Boron: Boron fibers are very stiff and have a high tensile and compressive strength. The fibers have a relatively large diameter and do not flex well; therefore, they are available only as a prepreg tape product.

5. Ceramic Fibers: Ceramic fibers are used for high-temperature applications, such as turbine blades in a gas turbine engine. The ceramic fibers can be used to temperatures up to 2,200 °F





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D. Hull and T.W. Clyne, *An Introduction to Composite Materials*, 2nd ed., Cambridge University Press, New York, 1996, Fig. 3.6, p. 47.

3- Hybrid Composite Materials

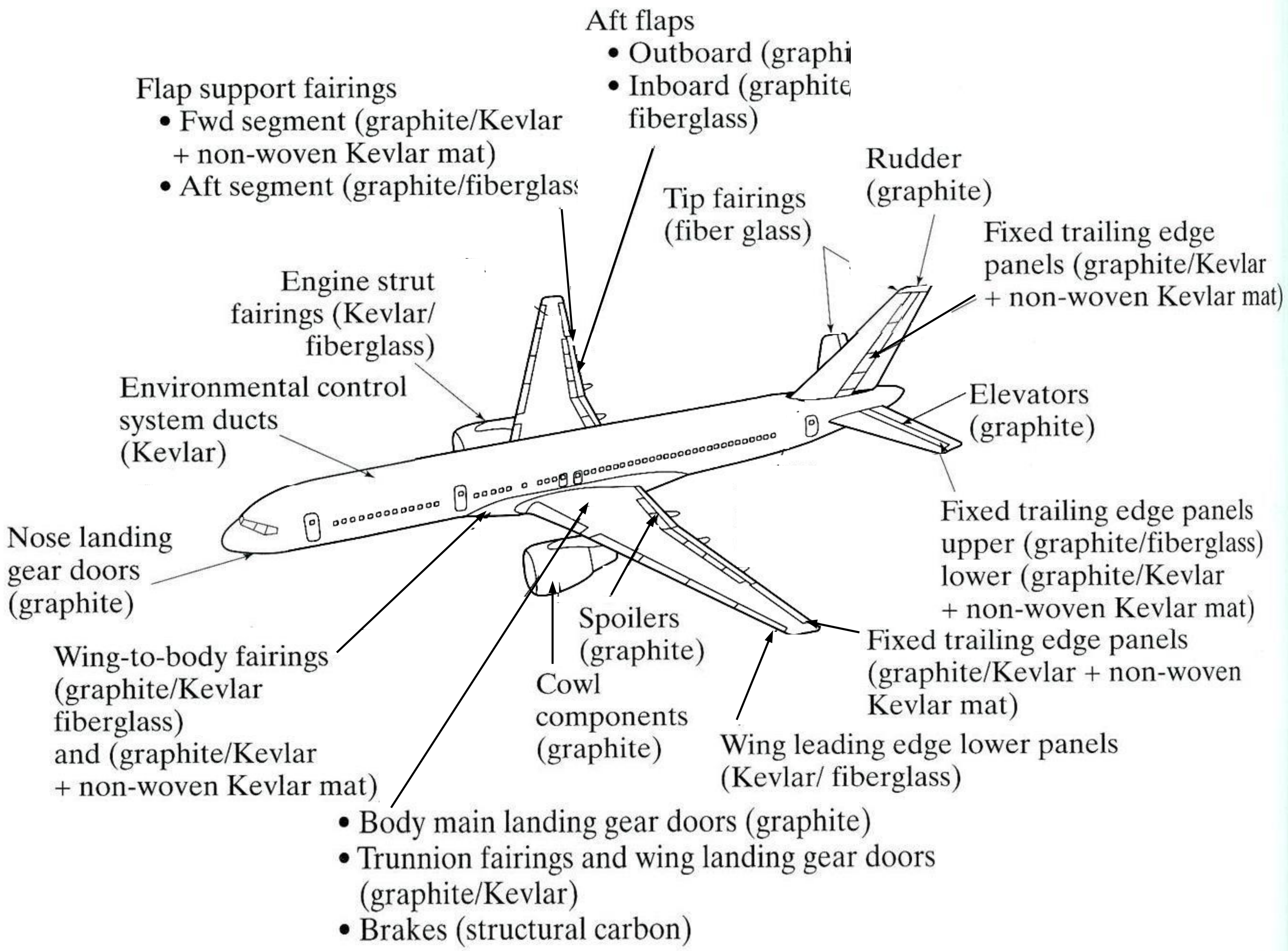
- Hybrid composite Materials have extensive engineering application where strength to weight ratio, low cost and ease of fabrication are required. Hybrid composites provide combination of properties such as tensile modulus, compressive strength and impact strength which cannot be realized in composite materials.

- Hybrid composites are usually used when a combination of properties of different types of fibers have to be achieved, or when longitudinal as well as lateral mechanical performances are required.

- Hybrid fiber reinforced materials can be made in two separate ways either by intimately mingling the fibers shown in figure in a common matrix, or by laminating alternate layers of each type of composite.

