CHAPTER 2
LITERATURE SURVEY

2.1 FIBER REINFORCED POLYMER COMPOSITES

Shinji Ochi [9] investigated the fiber fractions generated from bamboo range from very coarse to fine micronized powders, which are free-flowing and look like wood. Bamboo fibers are strong, light weight, wear resistant and have “very low” water absorption. This paper describes tensile properties of bamboo fiber reinforced biodegradable plastics. The unidirectional biodegradable composites were made from bamboo fiber bundles and a starch-based biodegradable resin. The tensile strengths of the composites increased with increasing fiber content up to 70%. Moreover, heat resistance of bamboo fibers and bamboo fiber reinforced plastics was investigated. As a result, tensile strength of both bamboo fiber and bamboo fiber reinforced plastics decreased at 160°.

Amit Rai et al. [10] observe the increasing concern about global warming, which is primarily due to deforestation leading to the ban on use of wood in government buildings. Most of the natural fibers have excellent physical and mechanical properties and can be utilized more effectively in the development of composite materials for various building applications. Advantages of using natural fiber materials over traditional building materials and their possible growth in future are also discussed. The technological gap for the overall development of various natural fiber composites and its world scenario has also been covered.

Yan Li et al. [11] reveals that sisal fiber is a promising reinforcement for use in composites on account of its low cost, low density, high specific strength and modulus, no health risk, easy availability in some countries and renewability. In recent years, there has been an increased interest in finding new applications for sisal-fiber-reinforced composites that are traditionally used for making ropes, mats, carpets, fancy articles and others. This review presents a summary of the recent developments of sisal fiber and its composites. The properties of sisal fiber itself interface between sisal fiber and matrix, properties of sisal-fiber-reinforced composites and their hybrid composites have been reviewed.
Herrera-Franco et al. [12] proposed the degree of fiber–matrix adhesion and its effect on the mechanical reinforcement of short henequen fibers and a polyethylene matrix was studied. The surface treatments were: an alkali treatment, a silane coupling agent and the pre-impregnation process of the HDPE/xylene solution. HDPE-henequen fiber composite materials were prepared with 20% v/v fiber content and the tensile, flexural and shear properties were studied. The comparison of tensile properties of the composites showed that the silane treatment and the matrix-resin pre-impregnation process of the fiber produced a significant increase in the tensile strength, while the tensile modulus remained relatively unaffected. The increase in tensile strength was only possible when the henequen fibers were treated first with an alkaline solution. It was also shown that the silane treatment produced a significant increase in flexural strength while the flexural modulus also remained relatively unaffected. The shear properties of the composites also increased significantly, but, only when the henequen fibers were treated with the silane coupling agent. Scanning electron microscopy (SEM) studies of the composites failure surfaces also indicated that there was an improved adhesion, between fiber and matrix. Examination of the failure surfaces also indicated differences in the interfacial failure mode. With increasing fiber–matrix adhesion the failure mode changed from interfacial failure and considerable fiber pull-out from the matrix for the untreated fiber to matrix yielding and fiber and matrix tearing for the alkaline, matrix-resin pre-impregnation and silane treated fibers.

Abdul Khalil et al. [13] have reported the reduction in the harmful destruction of ecosystem. To produce low cost polymeric reinforced composites, the researchers come out with policies of manufacturing the composites using natural fibers which are entirely biodegradable. The utilization of bamboo fibers as reinforcement in composite materials has increased tremendously and has undergone high-tech revolution in recent years as a response to the increasing demand for developing biodegradable, sustainable, and recyclable materials. The amalgamation of matrix and natural fibers yields composite possessing the best properties of each component. Various matrices used currently are soft and flexible in comparison to natural fibers, their combination leads to composite formation with high strength-to-weight ratios. Thus, this article gives a critical review of the most recent developments in bamboo fiber-based reinforced composites.
Fuentes et al. [14] discuss the recent attraction of bamboo fiber as a sustainable reinforcement fiber in (polymer) composite materials, due to specific mechanical properties which are comparable to glass fibers. To achieve good wetting and adhesion of the bamboo fiber with different polymers, the fiber surface needs to be characterized. The wetting behavior of the technical bamboo fibers is studied experimentally by using the Wilhelmy technique, and the results are modeled using the molecular-kinetic theory. The results indicate that the high concentration of lignin on the surface of bamboo fibers is responsible for their wetting properties, but the typical phenomena affecting wetting experiments on plant fibers can be minimized.

