Engineering Assessment of Composite Technology as an Alternative to Traditional Materials

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Presentation Outlines

- Introduction to materials
- Metals and alloys
- Polymers
- Ceramics
- Composites
- Composites as alternative materials
- Applications of Composites
- Challenges of conventional composites
- Sustainable composites
- Research gaps
- Summary and conclusions
- References

Materials

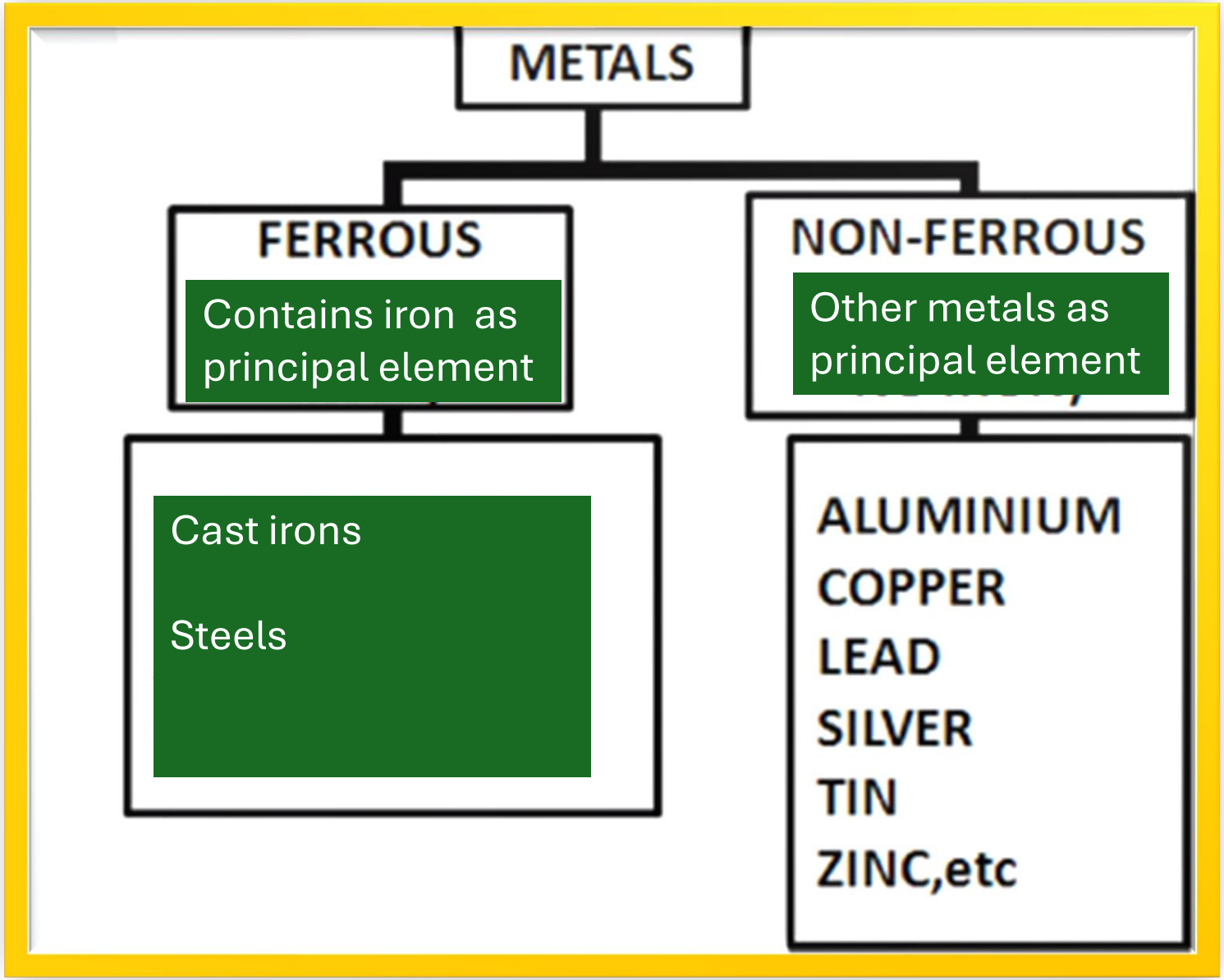
- Materials are natural or synthetic substances used in manufacturing of new products.
- They are expected to withstand service constraints which may include mechanical stresses, thermal stresses or chemicals.
- Since every product requires material components, materials become inevitable to every manufacturing industries.

Classifications of Materials

- Materials are classified into the followings:
  - Metals - An element (Mixing of elements leading to alloy)
  - Polymers - Organic compounds
  - Ceramics – Inorganic compounds
  - Composites – Mixture of any of metals, polymers or ceramics

Metals and Alloy

- Pure metals are rarely used in any applications because of their properties that don't meet most service requirements.
- Alloying systems address properties' limitations of pure metals.
- An alloy is a mixture of elements in which the principal element is a metal.
- It is classified into ferrous and non-ferrous metals.


METALS
FERROUS
Contains iron as principal element
Cast irons
Steels
NON-FERROUS
Other metals as principal element
ALUMINIUM
COPPER
LEAD
SILVER
TIN
ZINC,etc

Cast iron

- White cast iron – carbon exists as Fe_3C
- Gray cast iron – carbon as graphite flake
- Ductile cast iron – carbon as nodular graphite
- Malleable cast iron – tempered white cast iron

Mechanical properties of cast iron

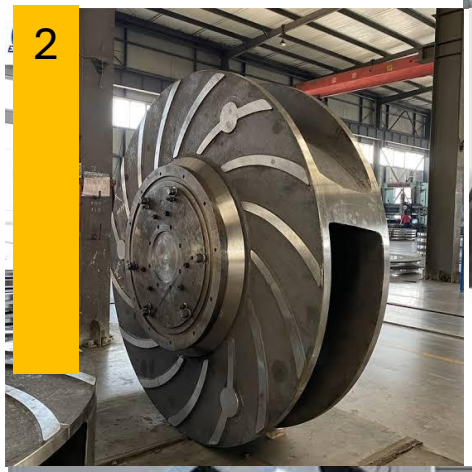
Alloys	Tensile strength (MPa)	Strain (%)	Young's modulus (GPa)	Charpy V-Notch Impact energy (J)
Grey cast iron	140 - 415	-	70 - 130	2- 6
Ductile iron	415 – 700	3-18	140 -170	3-25
Compacted graphite iron	350 - 500		140 -170	6-10
Malleable cast iron	350 -550		190-210	8-15
White cast iron	150 - 350		190-210	<2

Applications of cast iron

- White cast iron is used in areas requiring high resistance to wear like in production of:
  - Jaw crusher plates (1)
  - Slurry pump impeller (2)
  - Ball mill liners (3)
  - Shot blast machine parts (4)
  - Rail brake shoes (5)
  - Excavator bucket (6)
- Ductile iron being very strong and ductile, it is used in heavy machineries, pipe making and automotive components









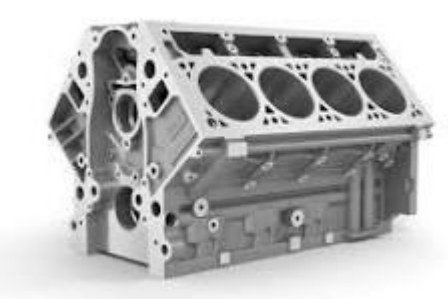




Uses of Ductile Iron

Ductile iron being very strong and ductile, it is used in:

- Automobile components like Engine blocks, crankshaft, gears.
- Municipal and Infrastructure like pipes, high pressure valves, manholes.
- Heavy machineries e.g agricultural machine, wine turbine rotor.



Engine block



Crankshaft



Gears



Sewage and water pipe



High pressure valve



Wine turbine rotor

Mechanical Properties of Steels

Alloys	Tensile strength (MPa)	Strain (%)	Young's modulus (GPa)	Charpy V-Notch Impact energy (J)
Low carbon steel (mild steel , 0.05 -0.25)	400 -550	0.12-0.18	200 - 210	40 -80
Medium carbon steel (0.25 – 0.6)	600 – 800	0.20-0,29	200 - 210	30-50
High carbon steel (0.6 – 1.5)	600 - 800	0.29 – 0.44	200 - 210	5-15
Alloy steel	1000 -2200	0.41-0,49	210-215	25-70

Alloys	Tensile strength (MPa)	Strain (%)	Young's modulus (GPa)	Charpy V-Notch Impact energy (J)
Stainless steel	515 -1300	0.49-0.68	193-210	15-200
Dual phase steel	600 - 700	0.17-0,22	200 - 210	37-60
Tool steel	1800-2200	0.65-0.88	200 - 210	4-10

Application of steels





Non-Ferrous Metals: Aluminium Alloy

Properties of aluminium alloys

- Al being the host has the highest proportion. About 99% in 1xxxx series
- Al alloy has E ranging from 69 -73 GPa which is about 3 times lower than that of steel.
- Strength of the Al alloy are ranked according to series as follows: 7xxx> 2xxx> 6xxx >5xxx > 4000 > 3xxx > 1xxx
- Strain is ranked accordingly: 1xxx> 5xxx > 3xxx > 4xxx > 6xxx > 2xxxx > 7xxxx.
- 7xxx has approximated 10% elongation while 1xxx has 45% elongation.
- Al alloy are hard to weld because of their high conductivity. However, 6xxx, 5xxx, 3xxx and 1xxxx are relatively weldable. 2xxx and 7xxx are poor in welding.
- New aluminium series is 8xxx which contains Li or Fe as the main alloying element.