Fig. Hybrid Laminates - Glass & Carbon

Application Areas of Hybrid composites



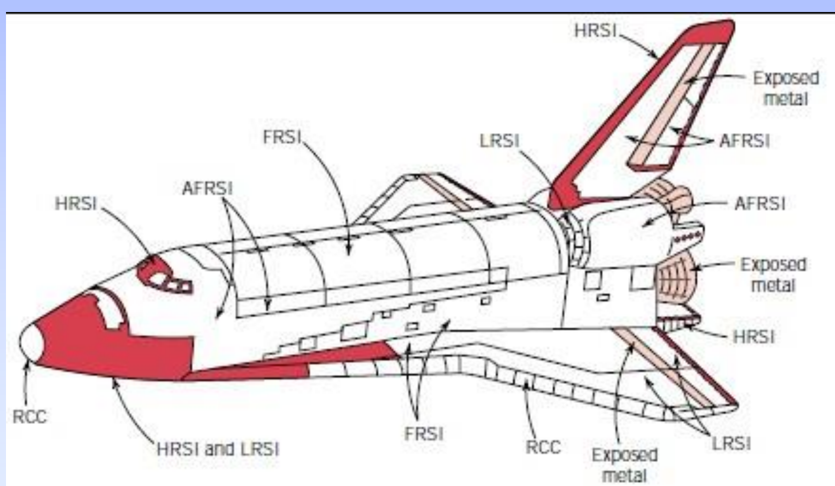
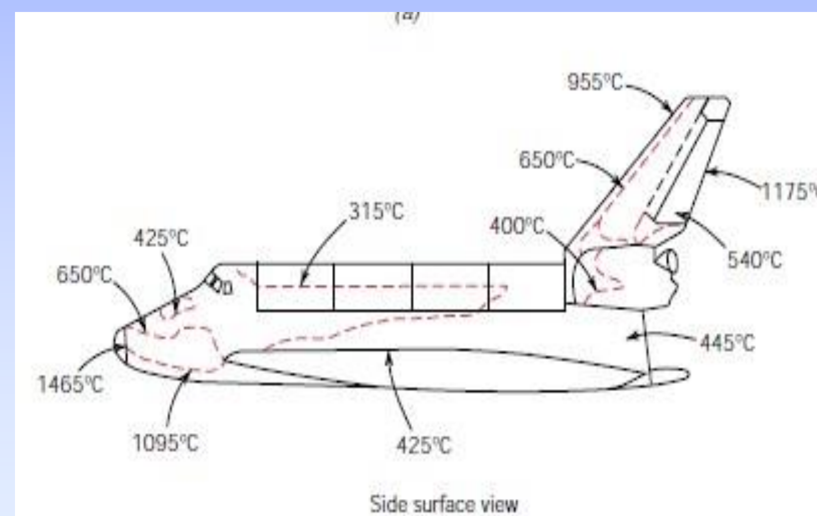
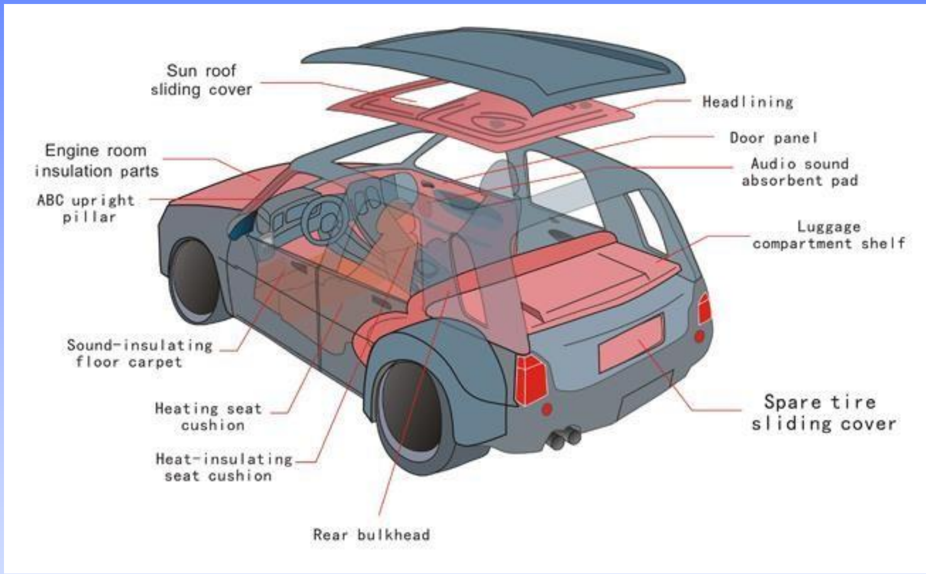


FIGURE 20.16 Locations of the various components of the thermal protection system on the Space Shuttle Orbiter: FRSI, felt reusable surface insulation;



Atlantis Space Shuttle Orbiter, USA


Boeing 787 Dreamliner
(50% composites by weight)
Carbon laminate
Carbon sandwich
Other composites
Aluminum
Titanium



Sun roof sliding cover
Headlining
Door panel
Engine room insulation parts
Audio sound absorbent pad
ABC upright pillar
Luggage compartment shelf
Sound-insulating floor carpet
Spare tire sliding cover
Heating seat cushion
Heat-insulating seat cushion
Rear bulkhead

Fig. Hybrid Composite Helmet Design.