Aiping Zhou et al. [15] reveals that the bamboo can be idealized as a 2-phase composite consisting of vascular bundles (fibers which serve as reinforcement) and ground tissues (serve as matrixes). And to determine the mechanical parameters of fibers and matrixes it is essential to quantitatively evaluate the mechanical properties of bamboo. In this study, the micromechanical analysis, macro tensile experiments, microscopic image analysis for bamboo samples and the mechanical properties of natural bamboo associated with the properties of fibers and matrixes and with the volume fraction of fibers were quantitatively established. The results indicated that the Young’s moduli and the tensile strength of bamboo in longitudinal direction are determined by those of fibers and matrix, and are linearly related to the volume fraction of fibers.

Tommy Y Lo et al. [16] investigated the effect of the diameter and age of bamboo on the compressive strength capacity of bamboo sticks. The fiber density of sclerenchyma tissues of two types of bamboo, namely Mao Zhu and Kao Zhu, was examined under scanning electronic microscope. Findings indicated that the compressive strengths for Mao Zhu and Kao Zhu ranged between 47.0 and 62.8 N/mm² and between 37.7 and 62.0 N/mm², respectively, and the strength decreased significantly with the increase in its outer diameter. The sclerenchyma fibers were more closely packed at the top section of the bamboo, resulting in a higher strength capacity of bamboo. The fiber density of sclerenchyma tissue within the bamboo is a good indicator of the strength capacity of bamboo.
Qing Shen et al. [17] studied the different touch senses from bamboo and cotton fibers, the surface properties of bamboo fiber, e.g., the surface free energy, the Lifshitz–van der Waals force, and Lewis acid and base components have been determined using the column wicking technique. A big difference between these two fibers observed is that the bamboo fiber, having greater Lewis acid component, seems to be double than the cotton linter fiber.

Wong et al. [18] examined the fracture behavior of short bamboo fiber reinforced polyester composites. The matrix was reinforced with fibers ranging from 10 to 50, 30 to 50 and 30 to 60 vol. % at increments of 10 vol. % for bamboo fibers at 4, 7 and 10 mm lengths respectively. The results revealed that at 4 mm of fiber length, the increment in fiber content deteriorated the fracture toughness. As for 7 and 10 mm fiber lengths, positive effect of fiber reinforcement was observed. The optimum fiber content was found to be at 40 vol. % for 7 mm fiber and 50 vol. % for 10 mm fiber. The highest fracture toughness was achieved at 10 mm/50 vol. % fiber reinforced composite, with 340% of improvement compared to neat polyester.

Trotignon et al. [19] investigated the injection-moulded polypropylene samples containing low concentrations of talc, mica or wollastonite as filler material. The fatigue test was conducted in the flexural mode, at constant strain amplitude and 10 Hz frequency, and the induced stress, dissipation modulus, dissipated energy per cycle and surface temperature were recorded. Scanning electron microscope observations were made on the fractured surfaces. The cracks propagated over a few hundred micrometers from their initiation site (in the subcutaneous region), and then stopped when 20 to 50% of the whole volume was damaged. The samples remained in this state for more than 95% of their lifetime and then underwent sudden rupture. The fillers materials increased the energy dissipation (in the undamaged state) and accelerated sample failure.

Marina Delucchi et al. [20] revealed that in the marine field epoxy-based materials currently used to insulate the surface of the vessels improved their surface finish. A wide variety of fillers have been added to the epoxy resins in order to achieve an improvement of some properties, such as lightness, thermical insulation, hardness/tenderness of the surface. Further, new hollow glass micro spheres and carbon nanotubes (CNTs) were added to an epoxy matrix to obtain noval epoxy
composites to compare with a traditional one. Their density, hardness, tensile strength and flexural strength were studied. The different hollow glass microspheres-filled composites showed a wide range of mechanical behavior. On the other hand, the mechanical properties of the CNTs-filled composites were slightly improved when compared to those of the control material.

