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A Mini Review Of Modern Composites For Advanced Applications

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Abstract
The field and scope of composites is constantly widening with the introduction of new materials and manufacturing technologies. Unknown properties of different engineering, non-engineering and bio-materials are regularly explored for the development of modern composites that show immense potential in future for applications in domestic, automotive, defence and aerospace industries. Some fundamental aspects, processing techniques, properties and applications of such composites are reviewed in the paper.
Keywords: *Metal Matrix Composite, Ceramic Composite, Polymer Composite, Nano Composite*

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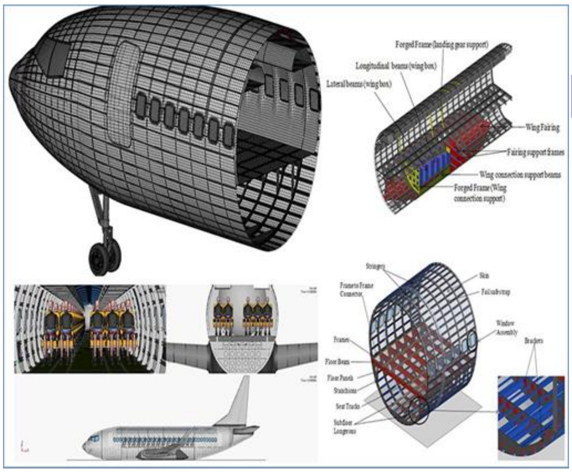


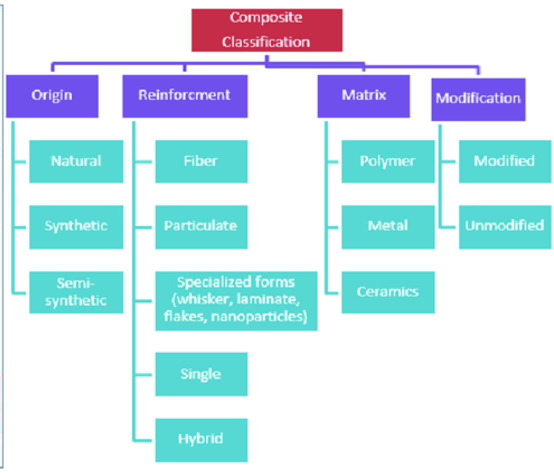


Fig.1 Applications of advanced composite materials in aerospace engineering
Fig. 2. Composites classification

I. Introduction

Conventional composites have limited strength, reduced high temperature resistance, low corrosion and wear and fatigue resistance etc. The pressing need for achieving improved properties of modern composites has given rise to appreciable shift in their manufacture and development. Use of non-conventional materials and manufacturing practices has been the highlight of current research in the field of composites. This review paper presents latest developments in the field of metal matrix, ceramic matrix, polymer matrix, laminated and nano composites. Some pertinent fundamental aspects, processing techniques, properties and applications of modern composites are briefly discussed in the paper.

II. Metal Matrix Composites

Nano-Structured ODS, Lanthanum Oxide–Tungsten Composites [1-4]

Theory: Tungsten is an important refractory metal renowned for its high strength and corrosion resistance at elevated temperatures thereby making it suitable for high temperature applications viz., fusion reactors. But due to its recrystallization brittleness, it is not possible to use tungsten directly in high temperature reactors. Carbon-carbon composites are also known to be good heat conductors but higher erosion rates and low sputtering resistance make them unacceptable in high quality and stable fusion reactor applications. However, it is found that nano-structuring of ODS [Oxide Dispersion Strengthened] tungsten alloys could be an effective way to use tungsten within permissible temperature frames and radioactive environment of a fusion reactor.

Process: ODS composites are fabricated by using wet processing technique which becomes handy in the development of nanostructured materials and promises to be a potentially reliable method for fabrication of tungsten based composites with high homogeneity and purity. The sintering of tungsten powder is carried out by Spark Plasma Sintering [SPS] which allows the consolidation of powder material into fine-grain and high-density sinters at relatively low temperatures as compared to conventional sintering techniques. SPS is a rapid densification process based on three factors namely [i] High mechanical pressure applied in the process [ii] Use of pulsed DC current and [iii] Very high heating and cooling rates. Tungsten powder doped by means of wet chemistry methods is employed for the production of Tungsten-ODS composites by utilizing SPS technique for consolidation.

Properties: It is inferred from the experiments that the distribution of oxide phase in bulk ODS metal is defined by APT [Atom probe tomography] particle size and its distribution in the powder. Sintering of the composite by SPS technique at temperatures significantly lower than those for conventional sintering methods avoids grain growth. It is also observed that there is a substantial increase in hardness with finer sub grains due to low angle boundaries.

Applications: These composites have the potential for use in critical nuclear applications.

Metal Polymer Hybrid Composites [5-7]

Theory: Sandwich Material Systems [SMS], as special hybrid materials, represent an interdisciplinary concept by combining the areas of materials/material composites, production engineering, design and functionality for fulfilling high demands of modern materials and structures. In order to seek the knowledge about tailoring of the requisite properties in the sandwich, the relationships between the thermal history, microstructure and mechanical behaviour are crucial. The physical properties and the forming behaviour based on [i] Process routes for the production of semi-finished sandwich sheets [ii] Metal skins (austenitic steels, aluminium alloy) and their combinations and [iii] Polymer cores with and without fiber reinforcements are studied.

Process: A continuous roll bonding process is selected for the production of SMS. Metal sheets having thickness of 0.2-0.5mm are cleaned, degreased and then coated with epoxy resin in a stationary convection oven. After activation of the adhesive at around 255°C, the metal sheets are joined with polymer sheets by employing a high rolling mill. Subsequently, the produced semi-finished sandwich structures are bonded with remaining metal sheets using the same method.