Fig. Hybrid wind turbine system

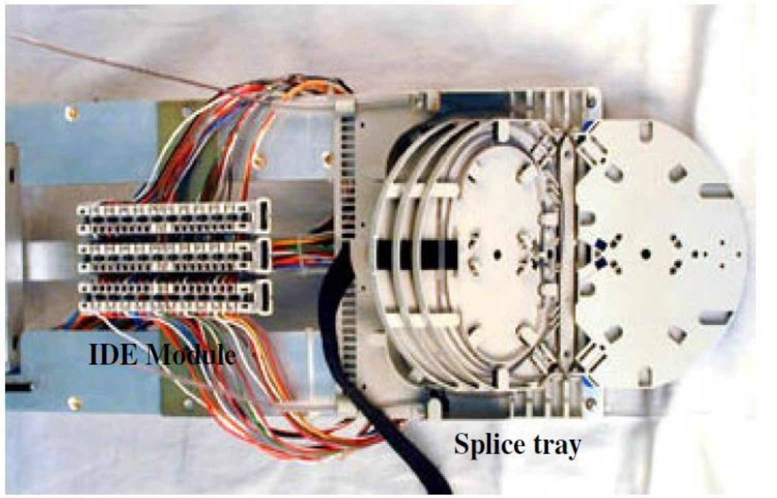


Fig. Hybird Composite Cable

Fig. Pedestrian Bridge in Okinawa, Japan made of Hybrid Composite.

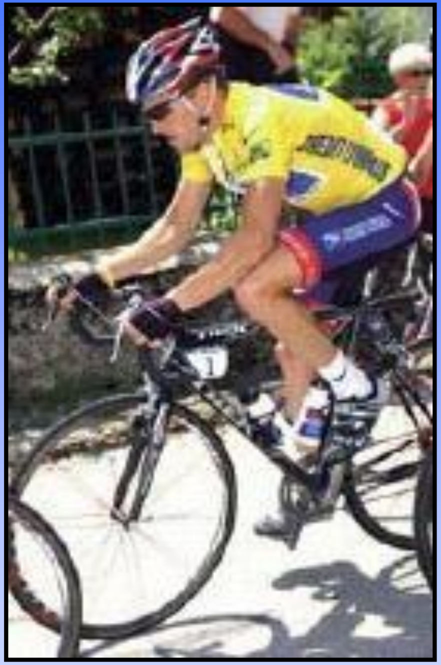
Thank You


Hebrews Making Mud Bricks
Tomb Of Rekhmire the Vizier
in Thebes (Luxor: tomb TT100)
Dated to Thutmosis III
brick wall
pond
www.bible.ca

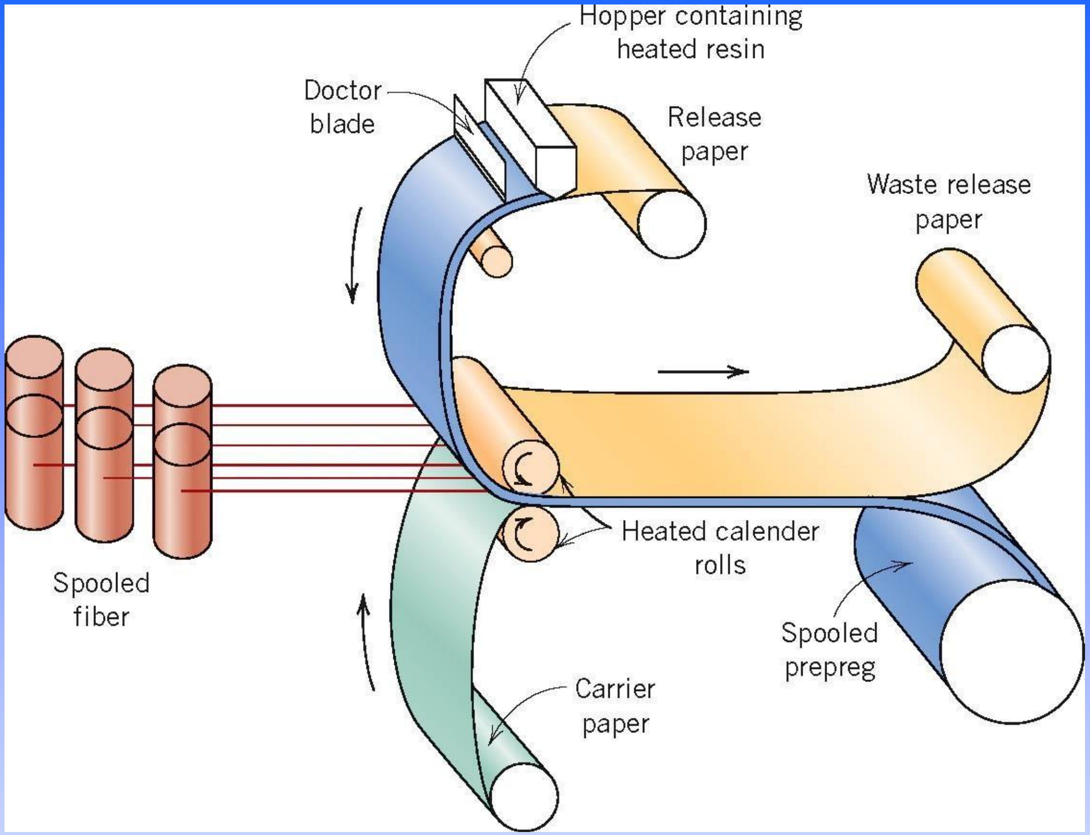
Application of Composites

Pedestrian bridge in Denmark, 130 feet long (1997)