Patricio Toro et al. [21] investigated the chicken egg shell (ES) which is an industrial byproduct containing 95% calcium carbonate, and its disposal constitutes a serious environmental hazard. Different proportions of chicken eggshell as bio-filler for polypropylene (PP) composite were compared with different particle sizes and proportions of commercial talc and calcium carbonate fillers by tensile test. The Young’s modulus ($E$) was improved with the increment of ES content, and this bio-filler was better than all types of carbonate fillers with different particle sizes used in this study. Scanning electron microscopy showed an improved interfacial bonding on the tensile fractured surface. The improvement in the mechanical properties was attributed to a better ES/matrix interface related to the geometric ratio of the ES particles similar to talc particles.

S. Husseinsyah et al. [22] showed that natural lignocellulosics has an outstanding potential as reinforcement in thermosets. Coconut shell is one of natural lignocellulosic materials. In this study, coconut shell (CS) was used as filler in polyester composites. Polyester composites were prepared by incorporating coconut shell at different contents (0, 15, 30, 45, 60 php) into polyester matrix. The effect of the coconut shell content on the mechanical, water absorption and morphological properties was studied. The results revealed that increase in the coconut shell content increased the tensile strength, Young’s modulus and the water absorption but reduced the elongation at break. Results from scanning electron microscopy (SEM) showed that increased in filler content increased the tendency of filler-matrix interaction.

Koay Seong Chun et al. [23] investigated the effects of the filler content and the coupling agent 3-aminopropyltriethoxysilane (3-APE) on the mechanical properties and thermal properties. The morphologies of polylactic acid (PLA)/coconut shell powder (CSP) biocomposites were studied. It was found that increasing the CSP content decreased the tensile strengths and elongations at break
of the PLA/CSP biocomposites. However, incorporating CSP increased their modulus of elasticity. The tensile strengths and modulus of the elasticity of the PLA/CSP biocomposites were enhanced by the presence of 3-APE, which could be attributed to a stronger filler–matrix interaction. The thermal stabilities of the biocomposites increased with the filler content, and they were enhanced by 3-APE treatment. Meanwhile, the presence of CSP increased the glass transition temperatures ($T_g$) and crystallinities ($X_c$) of the PLA/CSP biocomposites at a filler content of 30 php. After 3-APE treatment, $T_g$ and $X_c$ of the PLA/CSP biocomposites increased due to enhanced interfacial bonding. The presence of a peak crystallization temperature ($T_c$) for the PLA/CSP biocomposites indicated that the CSP had a nucleating effect. The melting temperatures ($T_m$) and the $T_c$ values of the biocomposites were not significantly affected by the filler content and 3-APE. PLA/CSP biocomposites that had been treated with 3-APE presented the strongest filler–matrix interaction, as confirmed by SEM.

Michael Ikpi Ofem et al. [24] studied the effect of filler content and particle size on the mechanical properties of the PWS filled CNSL composites. The results showed that there was an improvement on the mechanical properties as the filler content increased while properties decreased as filler size increased. All the properties tensile strength, flexural strength, % elongation, tensile modulus and impact strength slightly increased as the filler loading increased. While % elongation, tensile and flexural strengths decreased as particle sizes increased, tensile modulus and impact strength increased as particle sizes increased. The optimum properties were observed at 30% filler content and 400µm particle size.

Ishidi et al. [25] showed that alkaline aqueous solution treated and untreated coconut shell particulates were incorporated into a polymer matrix (HDPE) with the help of Two Roll Mill in order to have a homogenous mix. The treatment with aqueous sodium hydroxide solution was to roughen filler surface. Magnesium hydroxide flame - retardant additive was incorporated to reduce the flammability of the composite. The flammability characteristics of the composite fabricated were tested using Fire Testing Technology (FTT) Dual Cone Calorimeter. The results obtained showed that the sodium hydroxide treatment enhanced the flame retardant characteristics of the composites as properties such as HRR, EHC, MLR, TSP and
SEA were influenced. The filler – matrix interaction was analyzed by SEM and the images obtained showed enhanced compatibility of the filler – matrix for alkaline aqueous treatment of the shell.