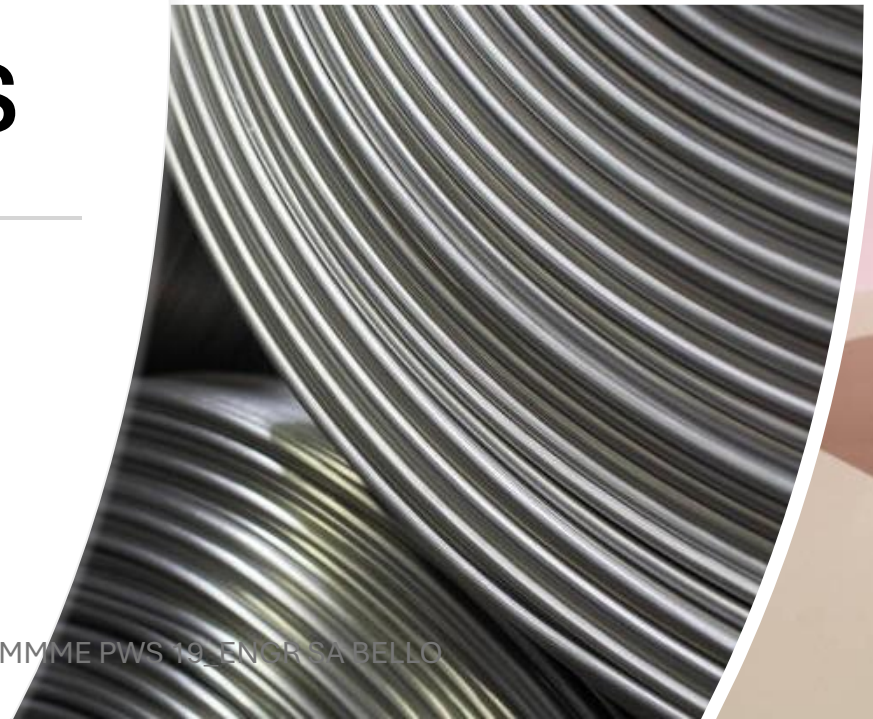
Aluminum Series Guidelines Car wheel

Alloy Series	Main Alloying Elements
1000 Series	Pure aluminum
2000 Series	Aluminum and copper. High strength used in aerospace manufacturing.
3000 Series	Aluminum and manganese. Beverage cans and tubing.
4000 Series	Aluminum and silicon. Automotive use and filler materials.
5000 Series	Aluminum and magnesium. Automotive structural and sheet.
6000 Series	Aluminum, magnesium and silicon. Sheet, extrusions and plate for automotive.
7000 Series	Aluminum and zinc, possibly other elements added. Aerospace and sheet for automotive.

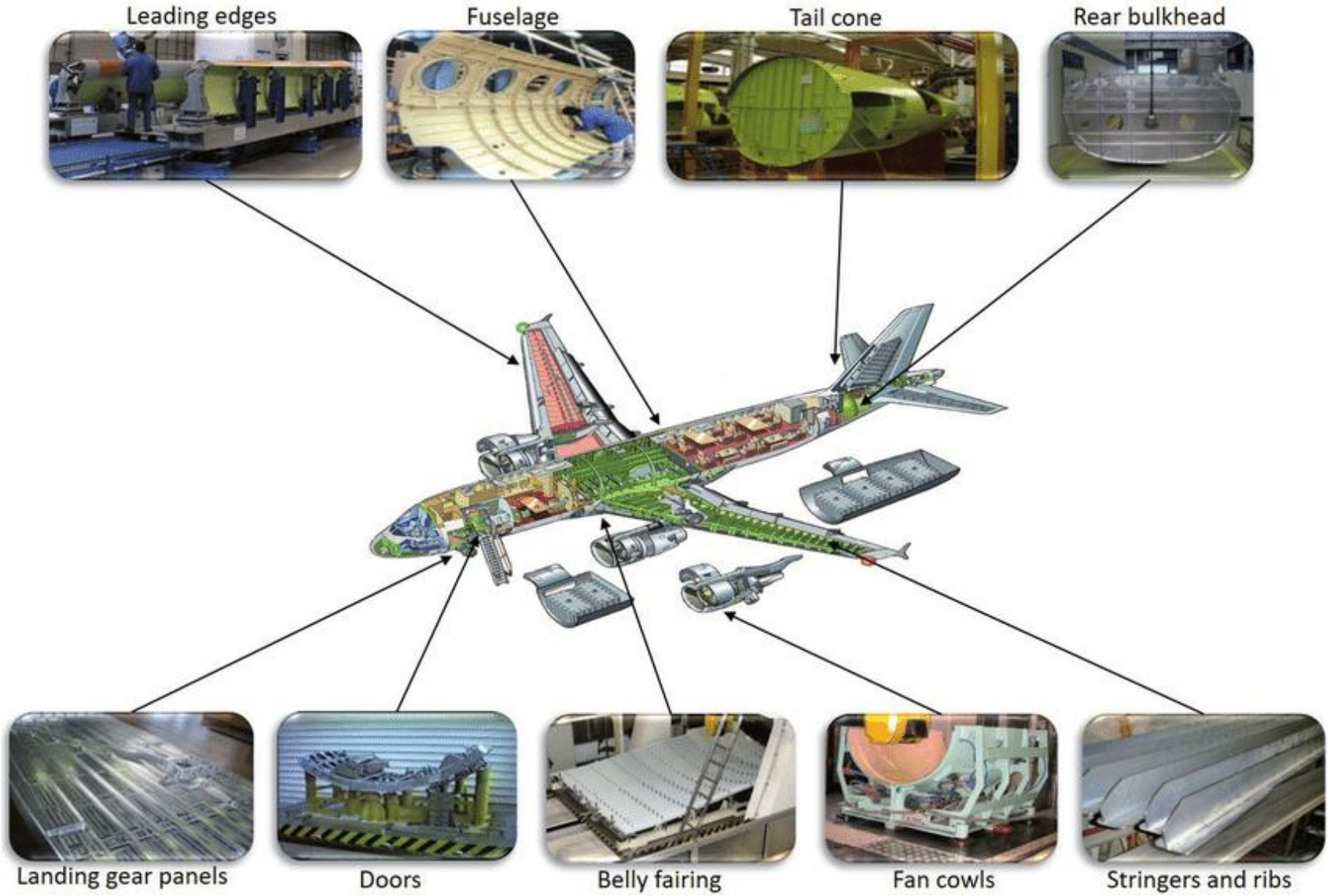
Applications of aluminium alloys











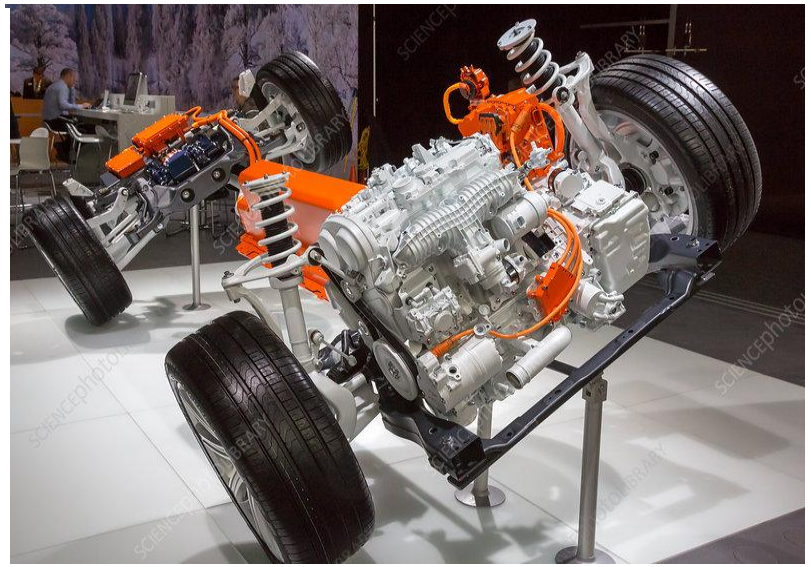
Applications of aluminium alloys in A319 aircraft

Applications of aluminium in powertrain components include:

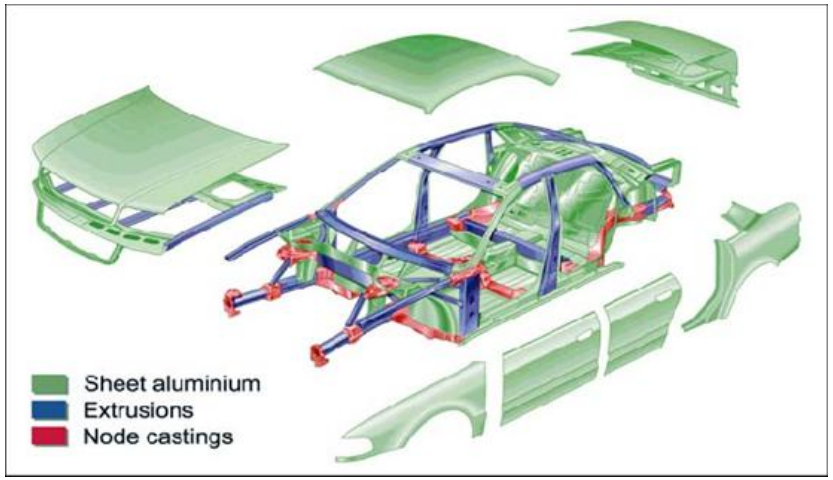
- Pistons
- Engine blocks
- Cylinder liners
- Cylinder heads
- Fuel systems
- Heat shields
- Heat exchangers
- Other engine components
- Transmission systems