Lance Armstrong's 2-lb. Trek bike, 2004 Tour de France



Swedish Navy, Stealth (2005)



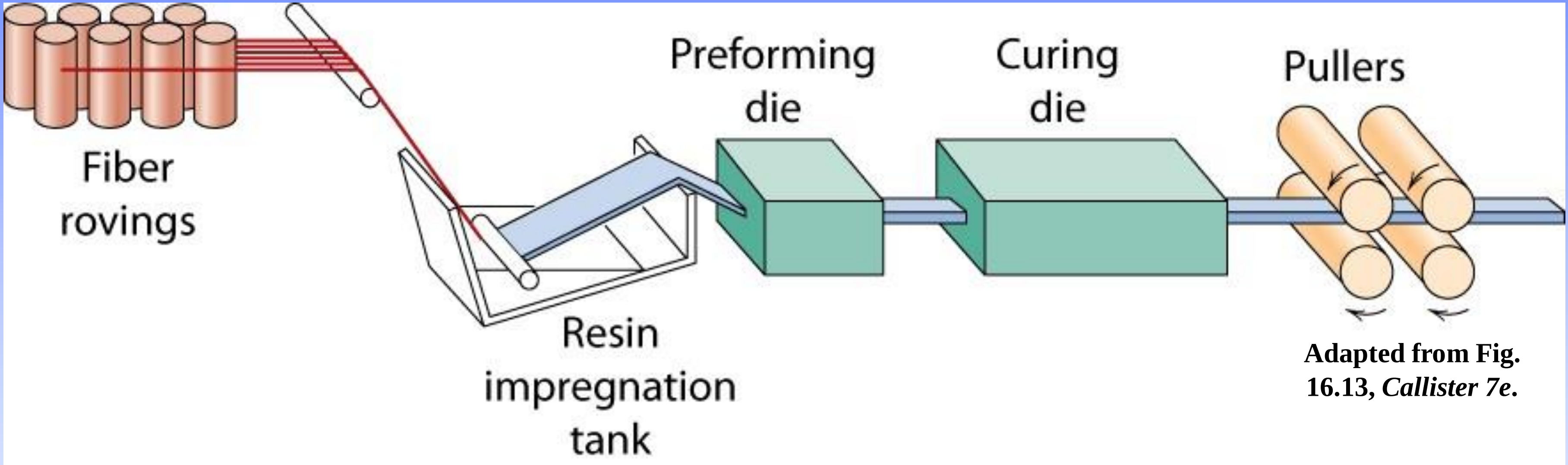
PREPREG PRODUCTION PROCESSES

- **Prepreg is the composite industry's term for continuous fiber reinforcement pre-impregnated with a polymer resin that is only partially cured.**
- **Prepreg is delivered in tape form to the manufacturer who then molds and fully cures the product without having to add any resin.**
- **This is the composite form most widely used for structural applications**

Composite Production Methods

Pultrusion

Continuous fibers pulled through resin tank, then preforming die & oven to cure –

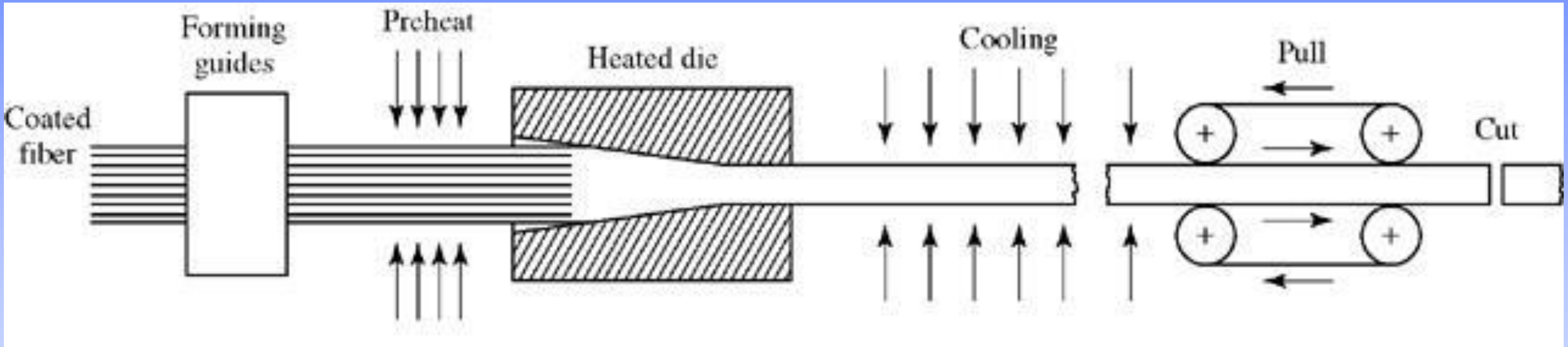


Adapted from Fig. 16.13, *Callister 7e*.