Properties: Tests for thermal behaviour, metal polymer interface microstructure, adhesion and mechanical behaviour are reported to be undertaken. It is found that the bonding strength between metal and polymers is raised upto 140% for roll bonded SMS in comparison with that obtained from heat pressed SMS. During formability tests, the roll bonded SMS reaches values of the order of that of the metal sheet. Also, the roll bonded SMS demonstrates enhanced drawability.

Applications: These composites find applications in aircraft construction sector, light weight application systems like hybrid metal-polymer structures, automotive, naval and other common construction industries.

Carbon Fiber Reinforced Aluminium Matrix Composite [8-10]

Theory: Several challenges such as higher processing temperatures, fiber matrix bonding issues, the ability to produce desired shapes stand in the way of production of Metal Matrix Composite [MMC] castings. However, these issues are resolved and quality castings are manufactured in minimum processing time by using appropriate fiber matrix systems and innovative strategies. Among various techniques available for fabrication of fibrous metal matrix composites, liquid metal infiltration is a special casting technique which combines the advantages of traditional pressure die casting, gravity permanent casting and common forging technology. This process proves advantageous over others in providing 100% casting yield, good dimensional accuracy, high strength to weight ratio and improved wear resistance. Aluminium Matrix Composites [AMC] are produced by liquid infiltration technique using carbon perform-A356 alloy matrix.

Process: Refer Fig. 3. Liquid metal is injected into the interstices of fiber usually called perform. In the process, it is seen that the liquid metal is pressurized while solidification and hence neat net shapes are produced.

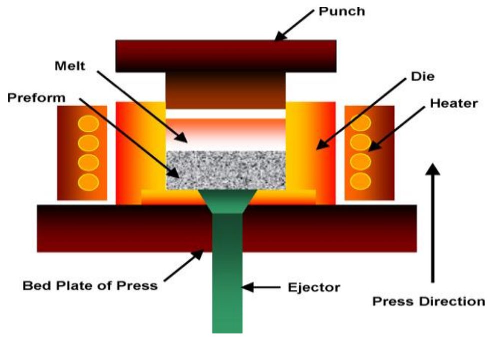


Fig. 3 Layout of the squeeze infiltration apparatus.

It is also demonstrated that the metal matrix composites can conveniently be fabricated from carbon fiber preforms and aluminium alloys using squeeze infiltration technique. This process is particularly appropriate for the manufacture of castings incorporating selective reinforcement in critical regions.

Properties: The density of developed AMC [2.47 g/cc] is noticed to be lesser than that of the matrix material [2.7 g/cc]. The process of metal matrix composite production results in enhancement of the hardness and impact energy of the composite than that of aluminium alloy. AMC specimen also shows better hardness characteristics both axially and radially. On critically observing the specimens, alternate layers of fibres within the infiltrated portion of the billet shows good fibre/matrix contact. Refer Fig. 4. The Charpy impact test of the composite reveals higher impact energy than that of squeeze cast alloy matrix. This is attributed to easy debonding of the infiltrated carbon fibre layers in the latter.

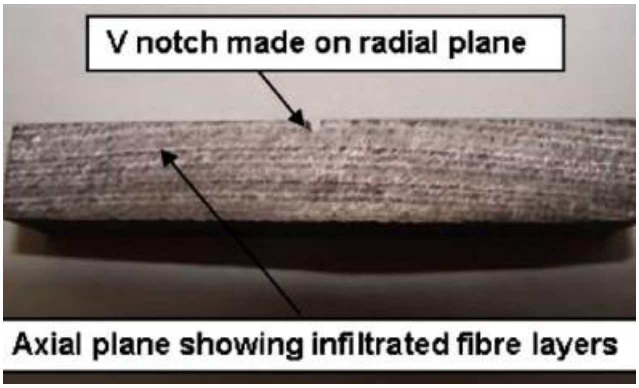


Fig.4. Placement of the V-notch on the Charpy test sample

Applications: AMC are employed in the wide range of aerospace and automobile applications.

Titanium Matrix Composites [11-13]

Theory: Titanium alloys possess low density and excellent specific strength which are of prime importance in components meant for critical low weight and high strength to weight ratio applications. In order to further enhance the elevated service temperatures of titanium alloys, Titanium Matrix Composites [TMCs] reinforced by ceramic particles [typically TiC and TiB] are developed.

Process: These composites are manufactured by using the method of Laser Melting Deposition [LMD] in which the focused laser beam is utilized as the heat source to melt the additive metallic powders or fine wires. The molten metals are then rapidly solidified and deposited as the laser beam and/or the substrate moves forward - the 3D metal part is finally formed through layer-by-layer fusion deposition manner.

Properties: There is a significant improvement in the creep resistance exhibited by TiC/A15 composite. The fracture in the composite is initiated by particle cracking, interface debonding and interparticle voiding which is followed by ductile failure through the matrix.

Applications: Titanium matrix composites are widely used in modern aerospace and military components due to their low density and excellent specific strength.

TiAl - B_4C Composites [14-16]

Theory: Refractory ceramic metals are best suited for demanding applications owing to their exceptional hardness and stability at high working temperatures. But, the disadvantage of ceramic materials is brittleness coupled with low fracture toughness. Of late, research has proved that Boron Carbide [B_4C] ceramic portrays excellent properties but is difficult to fabricate as sintered body due to covalent bond in its configuration. It is learnt that by adding 4 wt.% amount of Al using pressure less-sintering around 2100°C under argon atmosphere, the density and mechanical performance of B_4C can be improved. In-situ homogenous Ti-Al alloy and particulate reinforced B_4C composite is fabricated from Ti, Al and B_4C via High Energy Ball Milling and subsequent press sintering. As the Ti-Alloy percentage is increased in the matrix, the relative density increases while there is decrease in the hardness of the matrix. Overall, the composite exhibits good fracture toughness and bending strength.