Sapuan et al. [26] studied the tensile and flexural properties of the composites made from coconut shell filler particles and epoxy resin. The tensile and flexural tests of composites based on coconut shell filler particles at three different filler contents viz. 5%, 10%, and 15%, were carried out using universal tensile testing machine according to ASTM D 3039/D 3039 M-95a and ASTM D790-90 respectively. Experimental results showed that tensile and flexural properties of the composites increased with the increase in the filler particle content.

Risby et al [27] investigated the potential use of coconut shell powder-epoxy composite (COEX) panel bonded with Twaron CT716 fabric as a hard armour material and the characteristics of its fracture imprints from a specific threat level when subjected to ballistic tests (NIJ Standard 0108.01). It was observed that the imprint patterns on the particulate composite (COEX) could be identified according to the effectiveness in impact energy dissipation. COEX/Twaron test panel was found to withstand impact equivalent to NIJ Level IIIA using 9 mm FMJ ammunition but perforated at NIJ Level III of 7.62 mm FMJ bullet impacts. Test results showed that COEX panel did possess shock absorbance characteristics and could be utilized as an armour component in the hard-body armour system.

Agunsoye Olumuyiwa et al. [28] showed the morphology and mechanical properties of coconut shell reinforced polyethylene composite were evaluated to establish the possibility of using it as a new material for engineering applications. Coconut shell reinforced composite was prepared by compacting low density polyethylene matrix with 5% - 25% volume fraction coconut shell particles and the effect of the particles on the mechanical properties of the composite produced was investigated. The results showed that the hardness of the composite increased with increase in coconut shell content though the tensile strength, modulus of elasticity, impact energy and ductility of the composite decreased with increase in the particle content. Scanning Electron Microscopy (SEM) of the composites (with 0% - 25% particles) surfaces indicated poor interfacial interaction between the coconut shell particle and the low density polyethylene matrix.
Yan et al. [29] showed that noil hemp fiber (NHF) is a kind of textile hemp fiber after deep degumming from scutched hemp fiber (SHF), mechanically-degummed hemp fiber. Both NHF and SHF with strong mechanical properties are good candidates as reinforcing fibers for plastics such as polypropylene (PP). The PP/NHF and PP/SHF composites were blended via internal mixing process. The effect of fibers on the morphology, thermal resistance and reinforcement of the composites were investigated. PP/NHF composites showed higher impact strength, lower flexural strength than PP/SHF at the corresponding loading because NHF has smaller diameter and better thermal resistance than SHF. Meanwhile, NHF had the similar reinforcement to tensile strength with SHF. The effect of maleic anhydride polypropylene (MAPP) on the fiber-resin interface bonding was also comparatively studied. With increasing amount of MAPP, the tensile, flexural and impact strengths of PP/NHF and PP/SHF increased respectively. The morphology of PP/SHF and PP/NHF results well showed that MAPP improved the interaction of the fibers with PP through chemical adhesion.

Vivek Mishra et al. [30] observed that during last few years, the interest in using natural fibers as reinforcement in polymers has increased dramatically. Natural fibers are not only strong and lightweight but also relatively very cheap. In this research work, an investigation was carried out to make use of jute fiber, a natural fiber abundantly available in India. The present work described the development and characterization of a new set of natural fiber based polymer composites consisting of bidirectional jute fiber mat as reinforcement and epoxy resin as matrix material. The composites were fabricated using hand lay-up technique and were characterized with respect to their physical and mechanical properties. Experiments were carried out to study the effect of fiber loading on the physical and mechanical behavior of these composites. The results showed the significant effect of fiber loading on the mechanical properties of the composites. Also, the formation of voids in the composites was an influencing factor on the mechanical properties.

Yanjun Xie et al. [31] proposed that natural fiber reinforced polymer composites (NFPCs) provide the customers with more alternatives in the material market due to their unique advantages. Poor fiber–matrix interfacial adhesion may, however, negatively affect the physical and mechanical properties of the resulting
composites due to the surface incompatibility between hydrophilic natural fibers and non-polar polymers (thermoplastics and thermosets). A variety of silanes (mostly trialkoxysilanes) has been applied as coupling agents in the NFPCs to promote interfacial adhesion and improve the properties of composites. This paper reviews the recent progress in using silane coupling agents for NFPCs, summarizes the effective silane structures from the silane family, clarifies the interaction mechanisms between natural fibers and polymer matrices, and presents the effects of silane treatments on the mechanical and outdoor performance of the resulting composites.