Wheel

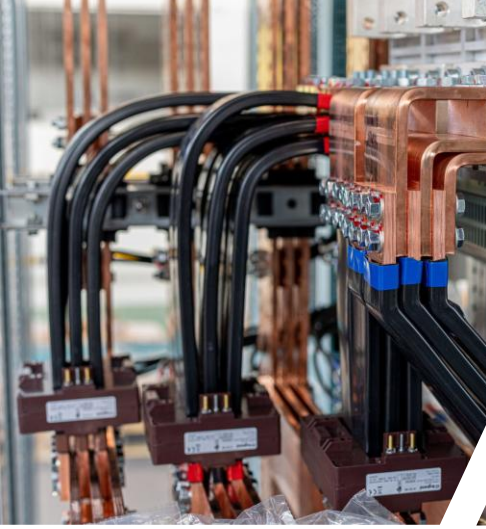


Powertrain



Body/frame


5083,5086,5456,5052
Outboard bottom plate
5083,6N01,5052
Ship Cockpit
5052,3004,3003
Ship roof side plate
5052,5083,5086,6061
Ship Deck

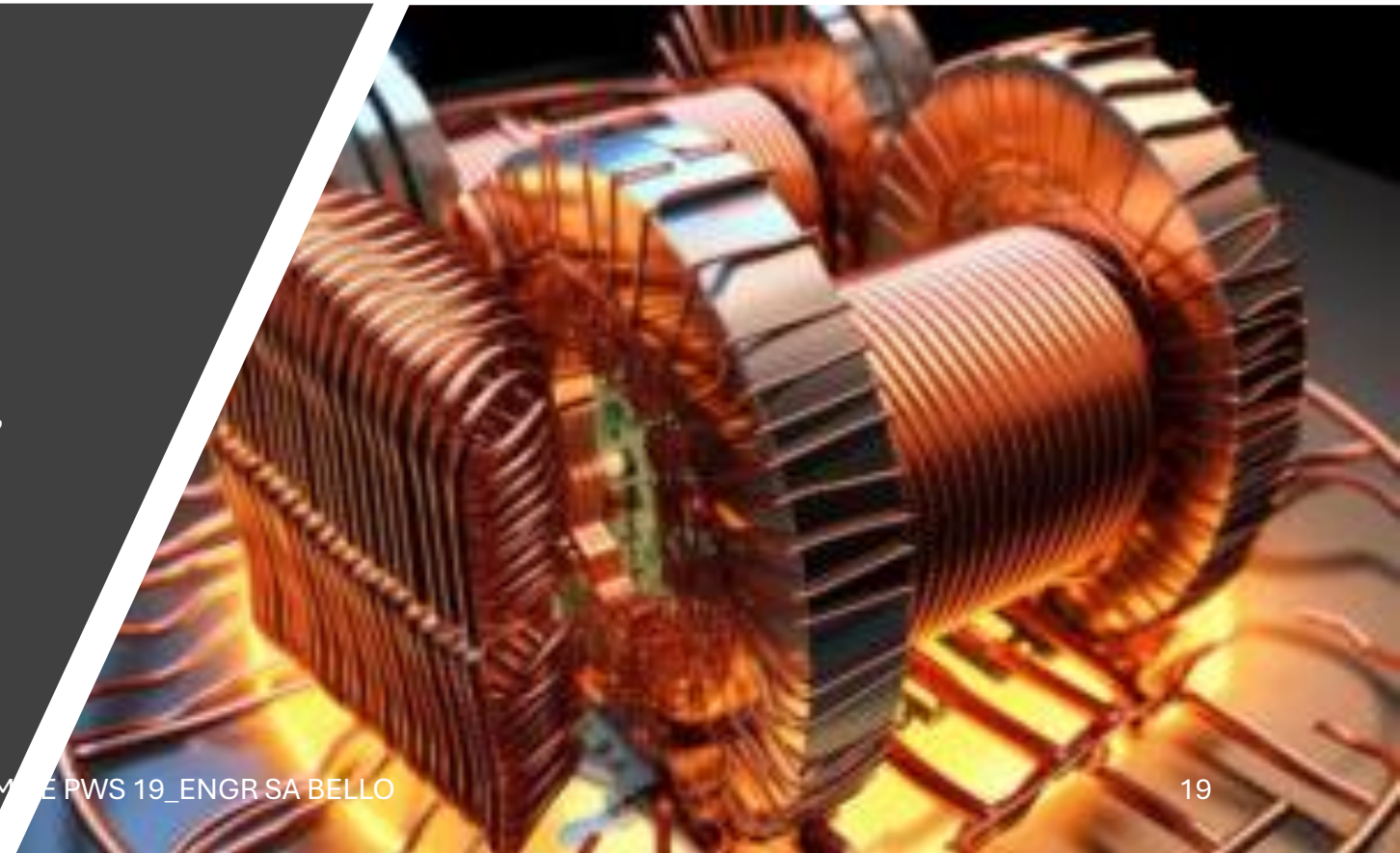






Copper alloys

- Pure copper is highly conductive, ductile and corrosion resistant.
- It is applied in making electrical wiring for cables, transformer and motors.
- It is used in plumping materials, heat exchangers, roofing materials and conductor in solar panel, circuit board and heavy-duty windings in wind turbine generator.
- Brass is used for pipe fittings, musical instruments and decorative hardware.
- Bronze is used in making sculptures, gears and ship components.



Alloys	Tensile strength (MPa)	Strain (%) (0.2%)	Young's modulus (GPa)	Charpy V-Notch Impact energy (J)
Copper-Beryllium	1300 – 1400	1-60	110-130	15-30
Aluminium bronze	750	10-15	220	13-60
Catridge brass	315	55-80	90-120	85-120
Bronze	310	45% (P bronze); 2% cold rolled bronze	70	30-115
Cupronickel	275	0.49-0.68	120-156	40-120
Annealed Pure copper	210	40-60	130	140-200
Heavily cold worked copper	455	5-15	110	80-130

Zinc Alloys

Alloys	Tensile strength (MPa)	Strain (%)	Young's modulus (GPa)	Charpy V-Notch Impact energy (J)
Zamak series	280 – 330	Highest 10%	85.5 -96	42 - 58
ZA series (ZA8, ZA12, ZA 27)	380-410	8-27	78 – 85	9 -48

- Uses of zinc alloy
- It is used to produce intricate parts in automobile and electronic components like door handles, engine brackets, machine components and device enclosure
- Sacrificial anode to protect bury pipeline; Zinc alloy sheet, cardiovascular implants

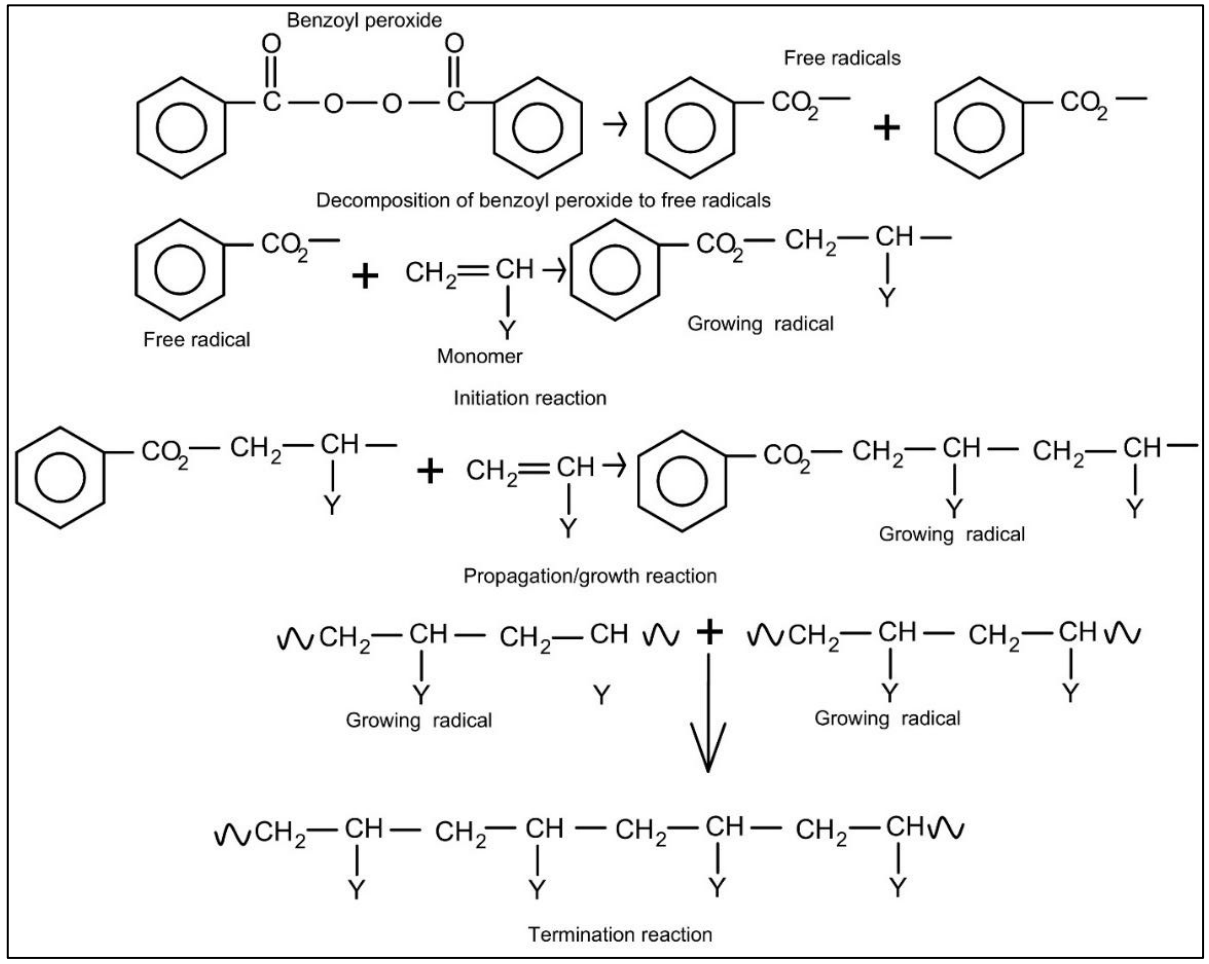
Polymer

- Polymers are macromolecules synthesised by chemical combination of a large numbers of small molecules known as monomers.
- Such chemical combination producing polymers from small molecules is called polymerization.
- Polymers can be classified as natural and synthetic, addition and condensation, homo and copolymers, thermoset and thermoplastics.
- Natural polymers are giant molecules occurred naturally and of plant and animal origins.
- Examples are proteins, starches, cellulose and natural rubbers.