Process: Refer Fig. 5. The suitable raw materials Al, Ti and B_4C composition is considered according to necessary percentage and blending followed by subjecting it to dry milling up to 30 hrs at the rate of 380 rpm in a planetary high energy ball mill with 1.27% stearic acid as process control agent. The powders are then sieved and transferred into graphite dies for hot press sintering in the furnace. This process is generally known as High Energy Mechanical Alloying.

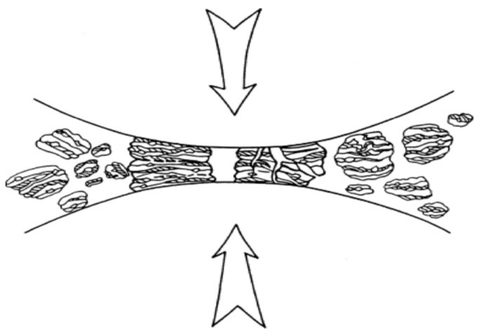


Fig. 5. High energy ball milling (Mechanical Alloying) process

Properties: Microscopic studies reveal that the ball milling product is flat and having regular lattice structure of the Ti-Al alloy. Under the pressure of 20 MPa and dwell time of 30 min, the liquid phase fills up pore spaces of ceramics while the residual gas diffuses or escapes making the composite more compact. As a result, the relative density of the composite is increased. It is found that TiAl/B_4C composite promises high fracture toughness and bending strength.

Applications: TiAl/B_4C composites are employed in aerospace structural applications.

III. Ceramic Composites

SiC Nanoparticle reinforced Al_2O_3–Nb Composite [17-18]

Theory: Ceramics have been used in an important application as an alternative to metal polythene bearing couple in Total Hip Arthroplasty (THA) for a long time now and Al_2O_3 being the most common type is employed for its promising wear reduction behaviour. But, due to the inherent property of brittleness, Al_2O_3 leads to catastrophic failure under load. A ceramic–metal composite consisting of SiC nanoparticles reinforced Al_2O_3 and Niobium [Nb] (referred to as SiC/ Al_2O_3–Nb) is therefore explored and evaluated for potential application as a femoral head material in THA.

Process: Dense composite laminates of SiC nanoparticles reinforced Al_2O_3 and Niobium are prepared by hot pressing and evaluated using SEM, microchemical analysis and mechanical testing techniques.

Properties: Refer Fig. 6. It is observed that reinforcing the Al_2O_3 phase with 5% vol. SiC nanoparticles results in marked improvement in the mechanical properties of Al_2O_3-Nb laminated composites without affecting the interfacial bond strength between Al_2O_3 and Nb layers. Reinforcement, typically 5–10 vol.%, has also shown to provide a marked improvement in the flexural strength and wear resistance besides resulting in small improvement in hardness and fracture toughness of the composite. Dense laminates of Al_2O_3 and Niobium, fabricated by hot pressing, have flexural strengths of 720±40 MPa, far higher than the flexural strength of dense Al_2O_3 [460±110 MPa].

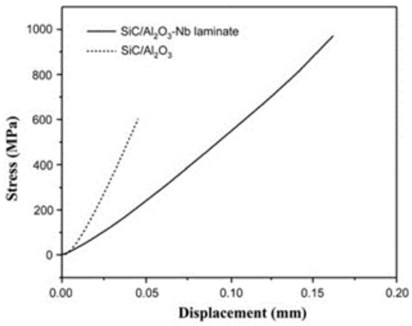


Fig. 6. Stress *vs* displacement curves in four-point flexural testing for SiC/Al2O3 and SiC/Al2O3–Nb beams

Applications: SiC nanoparticles reinforced Al_2O_3-Nb composite is a potential material for biomedical implants.

Titanium Silicon Carbide Hybrid Matrix Composites [19]

Theory: It is always a challenge to find newer materials for critical and tactical applications involving high precision and accuracy. Besides, aeronautics and aerospace domains constantly look for advanced materials and processing techniques for obtaining light, strong and reliable materials. Carbon fibre reinforced C/SiC binary matrix composite [C/C–SiC] and carbon fibre reinforced Ti-SiC matrix composite [C/Ti/SiC] are promising materials owing to their excellent oxidation resistance, high strength and thermal shock resistance not only at room temperature but also at high temperatures which are the requisites for spatial applications.

Process: These composites are manufactured by employing slurry infiltration [SI] which proves to be a good method to introduce ceramic particles into fibre reinforced ceramic matrix composites. On the other side, Ti_3AlC_2 based composite, which is a novel ceramic similar to Ti_3SiC_2, is synthesized from the reactions of TiC/Ti_2O_3 particle preforms and aluminum by Reactive Melt Infiltration. Owing to the above considerations, a joint process of SI and LSI [Liquid silicon infiltration] appears to be a good solution to introduce TiC particles and silicon melt into the composite, leading to the in-situ formation of Ti_3SiC_2 by controlling the reactions. A low-cost carbon fibre reinforced C–SiC– Ti_3SiC_2 hybrid matrix composite is manufactured by joint process of slurry infiltration and liquid silicon infiltration. TiC particles are introduced into porous ceramic composite [C/C] by means of slurry infiltration and TiC and carbon are converted into Ti_3SiC_2 and SiC matrix after reactive infiltration of liquid silicon leading to the formation of C/C–SiC– Ti_3SiC_2 composites.