Brahmakumar et al. [32] showed how coconut fiber was used as reinforcement in low-density polyethylene. The effect of natural waxy surface layer of the fiber on fiber/matrix interfacial bonding and composite properties has been studied by single fiber pullout test and evaluating the tensile properties of the oriented discontinuous fiber composites. The waxy layer provided such a good fiber–matrix bond that the removal of the layer resulted in drastic decrease in the fiber pullout stress, increase in the critical fiber length and corresponding decrease in tensile strength and modulus of the composites. The waxy layer of polymeric nature also exhibited a stronger effect on interfacial bonding than by the grafted layer of a C15 long-chain alkyl molecule on the wax-free fiber. The morphological features of the fiber along with its surface compatibility with the matrix favors oriented the flow of the relatively long fibers along with the molten matrix during extrusion.

Pramendra Kumar Bajpai et al. [33] reveal that the application spectrum of natural fiber reinforced polymer composites is growing rapidly in various engineering fields. The present study explores the possibilities of reinforcing thermoplastic bio-polymer with the locally available inexpensive plant fibers for developing a new tribo-material. Three different types of natural fibers (nettle, grewia optiva and sisal) were incorporated into PLA polymer to develop laminated composites using a hot compression technique. TGA analysis was carried out to investigate the thermal stability of the developed composites. Wear and frictional characteristics of the developed composites were investigated under dry contact condition at different operating parameters, such as applied load (10–30 N), sliding speed (1–3 m/s) and sliding distance (1000–3000 m). The experimental results indicated that the incorporation of natural fiber mats into PLA matrix significantly
improved the wear behavior of neat polymer. There was 10–44% reduction in friction coefficient and more than 70% reduction in the specific wear rate of the developed composites as compared to neat PLA. The worn surface morphology was studied using scanning electron microscope (SEM) to analyze the wear mechanism in the different types of the developed composites.

Yicheng Dua et al. [34] made a study of the creep response of the laboratory made natural fiber-reinforced thermoset polymer composite face/honeycomb core sandwich panels. Sandwich panel creep properties in a period of 30 days in ambient conditions and at 65% relative humidity were investigated. In ambient conditions (relative humidity (RH) at 20–50%), sandwich panels showed linear viscoelastic properties when the stress level was less than 30% of their failure stress. Higher relative humidity (65%) produced a significant acceleration of creep strain. Creep behavior in ambient conditions was successfully simulated by Findley and Bailey-Norton models. The sandwich panels’ creep resistance properties were compared with those of the relevant sandwich-structure composites studied in the literature.

Moe Moe Thwe et al. [35] studied the resistance of bamboo fiber reinforced polypropylene composite (BFRP) and bamboo-glass fiber reinforced polypropylene hybrid composite (BGRP) to hygrothermal aging and their fatigue behavior under cyclic tensile load. Injection molded samples were exposed in water at 25°C for up to 6 months and at 75°C for up to 3 months. The tensile strength and elastic modulus of BFRP and BGRP samples showed moderate reduction after aging at 25°C after 6 months, however, they were reduced considerably after aging at 75°C for 3 months. Moisture absorption and tensile strength degradation were suppressed by using maleic anhydride polypropylene (MAPP) as a coupling agent in both types of composite systems. BFRP and BGRP samples were also loaded cyclically at the maximum cyclic load of 35, 50, 65, and 80% of their ultimate tensile stress. Then results suggest that BGRP has better fatigue resistance than BFRP at all load levels tested.