Additional polymer

- Addition polymers are produced via addition polymerization of monomers without any accompanying products.
- Monomers for the reactions contain double bond like ethylene or triple bond like formaldehyde.
- They breaks up by activation with free radicals or ions to produce molecules with free valence joining to one each other to produce long chain molecules known addition polymers.

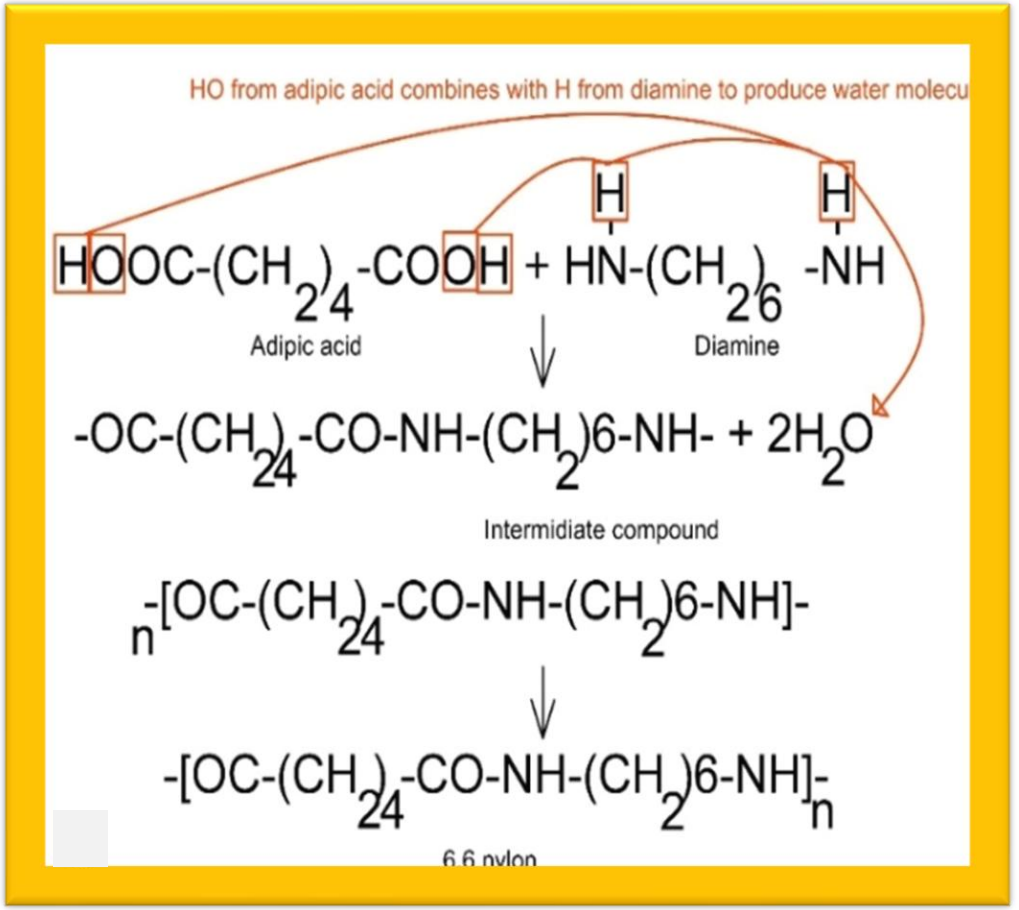
Additional polymer



- Polyethylene
- Polypropylene
- polyallylalcohols,
- polyallylamines,
- polyvinyl chloride

Condensation polymer

- Condensation polymers are produced by condensation polymerization involving addition of two different monomers to give intermediate products and a coproduct.
- The intermediate compounds have two ends reacting with one another to form progressive long chain molecules.
- Examples are polyethylene-terephthalate; polyamides e.g protein and 6.6 nylon, polyesters, epoxy resin



Properties of Polymer

Thermoplastics	Tensile strength (MPa)	Strain (%)	Young's modulus (GPa)	Charpy V-Notch Impact energy (J)
LDPE	10 – 18	80 -960	0.15 – 0.52	15 -23
LLDPE	10-35	400 -800	0.15 – 0.6	10 -50
HDPE	15 - 45	100 - 1000	0.4 -1.5	35 -57
UHMWPE - Bulk solid **Fibres**	39 – 48 3000 – 6400	3 – 5	0.69 – 1.2 100 - 150	No break
PP	20 - 40	100 - 600	1.3 – 2.0	1.5 – 37

Thermosets	Tensile strength (MPa)	Strain (%)	Young's modulus (GPa)	Charpy V-Notch Impact energy (J)
Polyester	50 -120	1.0 – 3.0	2.0 – 4.5	3.0 – 12.0
Epoxy resin	30 - 90	1.5 - 50	3.0 – 6.0	0.2 - 8.8
Cyanate ester	40 - 80	2.5 -4.9	3.0 – 3.5	0.01 – 0.05

Uses of Unfilled Polymers



Unfilled polycarbonate



Unfilled polytetrafluoroethylene



Unfilled epoxy



Unfilled LDPE





Unfilled HDPE





Unfilled PVC

Ceramic Materials

- Ceramics are materials that contain pieces of metallic or non-metallic compounds.
- Ceramics—Greek word (keramos meaning potters clay)
- Keramikos, (clay product)

Properties of ceramics

- Ceramics are hard, strong and dense.
- They are highly resistant to chemical and wear.
- They possess high fusion points.
- They have high dielectric properties.
- They are good thermal insulator even at high temperature.
- They have high compressive strength.
- They are resistant to high temperature creep.
- Low specific gravity (3 - 5.8<7.86 for Fe)
- They are easily available.

Uses of ceramics

















Composite Materials

- Composites are a group of materials that are made from two or more different substances combined to create a new material with specific properties.
- Composites are a sustainable resource with a high economic potential.
- Composites are important engineering materials having higher specific strength i.e. the strength per unit weight than that of the known very light metals such as aluminium and titanium.

- Specific strength of aluminium is at least three times that of steel and titanium when mixed with silicon carbides to produce aluminium-silicon carbide composites.
- Also that of fibre reinforced polymer matrix composite is higher by a factor of four.
- Society and culture have accepted the use of composites in several fields, including construction, transportation, aerospace, marine applications, and sporting goods.

Composites

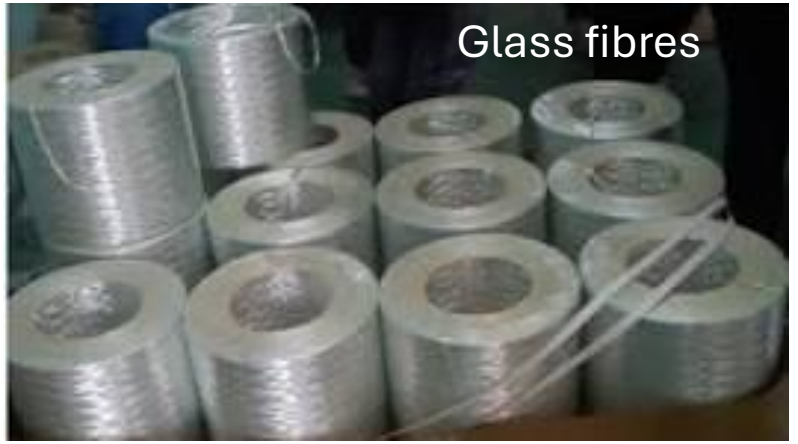
- Composite = Matrix + Reinforcement
- Matrix can be a single material or a blend of different materials.
- It acts like a motherboard in a computer that connects every unit together.
- It binds the reinforcement together.
- By connection, it helps in load distribution to the reinforcement.
- Reinforcement is the load bearers of the composites.
- Reinforcement can be a single material or mixture of different materials.
- It can be particles or fibres.

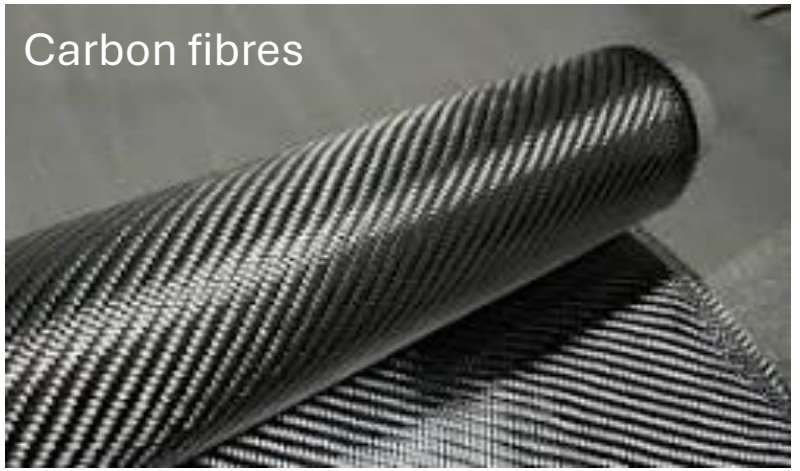
Classification of Composites

- Composites can be classified using fillers/reinforcements and the matrix.
- In accordance with reinforcements, composites are classified as fibre reinforced and particulate reinforced composites.
- For matrix classification, composites are grouped into three namely:
    - metal matrix composites (MMC);
    - ceramic matrix composites (CMC) and
    - polymer matrix composites (PMC).
- Metals, polymers and ceramics have been discussed in the previous slides with their mechanical properties.