Properties: Refer Fig. 7. With increasing amount of TiC infiltration into ceramic composites, the content of in-situ formed Ti_3SiC_2 in the C/C–SiC–Ti_3SiC_2 composite increases. The C/C–SiC–Ti_3SiC_2 composites demonstrate improved mechanical properties, the flexural strength improving from 125 to 200 MPa and fracture toughness from 8 to 9 MPa $m^{1/2}$. Also, Ti_3SiC_2 grains exhibit better resistance to delamination, deformation, laminate fracture and intergranular cracking characteristics.

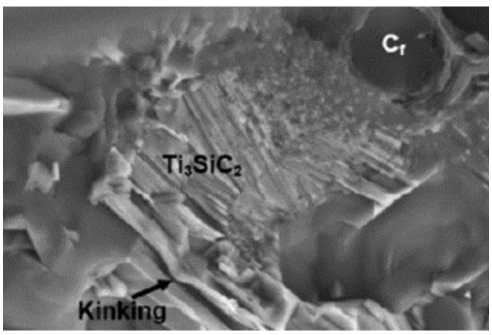


Fig. 7. Magnified image of the micro-structure of Ti_3SiC_2 grains

Applications: These composites have immense potential for use in space applications.

TiN-TiB$_2$ Ceramic Composites [20-22]

Theory: TiN/TiB_2 ceramic composites possess excellent physical properties like high hardness and strength retention combined with good thermal conductivity, high melting point and chemical stability. All these unique characteristics make this composite ideal for use in aerospace applications. In the referred work, the simultaneous synthesis and densification of TiN/TiB_2 ceramic composites [CC] via Reactive Spark Plasma Sintering [RSPS] is investigated. Usage of these materials in composites leads to enhanced fracture toughness and non-catastrophic failure mode.

Process: These composites are manufactured by Spark Plasma Sintering [SPS] which is also termed as Field Assisted Sintering or Electric Discharge Sintering. The advantages of employing SPS technique are high thermal efficiency, rapid heating up, self-cleaning of the surface particles and enhanced sintering activity which enables fast densification under low temperatures.

Properties: Refer Table 1. The highest relative density [97.0–97.8%] is obtained for CC containing 36 wt% TiB_2 and 64 wt% TiN. The hardness of sintered CC varies from 16 to 25 GPa, the fracture toughness varies in the range of 4–6.5 MPa $m^{1/2}$. Moreover, the heating rate within the interval 112.5–300 °C/min has no significant effect on the mechanical properties of the sintered CC. The composites containing 36 wt% TiB_2 and 64 wt% TiN is found to have the most homogeneous nanostructure with average grain sizes of 150–550 nm.

Table 1. Physical and mechanical properties of the CCs

Composition, wt%	Heating rate, °C/min	Relative density, %	Hardness, HV (GPa)		K_{IC}, MPa $m^{1/2}$
			Load, P = 0.1 kgf	Load, P = 2 kgf	
$20TiB_2$–80TiN	112.5	96.3	18.9 (±1.03)	17.7 (±0.40)	4.06 (±0.15)
	225	97.0	19.5 (±0.58)	18.0 (±0.58)	4.07 (±0.11)
	300	96.7	21.3 (±1.09)	18.4 (±0.61)	6.16 (±0.70)
$36TiB_2$–64TiN	112.5	97.7	21.0 (±0.98)	19.8 (±0.29)	4.37 (±0.09)
	225	97.8	20.4 (±1.67)	20.3 (±0.59)	5.05 (±0.17)
	300	97.0	21.5 (±0.91)	19.8 (±0.27)	4.80 (±0.12)
$60TiB_2$–40TiN	112.5	95.1	22.0 (±1.78)	20.6 (±0.58)	4.74 (±0.15)
	225	96.0	21.5 (±3.68)	19.5 (±0.64)	4.59 (±0.19)
	300	95.3	22.7 (±2.76)	19.2 (±1.84)	5.04 (±0.41)
$80TiB_2$–20TiN	112.5	93.5	24.7 (±4.40)	24.6 (±3.33)	5.17 (±0.38)
	225	94.2	16.5 (±3.15)	15.9 (±0.66)	6.46 (±0.88)
	300	Destr. at 865 °C	–	–	–

Applications: TiN–TiB_2 ceramic composites are an attractive option for jet engine parts, armour plates, cutting tools and dies as well as high performing electrical systems.

Cf -SiC composites [23-24]

Theory: Bolting and riveting are not advisable to join carbon fibers in [Cf/SiC] composite due to the brittle nature of these materials. Meanwhile, the high temperature application of the joint impedes the use of bonding adhesives.

Process: So far diffusion bonding and brazing have been reported for joining Cf/SiC composite. However, the high bonding temperature [up to 1200 °C] limits the application of the method of diffusion bonding. Brazing, due to its simplicity, lower cost investment and potential for mass production process, is used extensively thus becoming an effective method to join Cf/SiC composite to itself or with metals.

Properties: The Cf/SiC composite with density of 1.8 g/cm^3 is prepared by chemical vapor infiltration process and the SiC coating is deposited by chemical vapor deposition - its porosity is 10–15 vol.% and three-point flexural strength is 300–400MPa at room temperature. The carbon fibers distributed in the composite are in the form of bundles and each bundle consists of 1.2×104 pieces of carbon fibers.

Applications: Cf/SiC composites are promising new structural materials for a variety of high-temperature burner environments, including hypersonic aircraft thermal structures, advanced rocket propulsion thrust chambers, cooling panels for nozzle ramps, turbo pump shaft attachments and brake disks.