- **Production rates around 1 m/min.**
- **Applications are to sporting goods (golf club shafts), vehicle drive shafts (because of the high damping capacity), nonconductive ladder rails for electrical service, and structural members for vehicle and aerospace applications.**

Pultrusion

- Fibers are impregnate with a prepolymer, exactly positioned with guides, preheated, and pulled through a heated, tapering die where curing takes place.

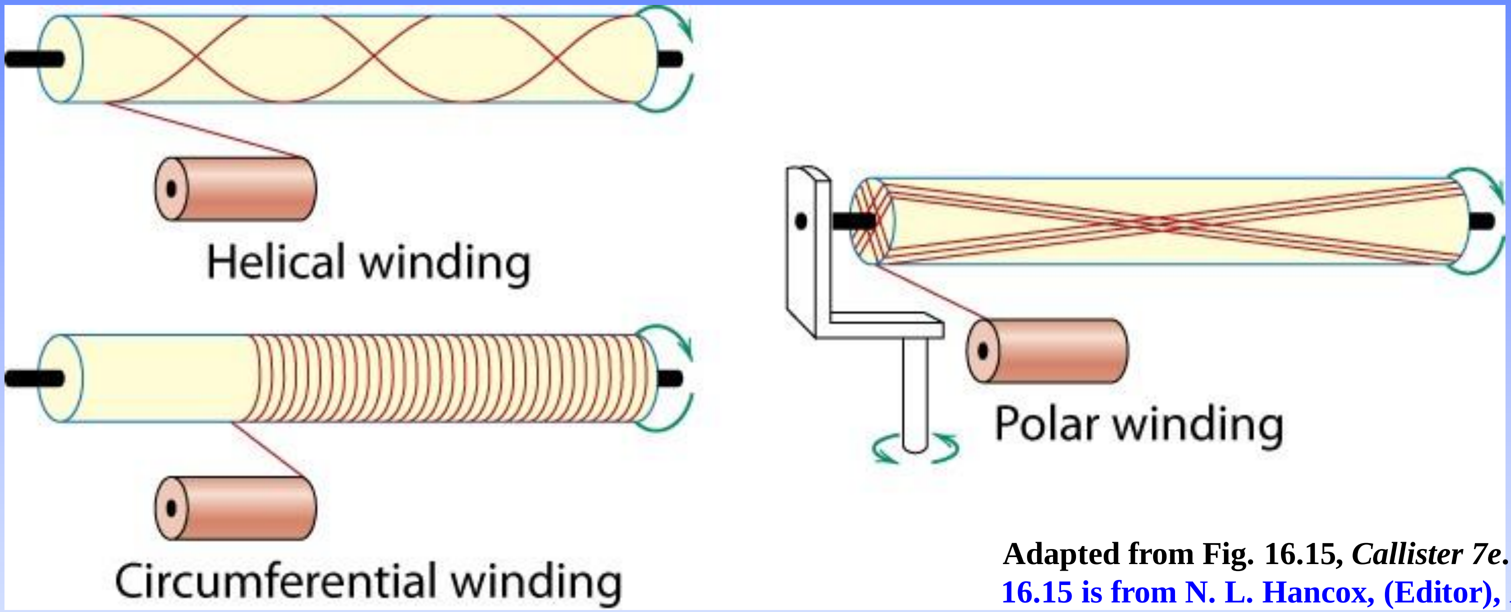


- Emerging product is cooled and pulled by oscillating clamps
- Small diameter products are wound up
- Two dimensional shapes including solid rods, profiles, or hollow tubes, similar to those produced by extrusion, are made, hence its name ‘pultrusion’