Fibres

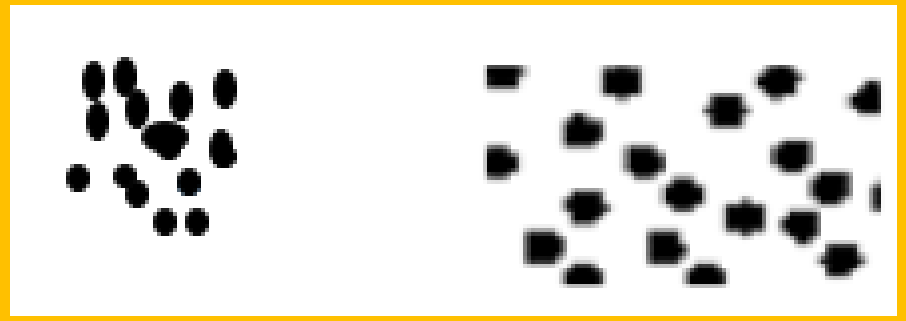
- Fibres are fillers, reinforcements or load bearers existing in the matrix of fibre reinforced composites.
- A single fibre is called a filament, for a glass fibre a strand is used to describe a single fibre.
- Bundles or packs of filaments are called yarns, roving or tows.
- Tows are twisted while yarns are not twisted.
- A dry fibre needs to be filled with resin before use. A prepreg fibres contain fibres already impregnated with resin.
- Fibre ply is used to reduce anisotropy in the fibre reinforced composites





Particulate reinforced composites

- Reinforcement are particles.
- Particle can be coarse or nanoparticles



Aluminium matrix composites

- Aluminium alloy is the base metal.
- Synthetic particles like CNTs, SiC and Al2O3 have been used as reinforcement.
- Sustainable reinforcing particles like eggshells, palm kernel shell, coconut shells, etc have been reported as well.
- Stir casting approach has been a major technique for the production of AMC.

Polymer matrix

- Different polymers like thermoplastics (polyethylene, polypropylene) and thermosets like polyester, epoxy resin are used as the matrix.

- Reinforcements include carbon fibre, glass fibre, CNTS, carbon particles, synthetic particles, sustainable fibres and particles from agricultural waste.

Mechanical properties of composites

Composites	Tensile strength (MPa)	Strain (%)	Young's modulus (GPa)	Charpy V-Notch Impact energy (J)
AMC	200 – 550	1.0- 10.0	88.0 – 200.0	3.0 – 30.0
CFRE	400 - 1500	0.5 – 1.5	70.0 – 150.0	2.0 – 15.0
GFRE	30 - 370	3.0 – 5.0	10.0 – 45.0	3.0 – 15.0
CFRP	150 - 450	0.5 – 1.5	40.0 – 150.0	2.0 – 15.0
GFRP	28 – 200	1.5 – 6.75	7.0 – 20.0	3.5 – 15.5
GFRPP	50 – 140	2.0 – 6.0	3.2 – 12 .0	0.5 – 1.5
CFRPP	30 – 1,100	1.0- 10z.0	3.0 – 13.0	1.2 – 2. 7
CFRPE	20 – 40	1.0 – 3.0	1.5 – 17.1	2.0 – 15.0
GFRPE	24 - 130	2.0 – 9.0	1.5 – 10.0	2.0 – 6.0
GFRUHMWPE GFRUHMWPE fibre	60 – 110 2500	3.0 – 10. 0	1.2 – 16.0	No break

Composites as alternative traditional materials

- ✓Higher strength-to-weight ratio than steel
- ✓Better corrosion resistance,
- ✓More design flexibility,
- ✓Better fatigue resistance, and
- ✓Tailored thermal/electrical properties.

That's why aerospace, automotive, wind energy, sports, construction, and defense all rely on composite materials for replacing steels.

Benefits include weight reductions, enhancements in fuel efficiency, higher speeds, less maintenance, etc

Applications of Composites Automotive applications

- It is used in automobile industries
  - Engine part applications: piston, connecting rod.
  - Brake system application: Brake disc and friction rings.
  - Drivetrain applications : Light weight rotating shaft. It achieves high fuel efficiency.
  - Leaf spring
  - Interior components
  - Glass fibre reinforced plastic for vehicle bonnet.
  - Sustainable composite for bumper applications

Uses of AMC and PMC reduce vehicle weight by 30% and improve fuel efficiency.