ZnO-Al_2O_3 Ceramic Composites [25-26]

Theory: Aluminium-doped zinc oxide [AZO] thin films that have more potential than indium-tin oxide [ITO] films are increasingly being used as the transparent and conductive electrodes for several optoelectronic devices. Nowadays, newer techniques for the deposition of AZO thin films have been developed to achieve high deposition speed and good adhesive properties. The high density of ceramic targets plays an important role in sputtering process and final quality of thin films. The manufacturing of large sized fully dense ceramic targets is quite challenging for commercial purposes. The goal of dispersion in this process is to achieve a high solid loading suspension with a high degree of stability. Very high values of green densities are easily obtained with well dispersed slips but the slip-casting green compacts are very brittle, therefore binders added are necessary.

Process: Slip casting is a well-known forming method for ceramics which is a suitable consolidation process to obtain materials with high green density and microstructure homogeneity. Commercial zinc oxide and alumina powders, which have specific surface areas of 10.8 m^2/g and 8.9 m^2/g respectively and average particle sizes around 260 nm and 320 nm respectively are used. Polyacrylic acid [PAA, MW5000] and a polyethylene glycol [PEG, MW40000] are used as deflocculant and binder agents respectively.

Properties: Slip casting of optimized suspensions leads to the maximum green density greater than 66.6% of theoretical density. The green particles of ZnO-Al_2O_3 mixtures are packed in the compactly homogeneous state. The microstructure observations reveal that very high homogeneous materials are obtained without abnormal grain growth and free of defects with proper distribution of Al species. Slip casting allows manufacturing of, defect-free, homogeneous ceramics with near-to-theoretical density of $ZnO-Al_2O_3$ ceramics.

Applications: Aluminium-doped zinc oxide thin films that have more potential than indium-tin oxide films are increasingly used as transparent and conductive electrodes for several optoelectronic devices such as photovoltaic solar cells, liquid crystal displays or light emitting diodes.

IV. Laminated Composites

Bio-Inspired Laminated Composites [27-28]

Theory: The hard outer skeletons of insects or arthropods exhibit outstanding structural properties with different functional capabilities such as supporting of the body weight, filtering chemicals and resisting external loads. The helicoidal structure can be characterized by the stacking sequence consisting of gradual rotation of each lamina in the multi-layered laminated composite. These helicoidal structures can be employed in designing and producing some important practical composites.

Process: The material selected for the model is unidirectional S_2-glass epoxy prepreg - DA409U/S_2 glass. The prepreg rolls are formed and stored in a contamination free container at -18^{o}C before processing. Prior to fabrication, each roll is removed from cold storage to allow for stabilization at room temperature followed by wrapping to prevent moisture from condensing on the prepreg. Prepreg rolls are cut into square pieces before being laid up to construct laminated composite plates. All laminates are formed in to stacks of plies using selected sequences corresponding to structural configurations. After curing by vacuum method, the plies are attached on both sides of the stacked prepreg to render a smooth finish on the laminates. The whole lay-up system, including the laminate and all the other facilities described above, is finally retrieved from the oven after the curing cycle, finished and then cooled to room temperature.

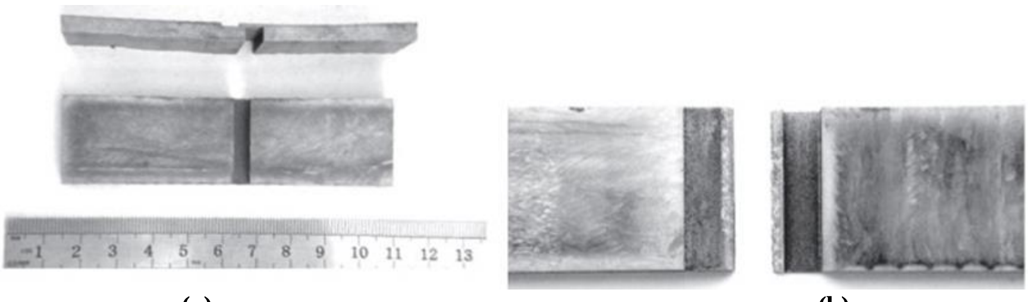
Properties: The bio-inspired structures show improved mechanical properties when compared to conventional baseline structure. Also, superior residual strength under static load conditions is observed in a bio-inspired composite.

Ti–6Al–4V/Ti–43Al–9V–Y *Laminated Composite* [29]

Theory: Laminated composites having ductile metal constituents with optimum combination and design results in advantageous properties such as low density, high corrosion resistivity, high strength and high fracture toughness. The interface quality and bonding strength play a vital role in controlling the mechanical properties of such composites.

Process: These composites are fabricated by rolling process which is efficient and economical. Ti–6Al–4V/Ti–43Al–9V–Y laminate composite sheet with a uniform interfacial microstructure and no defects at the interfaces is prepared by hot-pack rolling at 1180^{o}C. Hot roll bonding is a solid-state welding process where multiple layers of metal or alloys are stacked together. This causes deformation which results in production of solid-state welds. Hot roll bonding improves strengths of the individual constituent materials by refining their microstructures which facilitates enhanced overall strength of the laminated composite when compared to individual base materials.

Properties: Refer Fig. 8 for the sample fabricated for tensile testing to study fracture aspects. Improved bonding strength between the layers and better composite toughness are observed during the tests. Shear strength at interfacial layers increases with the percentage reduction in the thickness of the sheet. Microstructure studies reveal that two layers are formed and the formation of interfacial region is mainly caused by the interdiffusion of Ti and Al elements from one layer to another.