Lukas Sobczak et al. [36] have reported that natural Fiber Composites (NFCs) and Wood Polymer Composites (WPCs) based on polypropylene (PP) have gained increased interest over the past two decades, both in the scientific community and in industry. Meanwhile, a large number of publications is available, but yet the
actual market penetration of such materials is rather limited. To close the existing gap between scientific and technical knowledge on the one hand, and actual market applications on the other, it is the purpose of this paper to analyze the current state of knowledge on the mechanical performance profiles of injection molded NFCs and WPCs. As the composite properties are a result of the constituent properties and their interactions, special attention is also given to mechanical fiber/filler properties. Moreover, considering that NFCs and WPCs, for a variety of potential applications, compete with mineral reinforced (mr; represented in this study by talc), short glass fiber (sgf), long glass fiber (lgf) and short carbon fiber (scf) reinforced PP, property profiles of the latter materials are included in the analysis. To visualize the performance characteristics of the various materials in a comparative manner, the data were compiled and illustrated in the so-called Ashby plots. Based on these comparisons, an assessment of the substitution potential of NFCs and WPCs is finally made, along with a discussion of still open issues, which may help in guiding future material development and market application efforts.

Gironès et al. [37] obtained thermoplastic starch (TPS) from industrial non-modified corn starch and reinforced it with natural strands. The influence of the reinforcement on the physical–chemical properties of the composites obtained by melt processing was analyzed. For this purpose, composites reinforced with different amounts of either sisal or hemp strands were prepared and evaluated in terms of crystallinity, water sorption, thermal and mechanical properties. The results showed that the incorporation of sisal or hemp strands caused an increase in the glass transition temperature (Tg) of the TPS as determined by DMTA. The reinforcement also increased the stiffness of the material, as reflected in both the storage modulus and the Young’s modulus. The intrinsic mechanical properties of the reinforcing fibers showed a lower effect on the final mechanical properties of the materials than their homogeneity and distribution within the matrix. Additionally, the addition of a natural latex plasticizer to the composite decreased the water absorption kinetics without affecting significantly the thermal and mechanical properties of the material.

Tran Huu Nam et al. [38] developed poly (butylene succinate) (PBS) biodegradable composites reinforced with coir fibers. The effect of alkali treatment on the surface morphology and the mechanical properties of coir fibers, interfacial
shear strength (IFSS) and the mechanical properties of coir fiber/PBS composites was studied. The effect of the fiber mass content varying from 10% to 30% on the mechanical properties of coir fiber/PBS composites was also investigated. The coir fibers which were soaked in 5% sodium hydroxide solution at room temperature (RT) for 72 h showed the highest IFSS with 55.6% higher than the untreated coir fibers. The mechanical properties of alkali-treated coir fiber/PBS composites were significantly higher than those of the untreated fibers. The best mechanical properties of the alkali-treated coir fiber/PBS composite were achieved at fiber mass content of 25% in this study, which showed an increase of tensile strength by 54.5%, tensile modulus by 141.9%, flexural strength by 45.7% and flexural modulus by 97.4% compared to those of pure PBS resin. The fiber surface morphologies and fractured surface of the composites exhibited an improvement of interfacial fiber–matrix adhesion in the composites reinforced with alkali-treated coir fibers.

Kabir et al. [39] provides a comprehensive overview of the different surface treatments applied to natural fibers for advanced composites applications. In practice, the major drawbacks of using natural fibers are their high degree of moisture absorption and poor dimensional stability. The primary objective of surface treatments on natural fibers is to maximize the bonding strength so as the stress transferability in the composites. The overall mechanical properties of the natural fiber reinforced polymer composites are highly dependent on the morphology, aspect ratio, hydrophilic tendency and dimensional stability of the fibers used. The effects of the different chemical treatments on the cellulosic fibers that are used as reinforcements for thermoset and thermoplastics are studied. The chemical sources for the treatments include alkali, silane, acetylation, benzoylation, acrylation and acrylonitrile grafting, maleated coupling agents, permanganate, peroxide, isocyanate, stearic acid, sodium chlorite, triazine, fatty acid derivate (oleoyl chloride) and fungal. The significance of the chemically-treated natural fibers is seen through the improvement of mechanical strength and dimensional stability of the resultant composites as compared with a pristine sample.

Ramesh et al. [40] reveal that the composite materials are replacing the traditional materials, because of their superior properties such as high tensile strength, low thermal expansion, high strength to weight ratio. The developments of
new materials are on the anvil and are growing day by day. Natural fiber composites such as sisal and jute polymer composites have become more attractive due to their high specific strength, lightweight and biodegradability. Mixing of natural fiber with Glass-Fiber Reinforced Polymers (GFRPs) find increased applications. In this study, sisal–jute–glass fiber reinforced polyester composites are developed and their mechanical properties such as tensile strength, flexural strength and impact strength are evaluated. The interfacial properties, internal cracks and internal structure of the fractured surfaces are evaluated by using Scanning Electron Microscope (SEM). The results indicate that the incorporation of sisal–jute fiber with GFRP can improve the properties and can be used as a alternate material for glass fiber reinforced polymer composites.