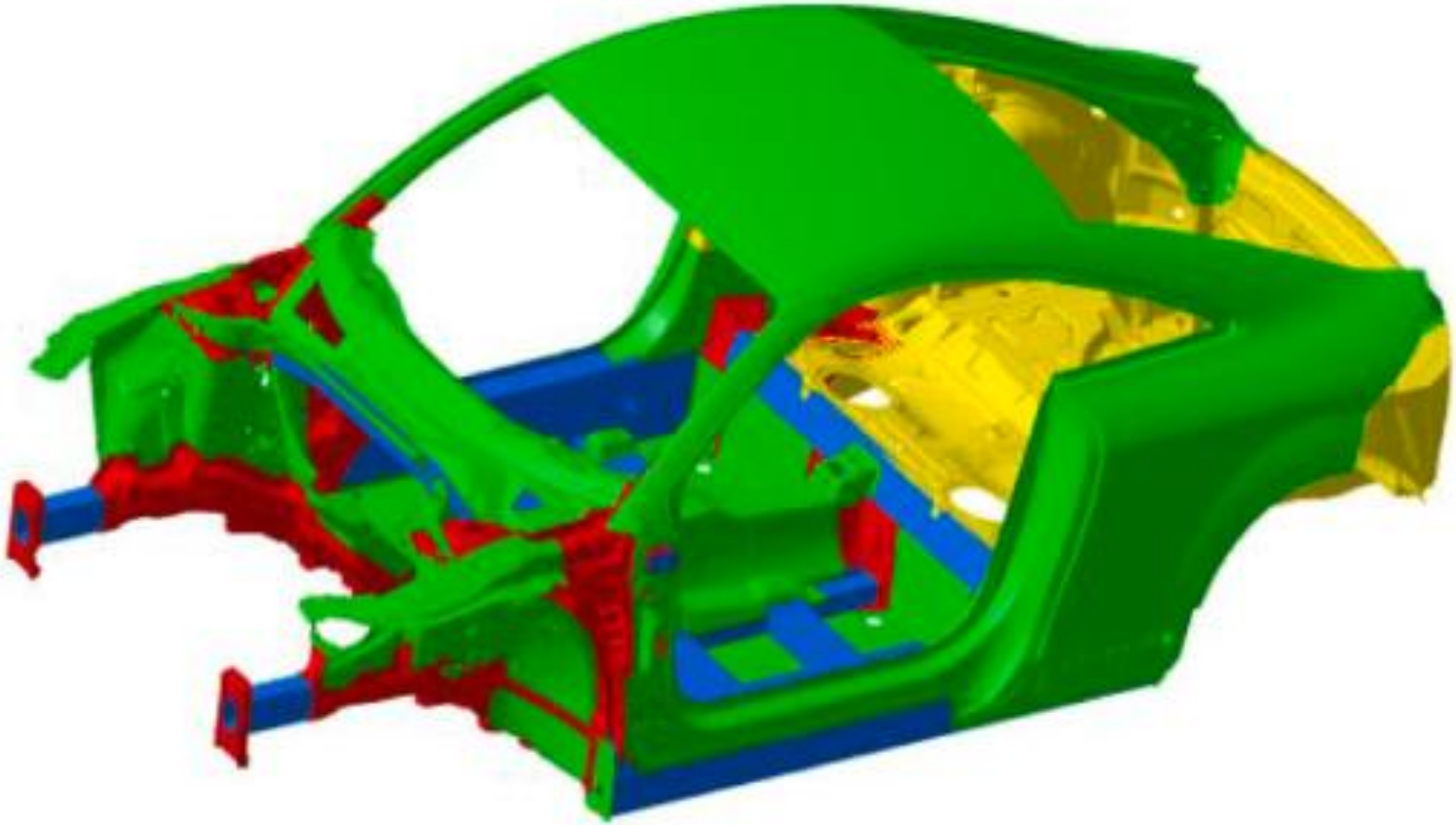


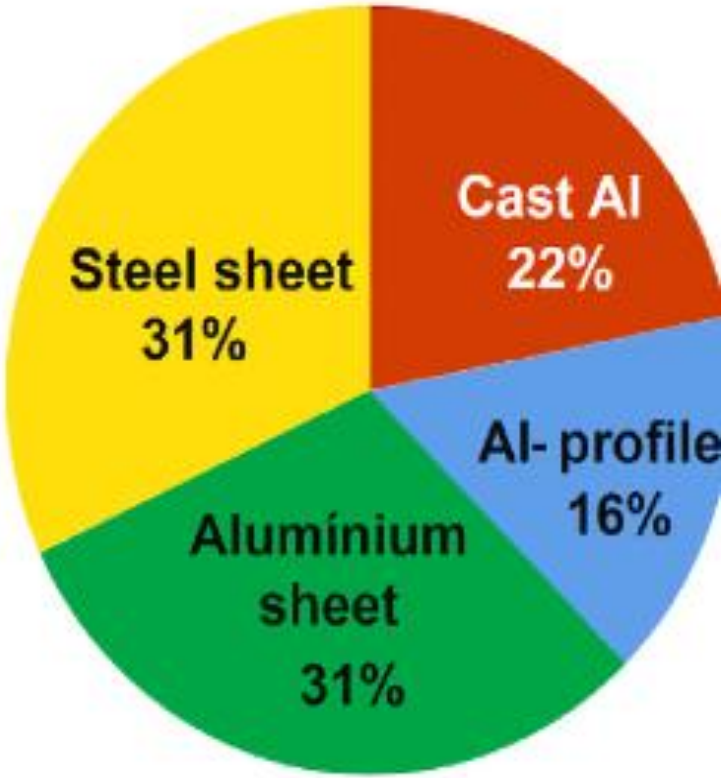












Uses of AMC in automobiles

Safety Seat and
Side Door Structure
BMW



Floor Panel
GF/ PP + PP-Honeycomb
Nissan

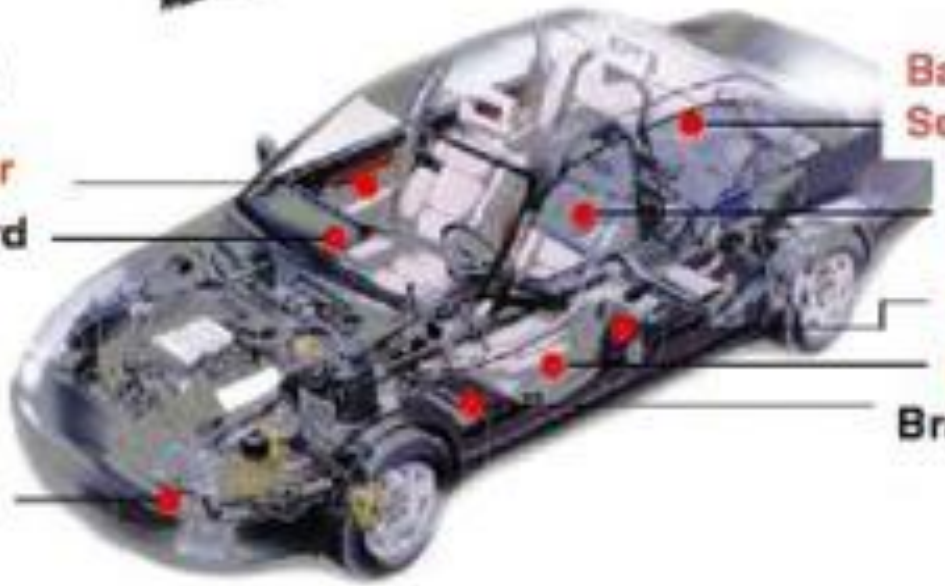




Bumper
GF/ PA 6
BMW

Transverse Support Beam
GF/ PA 66
IVW, Porsche



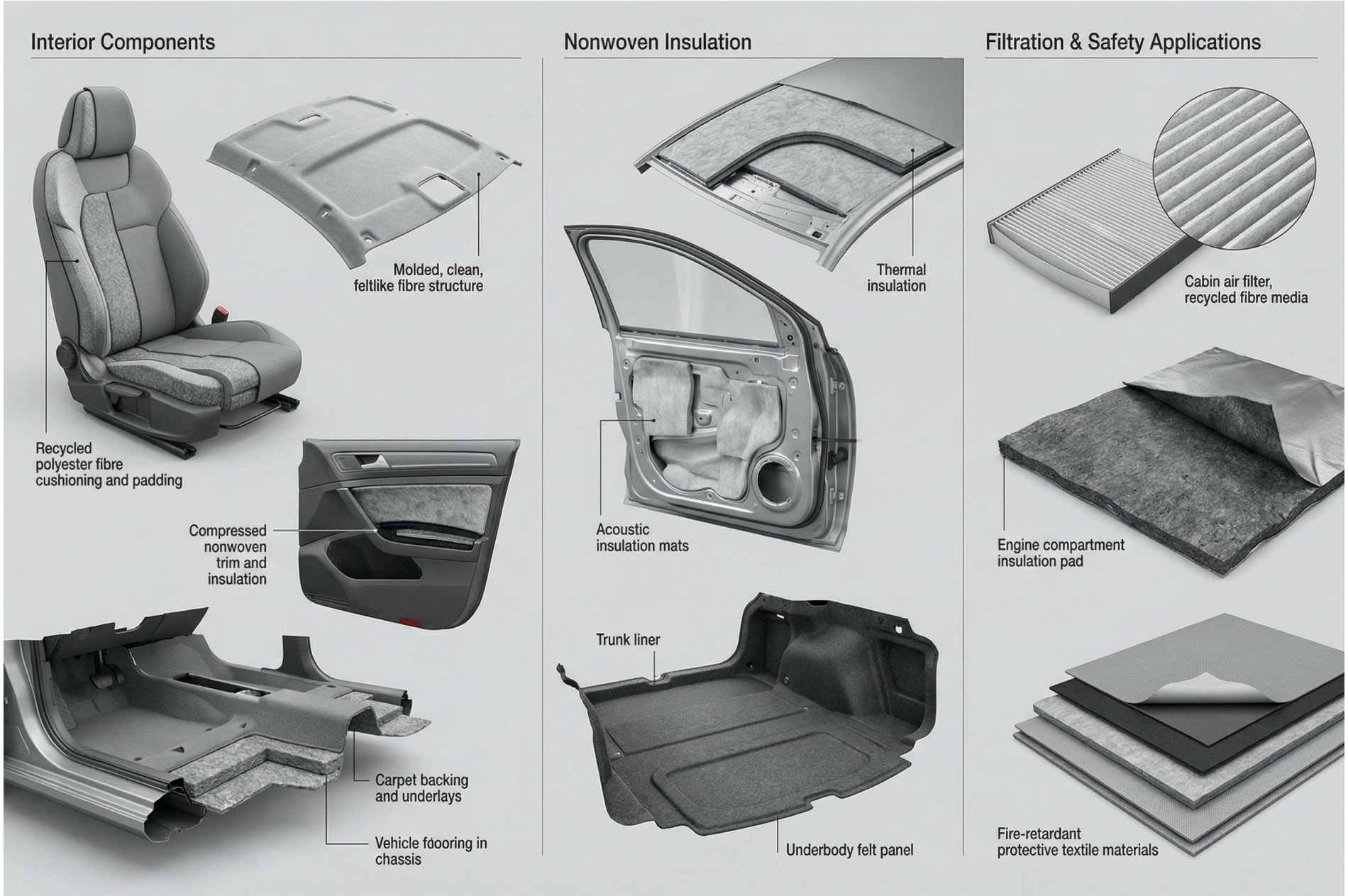


Triangle Joint
GF/ PA 66
Audi



Integral Seat
GF/ PP + PEI-Foam
IVW, DaimlerChrysler




Interior Components
Molded, clean, feltlike fibre structure
Recycled polyester fibre cushioning and padding
Compressed nonwoven trim and insulation
Carpet backing and underlays
Vehicle flooring in chassis
Nonwoven Insulation
Thermal insulation
Acoustic insulation mats
Trunk liner
Underbody felt panel
Filtration & Safety Applications
Cabin air filter, recycled fibre media
Engine compartment insulation pad
Fire-retardant protective textile materials

Aerospace application

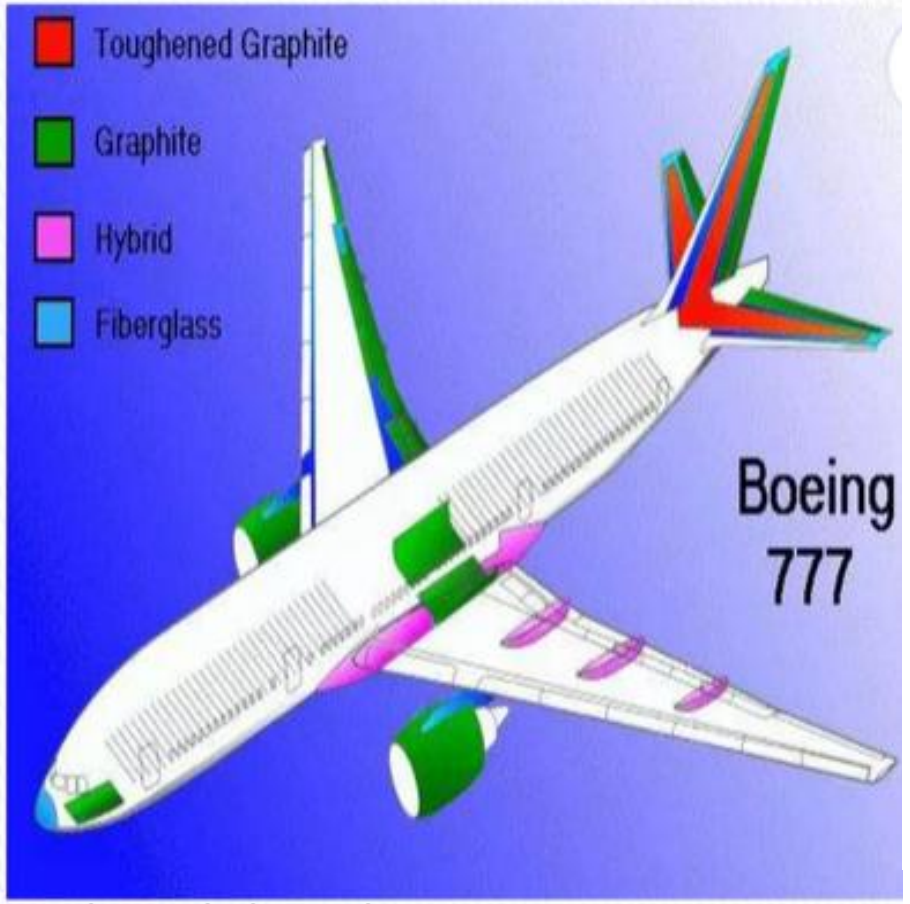
It is employed in aerospace industries for both