(a) (b)

Fig. 8 (a) Top and side view of the sample for tensile testing, and (b) Top view of the sample post fracture

Applications: These laminates have potential for use, as high temperature materials, in aerospace and automobile engines.

V. Fiber Reinforced Polymer Composites

Thermoset Composites with Carbon Nanofibers [30]

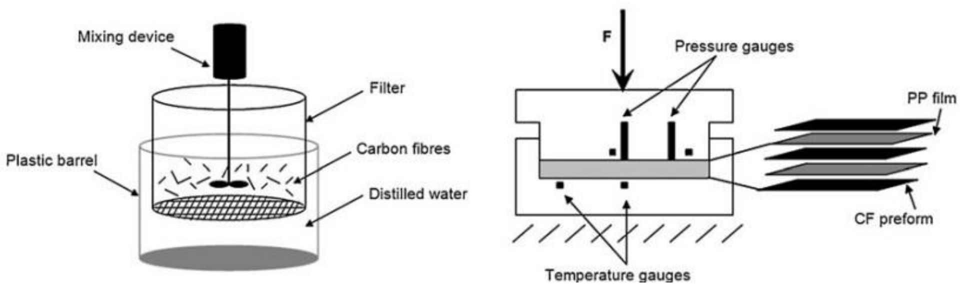
Theory: The flaming behaviour of thermoset composites is excellent under well-controlled combustion conditions. Multifunctional thermoset composites are made from polyester resin, glass fiber mats and carbon nanofiber sheets. Both the nanofibers and charred materials act as excellent insulators and mass transport barrier thereby improving the fire retardancy of the composite.

Process: The carbon nanofiber powders are ground with small amount of de-ionized water. After grinding, the mixture is transferred into a glass beaker and water is added together with few drops of surfactants. The mixture is agitated. The solution is then allowed to settle and suspension is collected. The final mixture is treated in the ultrasonic sonicator for 10 min before being filtered. Resin transfer moulding process is used to manufacture the samples in which several plies of glass fiber mats are pre-formed in moulds. With the help of vacuum pump, polyester resin flows and finally cures inside the channels of fiber mats and carbon nanofiber sheets.

Recycled Carbon Fiber-PP Composites [31]

Theory: Due to the shortage of raw materials and stringent environmental issues, recycling has assumed importance in composite production. These conditions are forcing material developers to think of recycling even composites. The carbon fiber is one such ingredient which is being used in many composites due of its versatility. These carbon fiber composites are generating lot of waste and are considered for recycling which of course is complicated due to the complex nature of the composites themselves.

Process: Refer Fig. 9. The carbon fibers and polypropylene (PP) used in the preparation of the composite are recycled. The polypropylene is obtained from PURE process technology where it is a scrap product. The fibers are produced by milling of carbon fiber composites obtained from the production waste that is generated by the aircraft industry. The fibers are recovered by using pyrolysis at approximately 1200°C. The principles of papermaking are used to obtain preforms with uniformly distributed carbon fibers for subsequent composite manufacturing. Two layers of polypropylene films manufactured by press forming are sandwiched between three carbon fiber perform layers in a stack. The stack is heated and pressed resulting in a new composite plate.



(a) (b)

Fig. 9. (a) Carbon fibre dispersion and (b) Press forming to form a composite plate

Properties: An increase in tensile strength of the composite is observed as compared to scrap material obtained from the industry. However, increase in strength decreases the elastic modulus. The micro-cracks are responsible for the eventual reduction in elastic modulus. The increase in fracture toughness around the micro-cracks is used as a possible explanation for the measured increase in flexural strength. The stress-strain curves in tension and the strength are sensitive to strain rate which indicates time-dependent behaviour. It is also noted that the development of visco-plastic strains is accompanied with increase in viscoelastic compliance which indicates that damage and visco-plasticity are coupled. The viscoelastic response of the composite is slightly nonlinear.

PET Composites [32]

Theory: Research has been undertaken on the properties of flax fiber reinforced composites. In this work, flax fiber/low melting point PET (Polyethylene terephthalate) fibres [flax/LMPET] hybrid nonwoven mats are directly made into flax reinforced PET composites by hot press moulding. It is found that nonwoven mats used for direct forming method is an efficient cost saving way for industrial production.

Process: The fibers are first treated with alkali solution before blending with low melting point polyester (LMPET) fibers in the Fearnaught machine. Hybrid fibers are carded with flat and cylinder carding machines whereas nonwoven mats are obtained directly. The mechanical performances are studied by tests with the universal testing machine [UTM]. The microscopic studies reveal the data related to the fractured surface.

Properties: From the tensile test, it is observed that the strength of the composite is mostly dependent on the flax fiber strength and interfacial strength between flax fiber and LMPET matrix. Also, 40 wt.% and 35 wt.% flax fibers show largest tensile and flexural strength respectively. It is noted that the strength of composite plates increases with increase in temperature that is due to higher temperature prompting LMPET melting which reduces the melt viscosity thereby enhancing interfacial adhesion. Fiber orientation with nonwoven mats is dominantly controlled by carding methods. Refer Fig. 10. It is found that cover plate shows better tensile and flexural strengths than cylinder due to the orientation of flax fibers along the longitudinal direction in the flat carded mat than in the cylinder carded mat.