Paramasivam et al. [41] propose that the fiber which serves as a reinforcement in reinforced plastics may be synthetic or natural. So far, only artificial fibers such as glass, carbon, boron, etc., have been used in fiber-reinforced plastics. Although glass and other synthetic fiber-reinforced plastics possess high specific strength, their fields of application are very limited because of their inherent higher cost of production. In this connection, an investigation has been carried out to make use of the natural fibers available in plenty in India. Some of these natural fibers are not only strong and lightweight but also relatively very cheap.

Badie et al. [42] examined the effect of fiber orientation angles and stacking sequence on the torsional stiffness, natural frequency, buckling strength, fatigue life and failure modes of the composite tubes. Finite element analysis (FEA) has been used to predict the fatigue life of the composite drive shaft (CDS) using linear dynamic analysis for different stacking sequences. Experimental program on scaled woven fabric composite models was carried out to investigate the torsional stiffness. FEA results showed that the natural frequency increased with decreasing fiber orientation angles. The CDS had a reduction equal to 54.3% of its frequency when the orientation angle of carbon fibers at one layer, among other three glass ones, was transformed from 0° to 90°. On the other hand, the critical buckling torque had a peak value at 90° and the lowest at a range of 20–40° when the angle of one or two layers in a hybrid or all layers in non-hybrid changed similarly. Experimentally, composite tubes with fiber orientation angles of ±45° experienced higher load
carrying capacity and higher torsional stiffness. Specimens of carbon/epoxy or glass/epoxy composites with fiber orientation angles of ±45° showed catastrophic failure mode. In a hybrid of both the materials, [±45°] configuration influenced the failure mode.

Munikenche Gowda et al. [43] evaluated the mechanical properties such as modulus, Poisson's ratio and strength of woven jute fabric-reinforced composites. The specimens were prepared using hand lay-up techniques as per the ASTM standard. This was the first report by any single group of researchers in which tensile strength, compressive strength, flexural strength, impact strength, inplane shear strength, interlaminar shear strength and hardness were given. This work being an experimental study on untreated (‘as received’ jute fabric) woven jute fabric-reinforced polyester composites, demonstrated the potential of this renewable source of natural fiber for use in a number of consumable goods.

Mansor et al. [44] reveal that due to the recent trend and increasing awareness of sustainable product design, natural-based fiber materials are gaining a revival of popularity to replace synthetic-based fiber in the formulation of composites especially for automotive structural and semi structural applications. In this paper, the Analytical Hierarchy Process (AHP) method was utilized in the selection of the most suitable natural fiber to be hybridized with glass fiber reinforced polymer composites for the design of a passenger vehicle center lever parking brake component. Thirteen (13) candidate natural based fiber materials for the hybridization process were selected and analyzed to determine their overall scores in three (3) main performance indices according to the component product design specifications. Using the AHP method, the kenaf bast fiber yielded the highest scores and was selected as the best candidate material to formulate the hybrid polymer composites for the automotive component construction. Sensitivity analysis was also performed and the results showed that kenaf bast fiber emerged as the best candidate material in two out of three simulated scenarios, which further validated the results gained through the AHP method.

Jawaid et al. [45] studied the recent development of cellulosic/cellulosic and cellulosic/synthetic fibers based reinforced hybrid composites. Hybrid composites made up of two different cellulosic fibers are less common compared to
cellulosic/synthetic fiber, but these are also potentially useful materials with respect to environmental concerns. Hybrid composites fabrication by cellulosic fibers is economical and provides another dimension to the versatility of cellulosic fiber reinforced composites. As a consequence, a balance in cost and performance could be achieved through proper material design as per the directive of Europe states by 2015. Recent studies relevant to hybrid composites have cited in this review. This work intended to present an outline of the main results presented on hybrid composites focusing the attention in terms of processing, mechanical, physical, electrical, thermal and dynamic mechanical properties. Hybrid composites are one of the emerging fields in polymer science that triumph attention for application in various sectors ranging from automobile to building industry.