- commercial airplanes:
  - Boeing 777,
  - Boeing 787,
  - Airbus 321XLR,
  - A380
- And military airplanes
  - B-2 Bomber ,
  - LCA Tejas ,
  - F-35 fighter Jet

Uses of Composites

Boeing 777 composite Structure

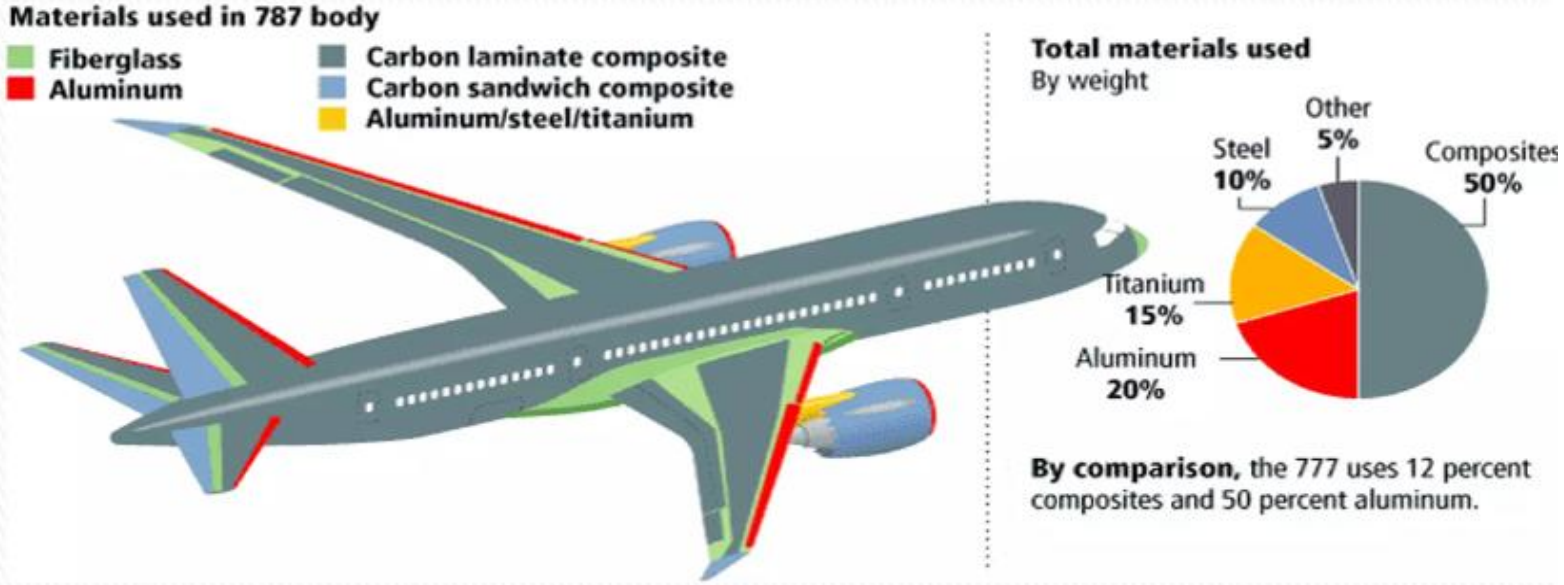
- Components that uses composite structure are:
  - Horizontal Stabilizer
  - Vertical Fin
  - Radom
  - Wing fairings
  - Passenger floor beams
  - Wing Box
  - Engine Cowlings
  - Engine fairings
- Reduction in weight is over 5800 pounds.



Rankings of Materials Used

- ✓ Aluminium alloy – 70% (Fuselage, wing box, upper wing skin)
- ✓ Polymeric composites: 9 – 12% (Interior parts)
- ✓ Steel – 11% (Landing gear)
- ✓ Titanium – 7% (Engine, fasteners)

Boeing 787 "Dreamliner" Composite Structure



- Components that uses composite structure are:
  - Almost full fuselage
  - Upper and lower wing skin
  - Radom
  - Wing flaps, elevators, ailerons
  - Vertical Fin and Horizontal Stabilizer
- Use of composite is 80% by volume and 50% by weight.

Comparison

- ✓ Boeing 777 used 12% polymeric composites
- ✓ 70% aluminium alloy
- ✓ Others are steel, titanium, etc.
- ✓ **Boeing 787 used 50% polymeric composites**.
- ✓ 20% aluminium
- ✓ Titanium – 15%
- ✓ Steel – 10%
- ✓ Other material – 5% (GE's leap aircraft engine uses CMC (SiC/SiC shrouds). It is 1/3 lighter than Ni aalloy engine and run 200°C hotter

Airbus A380 Composite Structure



- Components that uses composite structure are:
  - Horizontal Stabilizer
  - Vertical Fin
  - Radom
  - Wing Fairings
  - Wing Box
  - Belly Fairings
  - Engine Cowlings
  - Engine fairings
- Wing box, made of CFRP, has reduced weight up to one and a half tones.

Airbus A380 used

- 61% Aluminium alloy
- 20-25% polymeric composites
- Titanium and steel – 10%
- AMC (Glass laminate Reinforced Aluminium – 3-4%
- Polymeric composite usage in Airbus A380 is higher than that used in A321XLR that contains 10-15% polymeric composites

- ✓B-2 bomber has 50-80% polymeric composites (carbon-graphite epoxy, glass fibre polyimide-epoxy)
- ✓Remaining 20-50% contains aluminium alloy and titanium.


B- 2 Bomber

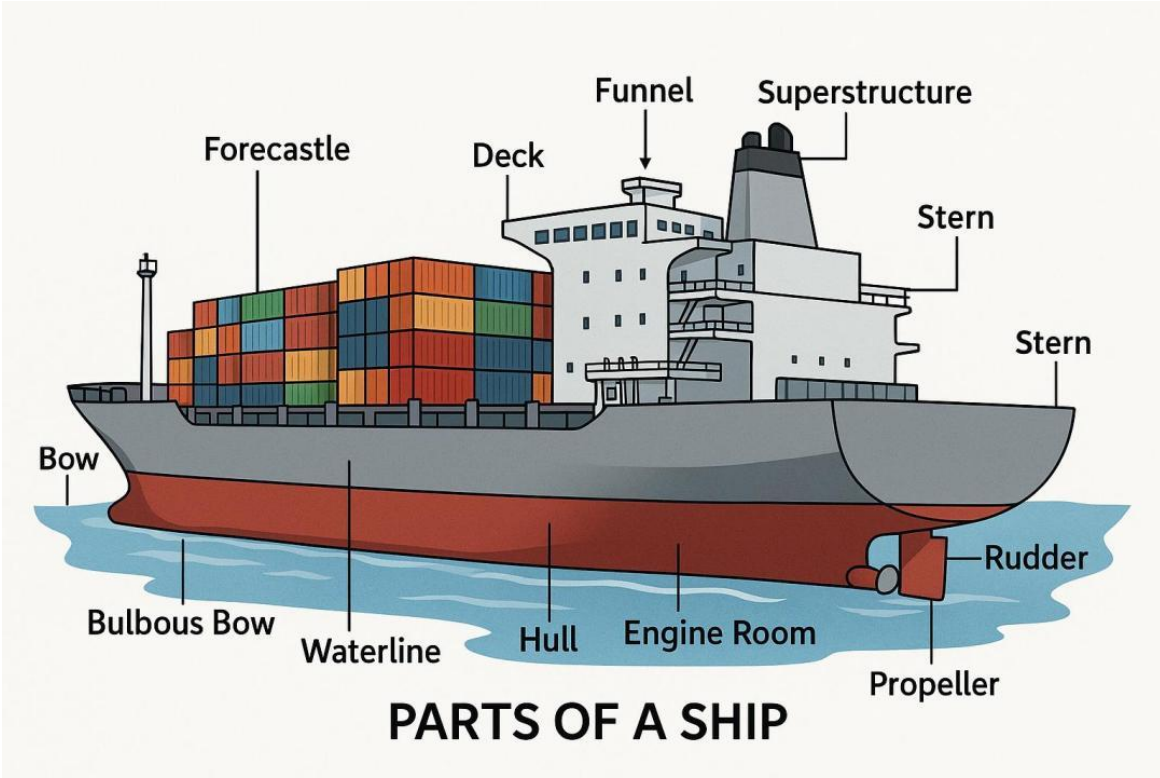
- ✓F-35 fighter jet has 35% for exterior skin and lifting surfaces
- ✓Remaining 65% contains aluminium alloy for fuselage
- ✓ and titanium for high temperature near engine and high stress components.


F- 35 Fighter jet

Marine applications

Polymeric composites dominate marine applications since steel and aluminium alloy/AMCs corrode in the sea.