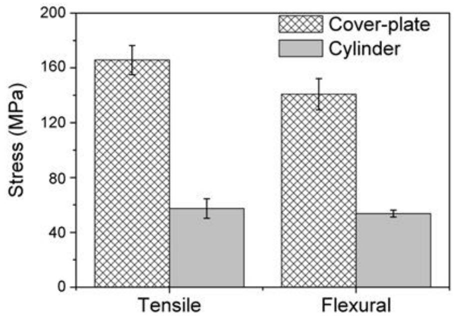


Fig. 10 Effect of carding method on the composite strength in the longitudinal direction (moulding temperature is 180 ^{0} C; moulding time is 30 min; flax fiber content is 40 wt%)

Applications: This is a novel composite which is eco-friendly with no chemical adhesives. Since the processing procedure is cost effective and simple, it can be implemented in the industrial scale for producing thermal plastic composites, automobile interiors, ornaments and decoration materials.

Wild Cane Grass Fiber-Reinforced Polyester Composites [33]

Theory: Due to environmental concerns and low-cost requirements, natural fibers have gained a lot of importance in the last few decades. High specific strength, less degradation and low cost make them attractive. Refer Fig. 11 Usage of natural vegetable fibers as reinforcements in polymer composites over synthetic fibers like glass and carbon is currently a spotlight because of the advantages including cost effectiveness, low density, high specific strength, bio-degradability as well as their availability as renewable resources. New natural fiber is introduced as reinforcement in polymers for making composites. Wild cane grass stalk fibers are extracted from its stem using retting and chemical [NaOH] extraction processes and then treated with $KMnO_4$ solution to improve adhesion with matrix. The resulting fibers are reinforced in a polyester matrix unidirectionally and the flexural properties of the composite are determined. Refer Table 2 for properties of natural fibers.

Table 2. Comparison of tensile properties of natural fibres

Fiber name	Density (kg/m^3)	Diameter (μm)	Tensile strength (MPa)	Tensile modulus (GPa)	% elongation at break
Sisal	1450	80–300	227–700	9–20	3–14
Coir	1150	100–460	131–175	2.5–6	15–40
Banana	1350	80–250	529–759	8–20	1–3.5
Wildcane grass	844	190–560	159	11.84	1.34

Process: The fibers are extracted by two methods namely [i] Retting and [ii] Chemical methods, both followed by manual extraction. In the first process, culms are dried for one week and the central portion containing lignin is peeled longitudinally. Removed lignin strips are then soaked in water for 3-5 days to soften them. These strips are subjected to mechanical process by beating gently in order to loosen the fiber. In the second process, the strips are soaked in 0.1 NaOH solution for different periods and kept at 72 hrs for chemical treatment. After the treatment, the strips are washed in water and are subjected to mechanical processes for separation of fibers. Hand-lay-up method is adopted to fill up the prepared mould with appropriate amount of polyester resin mixture and layers of unidirectional wild cane grass fibers. The quantity of accelerator and catalyst added to resin at room temperature for curing is 1.5% by volume of resin.

Fig.11. Wild Cane Plant

Properties: Although the density and tensile properties of wild cane grass fibers are lower than that of established fibers, they are an attractive option in manufacturing light weight composites. It is observed that a yield of 64% is obtained by retting process as compared to 35% with that of the chemical process. This may be due to the removal of lignin by chemical reaction. The flexural strength and modulus of wild cane grass increase with increase in loading. Wild cane grass fiber also possesses high toughness.

Applications: Wild cane grass is an abundantly available material resource which is renewable and whose extraction is simple and economical. Its very good characteristics make it apt for usage as reinforcement in applications demanding light-weight materials with reasonably good toughness.

VI. Nanocomposites

Al6061– Al_2O_3 Nanocomposites [34-35]

Theory: Aluminum (Al) based MMC's reinforced with nano ceramic particles depict better mechanical properties than unreinforced aluminum alloys and are used in automotive industry due to their high ratio of strength/density and better wear resistance. Tribological properties are improved by synthesizing nanocomposite bulk materials where non-metallic nanoparticles are embedded in a relatively compliant metallic matrix.

Process: Al6061 chips are mechanically milled in a planetary hardened steel ball mill in a high purity argon atmosphere up to 30h. The rotational speed of 500 rpm and ball to powder weight ratio of 10:1 is preferred. In order to produce Al6061–3 % vol. Al_2O_3 nanocomposite powder, an ultrasonic treatment is carried for 90 min. Particles which are dispersed ultrasonically are then added for milling. The milled powders are filled in a uniaxial die. Finally, the specimen is heated to 400 ^{o}C and pressed at constant pressure of 128 MPa. The duration of hot pressing is 30 min.

Properties: Milling time and Al_2O_3 particle size significantly affect the relative density, hardness and wear rate of the composite. Increasing the milling time of Al6061 and Al_2O_3 nanoparticles simultaneously up to 15h causes a significant improvement in the surface quality of powder particles in addition to uniform distribution of fine alumina particles. The hardness of the composite decreases with increase in porosity. Relative density decreases with increase in Al_2O_3 particulates size.

MnO_2 Nano-particles in Polyaniline (PANI) [36]

Theory: These composites are prepared with conductive supporting materials such as carbonaceous materials/MnO_2 and conducting polymers/MnO_2 composites. Among these composites, polyaniline (PANI)/MnO_2 composites are used owing to the following reasons. Firstly, the capacitance of the composites is better as compared with the pure PANI and MnO_2. Secondly, the amorphous polyaniline is a good buffer layer for MnO_2 thereby improving the performance under rapid charge - discharge conditions.