Filament Winding •

Ex: pressure tanks –

Continuous filaments wound onto mandrel –



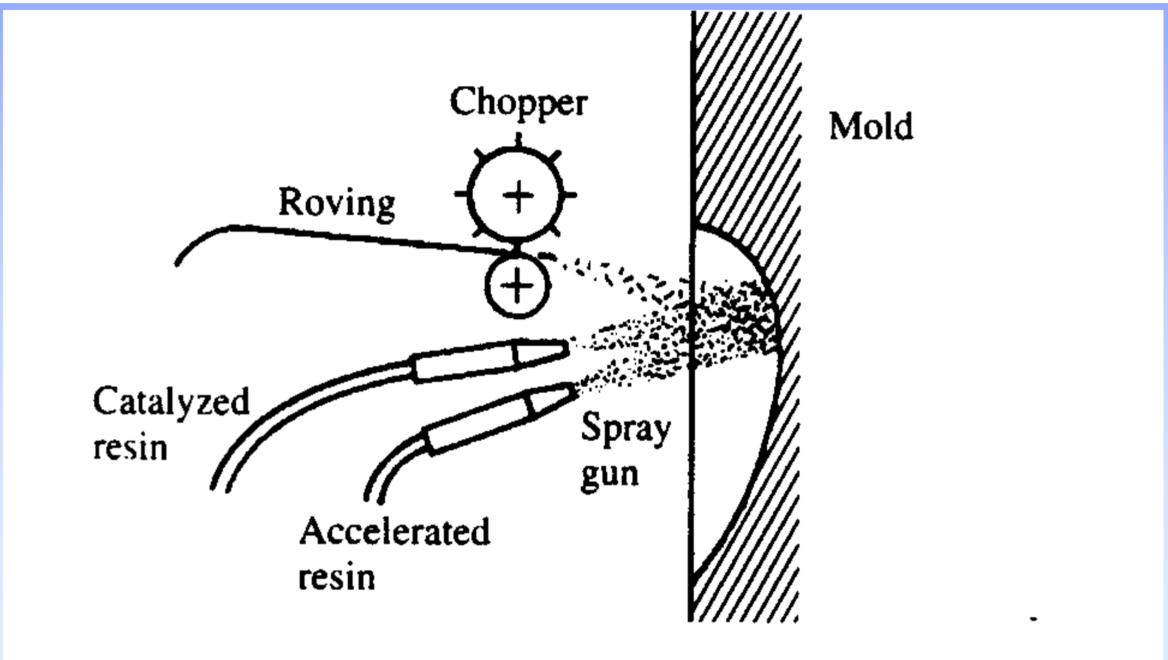
Adapted from Fig. 16.15, *Callister 7e*. [Fig. 16.15 is from N. L. Hancox, (Editor), *Fibre Composite Hybrid Materials*, The Macmillan Company, New York, 1981.]

SPRAY-UP MOLDING

A spray gun supplying resin in two converging streams into which roving is chopped