- ✓Hull and deck
- ✓CFRP propeller for high-speed watercraft.
- ✓CFRP shaft – Lighter with reduced vibration
- ✓GFRP pipes for seawater ballast
- ✓Storage tank
- ✓Mine sweeper and patrol boat for defence
- ✓Wind turbine blade

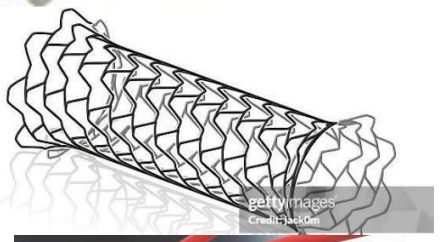


Biomedical applications

- Ceramic matrix composites for artificial teeth
- Polymeric composites for scaffolds, bone cement
- Absorbable metal matrix composites for stent applications
- Sensing composite for real time health monitoring without external sensor





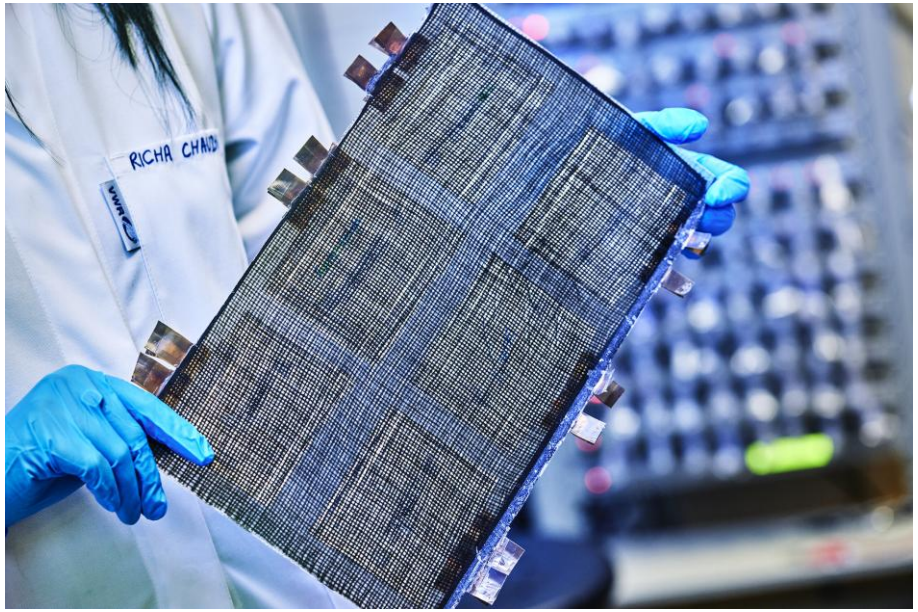






Energy application

- Polymeric composites for a low-tension electrical insulation
- Wind turbine blades
- Solar panel back sheet
- CNTRP structural battery for energy storage



Mining and quarrying applications

- CMC for pipe and impeller lining to prevent erosive wear in mineral slurry transportation.
- CMC for crusher, and mill lining.
- CMC like cermet for producing/coating drill bit to improve durability.
- Lining of furnaces, kiln and reactors.





Challenges of conventional composites

Challenges of conventional composites spur room for further research includes:

- High cost of conventional reinforcing fibres
  - Aerospace grade carbon fibre is $20/kg against $2/kg of steel
- Recycling of expired fibre reinforced thermoset like CFRP, GFRP.
- Standardisation: Lack of design codes militates against composite uses in civil infrastructure.
- NDT of thick composites and bonded joints is currently difficult.

Sustainable Composites

- Sustainable composites are emerging to replace conventional composites.
- Sustainable technology involves integration of waste into production chain for manufacturing new products.
- It addresses menaces of industrial and agricultural wastes and enables ecofriendly composites to address high cost of conventional CFRP and GFRP.
- This technology addresses recycling issues of the expired FRP through refinement to produce reinforcing particles for green production of sustainable composites
- Renewable fibres and particles from agricultural wastes are embedded in polymers (thermoset and thermoplastics) for producing composites.

Application of Sustainable Composites Marine applications

- Flax, hemp and jute fibre reinforced epoxy and polyester have been used for producing ship interiors, decks, and hulls.
- Recycled carbon fibre from aerospace wastes are used for green production of composites for non -critical ship parts.
- Particle reinforced PET from plastic bottle is used in making hull cores.
- Basalt fibre reinforced vinyl ester for superstructures.
- Recycled carbon fibre reinforced epoxy for wind boats and service vessels.
- Kayaks/paddleboards are produced from hemp fibre reinforced plastics.
- Above applications are limited to small ships and interior of big cargo ships.

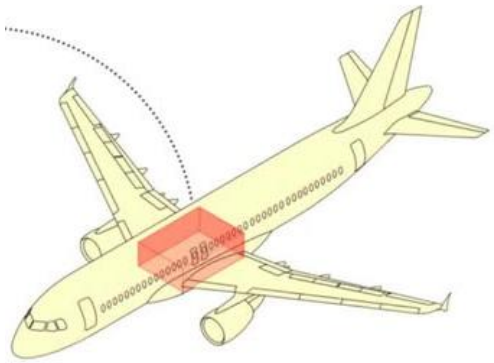
Challenges of sustainable composites as maritime materials and possible solutions

- Uses of sustainable composites in non-critical ship parts like interior panel, decking and bulkheads have been confirmed.
- This achievement of replacing GFRP in some ship parts encounter issue of inconsistence in fibre quality, biological degradation of sustainable fibre and water absorption.
- Use of fibre-particle hybrid reinforcement addresses the fibre quality inconsistences and biological degradation.
- Good resin sealing solves water absorption issue.

Sustainable composites in aerospace industries

- Radome manufacturing
  - Banana stem , bamboo, oil palm, kenaf and pineapple leaf fibre have been used to replace carbon and glass fibre in epoxy and polyester for radome application.
  - Radome is used for aircraft navigation and weather detection.
  - Dielectric constant of the used sustainable fibre composites ranges from 2.8 – 3.2 while those of woven EGFR Polyester ranges from 4.03 – 4.43.
- Airbus A320-200 Aircraft wing box
  - Using ramie fibre reinforced PLA.,12 -14% weight reduction was achieved comparing with aluminium alloy wing box.
- Fire retardant woven flax fibre reinforced phenolic-honeycomb sandwiching structure for aircraft cabin







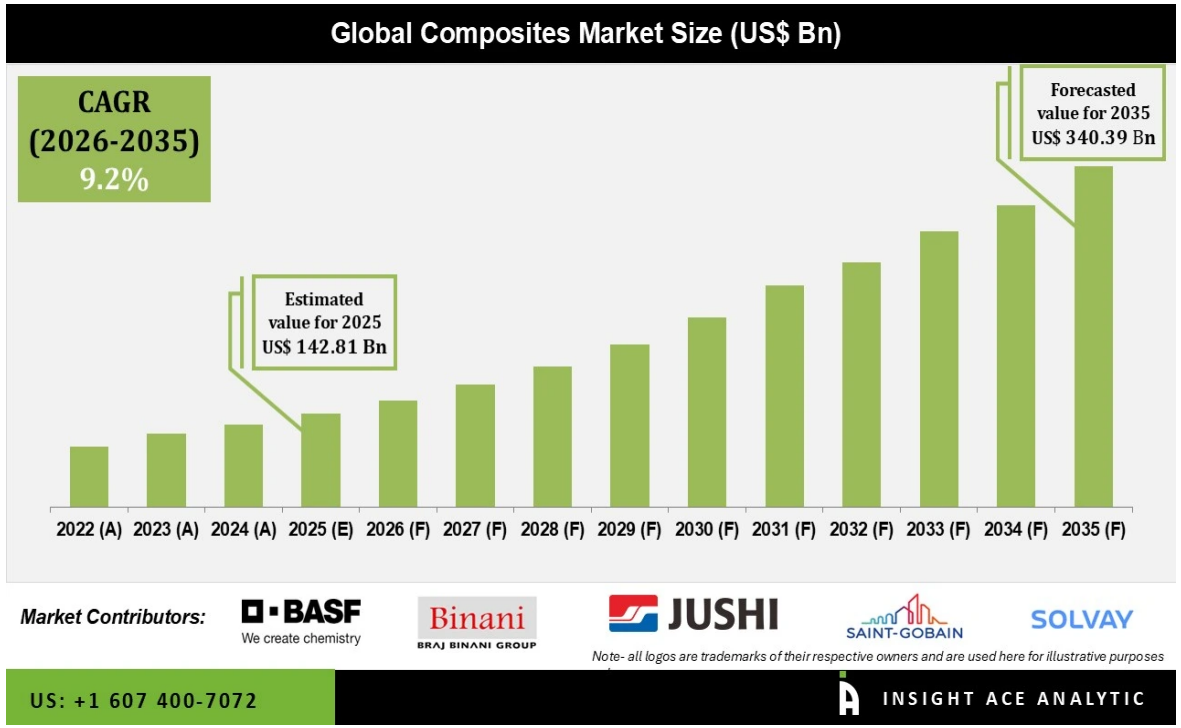
Sustainable composites in automobile industries

- Nanosilica reinforced $Al_{0.44}Si_{0.32}Ni_{0.09}Fe_{0.05}V_{0.05}$ for vehicle bonnet applications
- Eggshell nanoparticles reinforced low-density polyethylene for bumper fascia
- Aluminium particle – coconut shell reinforced epoxy for vehicle bumper beam
- Eggshell-flamboyant pod nanoparticle reinforced low-density polyethylene for vehicle dashboard
- Bean pod nanoparticle reinforced Al – Cu-Mg for vehicle connecting rod



Composite projections

- Aluminium metal matrix composites are projected to grow from $ 0.41 -3.2 billion to $ 5.6 billion at 2035.
- This is equal to 5.8 -9.9 % increase which driven by lightweight materials demands in aerospace, automotive and defence.
- Moreover, composites market is expected to expand from the current worth of $ 112.4 - $ 142.81 to $ 340.39 billion. This implies 8.4 – 9.2 % increase.



Research gap

- Sustainable fibres for permanent replacement of synthetic carbon and glass fibre
- Sustainable thermoplastic composites for replacing thermoset based composites in engineering structures
- Design code creation (standardization) to give room for adoption of composites in civil infrastructure like bridge building.
- Non destructive testing of thick composites and bonded joints remain issues.

Summaries and conclusions

- Composites have competed favourably with traditional materials like steels and other heavy alloys.
- They are alternative replacements for traditional materials in engineering structures.
- Uses of composites result in lightweight and faster aircrafts, automobiles, and ships with high fuel efficiency, and reduction in emissions, and enhanced environmental safety.

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Thank you all