Process: The PANI/MnO_2 nanocomposites are obtained in three steps a) Preparation of solution A: 0.10g MnO_2 nanoparticles are dispersed in deionized water by using ultra-sonification process b) Preparation of solution B: Aniline monomer is added into the mixed solution of sulfuric acid and deionized water and then cooled in an ice bath c) Fabrication of nanocomposites: Solution B is added to solution A thoroughly and quickly, then the resulting mixed solution is stirred violently to ensure proper mixing and the reaction that is carried out in the stationary state. The obtained green solid product is filtered and washed with ethanol and deionized water. Finally, the product isried at 60^{o}C in vacuum oven for 24 hrs for obtaining PANI/MnO_2 nanocomposites. Refer Fig. 12 for the sample image of MnO_2.nanoparticles.

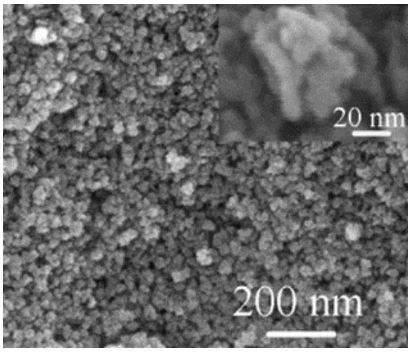


Fig. 12. Highly magnified image of MnO_2 nanoparticles

Properties: These nano-composites have a specific capacitance as large as 510 F g−1 in the potential range from 0.0 to 0.65V at the charge discharge current density of 1.0Ag−1 which is vastly improved as compared with pure PANI and MnO2 materials.

Applications: These composites are used in electrochemical devices and supercapacitors where high specific capacitance ratings are required.

VII. Discussion

When it comes to material performance, composites are far superior to mono-material alternatives, especially when it comes to the independent use of the component parts. One of the primary justifications for using composite materials for components over traditional materials is weight savings. Although composites are lighter than other materials, they can also be stronger. For instance, reinforced carbon fiber is ideal for structural applications since it can be up to five times stronger than 1020 grade steel while weighing only a fifth of the latter. The qualities of a composite, such as its electrical insulation and resilience to heat and chemicals, are further advantages over traditional materials. Modern composite materials, as opposed to traditional materials, can have a variety of new qualities that are uncommon in a single material. The use of fiber reinforced composites (FRP) is ever growing in the design and production of finished goods intended for retail sales.

a) The modern composites that fall within the ambit of metal matrix composites are Nano-Structured ODS Lanthanum Oxide–Tungsten Composites, Metal Polymer Hybrid Composites, Carbon Fiber Reinforced Aluminium Matrix Composite, Titanium Matrix Composites and TiAl - B_4C Composites. Among them, titanium matrix composites (TMCs) are high-performance materials designed for structural applications requiring minimal weight. The materials utilize the high strength, high stiffness, and creep resistance of silicon carbide (SiC) fibers at elevated temperatures along with the damage tolerance of titanium alloys. The SiC fibers are embedded in a titanium matrix. TMC processing is crucial since the quality of the fabrication process is directly correlated with the qualities of the materials. Nanostructured or ultrafine-grained tungsten materials can help with some issues like brittleness, high ductile–brittle transition temperature.

The stated composites have the potential for application in critical nuclear industry, aircraft – automotive – naval – construction industries, aerospace – automotive industries, aerospace – military equipment, aerospace structures respectively.

b) The modern composites that fall within the ambit of ceramic composites are SiC Nanoparticle reinforced Al_2O_3–Nb Composite, Titanium Silicon Carbide Hybrid Matrix Composites, TiN-TiB_2 Ceramic Composites, SiC-Cf composites and ZnO-Al_2O_3 Ceramic Composites. These composites have the potential for application in bio-medical implants, space industry, jet engine parts – armour plates - cutting tools and dies – high performing electrical systems, high-temperature burner environments - hypersonic aircraft thermal structures - advanced rocket propulsion thrust chambers - cooling panels for nozzle ramps - turbo pump shaft attachments - brake disks, conductive electrodes for several optoelectronic devices - photovoltaic solar cells - liquid crystal displays - light emitting diodes respectively.

c) The modern composites that fall within the ambit of laminated composites are Bio-Inspired Laminated Composites and Ti–6Al–4V/Ti–43Al–9V–Y Laminated Composite. They have the potential for application in high temperature materials. Besides, Bio-Laminated composite structures are being used in a wide range of engineering applications, including automotive, aircraft, spacecraft, and marine structures, due to their better specific strength and stiffness.

d) The modern composites that fall within the ambit of fiber reinforced polymer composites are Thermoset Composites with Carbon Nanofibers**,** Recycled Carbon Fiber-PP Composites**,** PET Composites and Wild Cane Grass Fiber-Reinforced Polyester Composites. They have the potential for application in producing thermal plastic composites, automobile interiors, ornaments and decoration materials and reinforcement in applications demanding light-weight materials with reasonably good toughness.

e) The modern composites that fall within the ambit of nano composites are Al6061– Al_2O_3 Nanocomposites and MnO_2 Nano-particles in Polyaniline. The structure, content, interfacial interactions, and constituents of individual property have a significant impact on nanocomposites. In situ growth and polymerization of biopolymer and inorganic matrix are the most common methods used to prepare nanocomposites. These remarkable, possibly cutting-edge materials are expected to be in high demand quickly, which will make them extremely valuable in a variety of industries with production facilities ranging in size from modest to enormous. They offer cutting-edge technologies and improved economic prospects to several industrial sectors. They have the potential for application in electrochemical devices and supercapacitors where high specific capacitance ratings are required.

VIII. Conclusion

A mini-literature study is presented on some fundamental aspects, processing techniques, properties and applications of metal matrix, ceramic matrix, polymer matrix, laminated and nano composites that are meant for advanced applications. Latest trends involving usage of newer materials and innovative fabrication technologies are briefly discussed.

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