- **Automation with robots results in highly reproducible production**

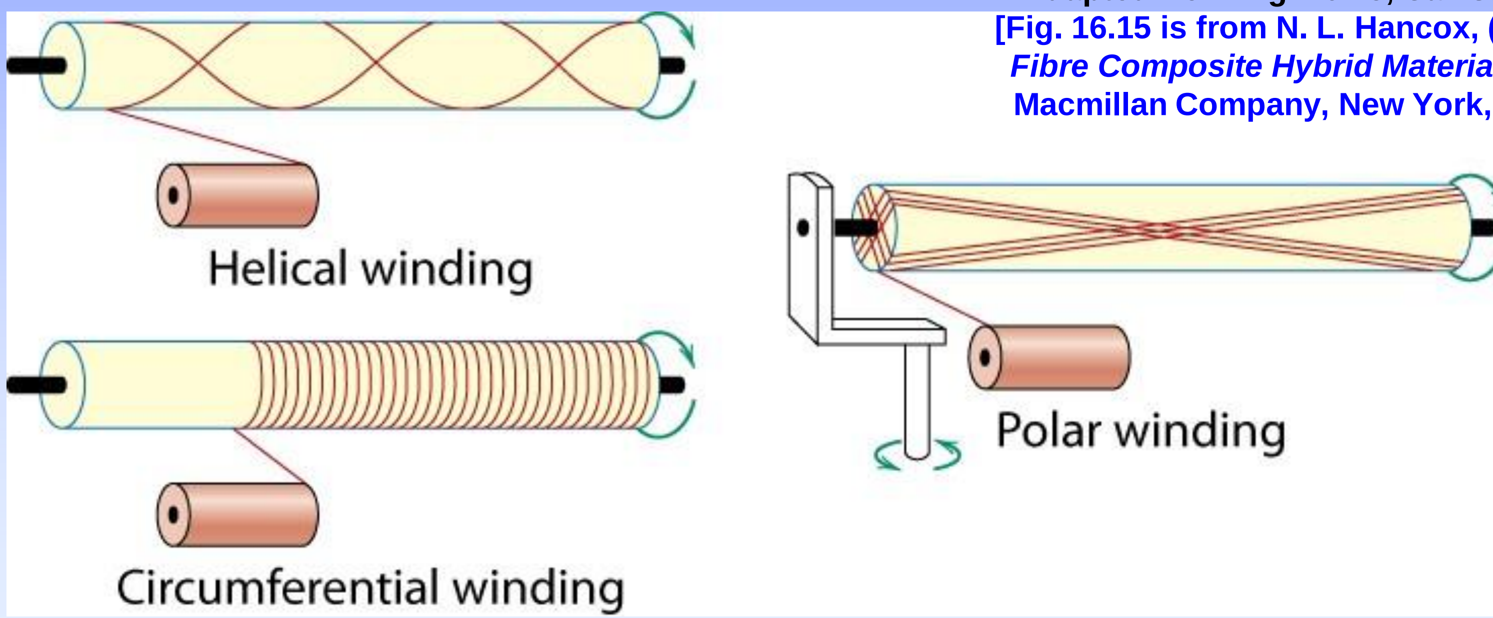
- **Labor costs are lower**



Composite Production Methods-II

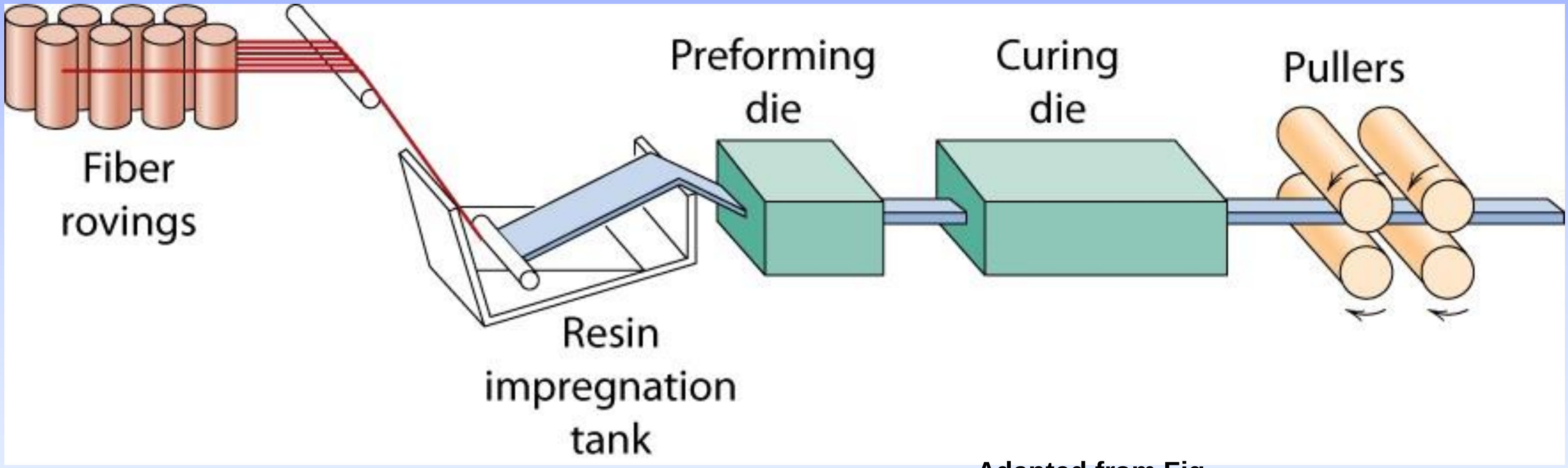
- Filament Winding
  - Ex: pressure tanks
  - Continuous filaments wound onto mandrel

Adapted from Fig. 16.15, *Callister 7e*.
[Fig. 16.15 is from N. L. Hancox, (Editor), *Fibre Composite Hybrid Materials*, The Macmillan Company, New York, 1981.]



Composite Production Methods-I

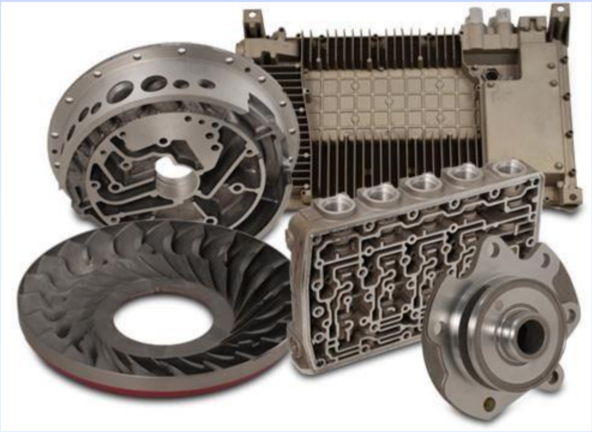
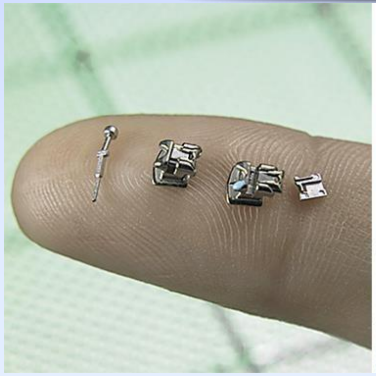
- Pultrusion
  - Continuous fibers pulled through resin tank, then preforming die & oven to cure



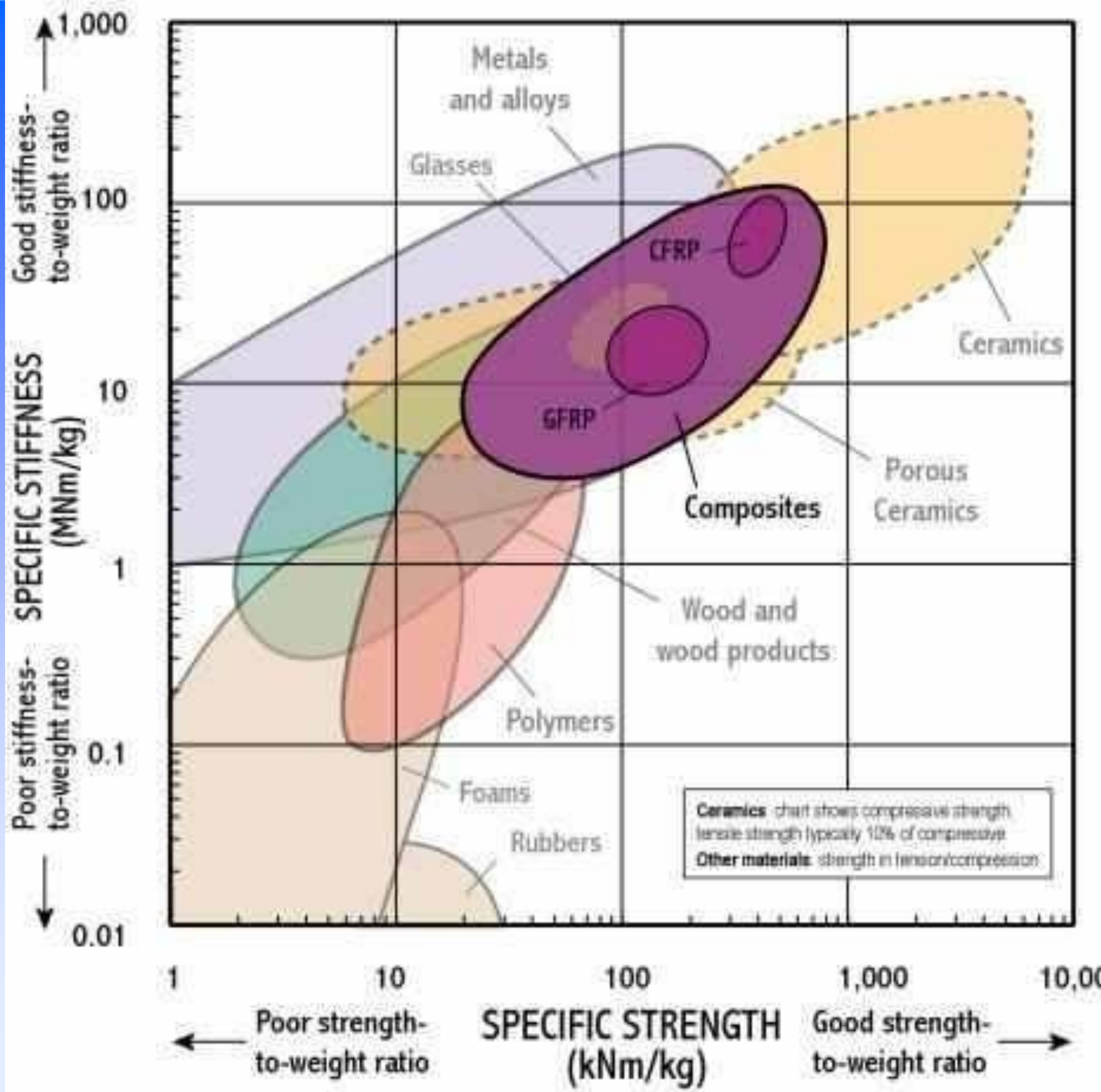
Adapted from Fig. 16.13, *Callister 7e*.





4 5 6 7 8 9



Metals and alloys
Glasses
CFRP
GFRP
Ceramics
Composites
Porous Ceramics
Wood and wood products
Polymers
Foams
Rubbers
Ceramics: chart shows compressive strength, tensile strength typically 10% of compressive
Other materials: strength in tension/compression
1,000
100
10
1
0.1
0.01
Good stiffness-to-weight ratio
SPECIFIC STIFFNESS (MNm/kg)
Poor stiffness-to-weight ratio
1
10
100
1,000
10,00
Poor strength-to-weight ratio
SPECIFIC STRENGTH (kNm/kg)
Good strength-to-weight ratio

Yield strength is the lowest stress that produces a permanent deformation in a material. In some materials, like aluminium alloys, the point of yielding is difficult to identify, thus it is usually defined as the stress required to cause 0.2% plastic strain. This is called a 0.2% proof stress.[5]

Compressive strength is a limit state of compressive stress that leads to failure in a material in the manner of ductile failure (infinite theoretical yield) or brittle failure (rupture as the result of crack propagation, or sliding along a weak plane - see shear strength).

Tensile strength or *ultimate tensile strength* is a limit state of tensile stress that leads to tensile failure in the manner of ductile failure (yield as the first stage of that failure, some hardening in the second stage and breakage after a possible "neck" formation) or brittle failure (sudden breaking in two or more pieces at a low stress state). Tensile strength can be quoted as either true stress or engineering stress, but engineering stress is the most commonly used.

Fatigue strength is a measure of the strength of a material or a component under cyclic loading,[6] and is usually more difficult to assess than the static strength measures. Fatigue strength is quoted as stress amplitude or stress range (), usually at zero mean stress, along with the number of cycles to failure under that condition of stress.

Impact strength, is the capability of the material to withstand a suddenly applied load and is expressed in terms of energy. Often measured with the Izod impact strength test or Charpy impact test, both of which measure the impact energy required to fracture a sample. Volume, modulus of elasticity, distribution of forces, and yield strength affect the impact strength of a material. In order for a material or object to have a high impact strength the stresses must be distributed evenly throughout the object. It also must have a large volume with a low modulus of elasticity and a high material yield strength