Arrakhiz et al. [46] proposed that polymer composite materials with vegetable fibers were an attractive field for many industries and researchers. However, these materials required the issues of compatibility between the fibers and the polymeric matrix. This work evaluated the thermal and mechanical properties of Doum-fibers reinforcing a low density polyethylene (LDPE) composite to follow the effect of adding fibers into polymer matrix. Doum-fibers were Alkali treated to clean the fiber surface and improve the polymer/fibers adhesion. The Doum-fibers were compounded in LDPE matrix at various contents and extruded as continuous strands. An enhancement on the mechanical properties of the composites found a gain of 145% compared to neat polymer at 30 wt.% fiber loading in Young’s modulus, a gain of 135% in flexural modulus at 20 wt.% fiber loading and a gain of 97% in torsional modulus at 0.1 Hz. Thermal properties were evaluated and the results showed a slight decrease with an increase of added Doum.

Libo Yan et al. [47] obtained the use of cost-effective natural fibers, i.e. flax in fiber reinforced polymer composites and coir in concrete as building materials as a step to achieve a sustainable construction. Both flax fiber reinforced polymer tube encased-plain concrete and the tube encased-coir fiber reinforced concrete composites have potential to be axial and flexural structural members. However, in flexure, slippage between the tube and the concrete core may compromise the performance of the composites. In this study, thin flax fiber reinforced polymer band rings were embedded into the tube inner surface in order to eliminate the slippage
because a better tube and concrete interlocking was achieved. Therefore, one purpose of this study was to investigate the effect of band rings on the compressive and flexural properties of flax fiber reinforced polymer tube encased-plain concrete and the tube encased-coir fiber reinforced concrete. The ductility of these composites was evaluated using an energy ductility index based on the measurement of fracture energy. Next, the cracking strength and the neutral axis depth of the composite beams without band rings under flexure were analyzed. Finally, based on the linear elastic analysis, a simplified analytical method was developed to predict the resisting moment capacities of these composite beams. The test results indicated that in axial compression, the use of band rings reduced the ultimate compressive strength and the ductility of both the composites. In flexure, the band rings eliminated the slippage but increased the load carrying capacity and deflection. The predicted ultimate moment capacities of these composite beams matched the experimental results well.

Riedel [48] reveals that so far, aerospace technology, the area of origin for fiber-reinforced polymers (FRPs), has been the field in which these polymers have mainly been applied. However, these construction materials are now also being used for numerous technical applications, especially where a high strength and stiffness is required at a low weight. Classic FRPs, however, often pose considerable problems in terms of being able to reuse or recycle at the end of their lifetimes. This is mainly due to the miscellaneous compound and usually very stable fibers and matrices. An interesting option may be provided by the use of construction materials made of renewable resources that consist of natural fibers embedded in biopolymers (so-called biocomposites) and would also involve economically and ecologically acceptable manufacturing technologies.

Mohammad Alzeer et al. [49] made a study on the synthesis and mechanical properties of the new inorganic polymer (geopolymer) composites unidirectionally reinforced with 4–10 vol.% natural cellulose-based fibers (NZ flax, phormium tenax). The geopolymer matrix was derived from dehydroxylated kaolinite-type clay. The mechanical properties of the fiber-reinforced composites improved with increasing the fiber content and, achieved the ultimate flexural strengths of about 70 MPa at 10 vol.% fiber content. This represented a significant improvement on the flexural strength of the unreinforced geopolymer matrix (about 5.8 MPa), and all the
composites showed graceful failure, unlike the brittle failure of the matrix. Scanning electron microscopy was used to study the morphology of the fiber-matrix regions and a combination of thermogravimetric analysis (TGA) and the thermal shrinkage measurements of these composites suggested that despite the formation of microcracks due to water loss from the geopolymer matrix, the fibers were thermally protected by the matrix up to 400 °C. The flax fibers did not appear to be compromised by the alkaline environment of the matrix, suggesting new possible applications for these low-cost simply prepared construction materials.

Ishak et al. [50] suggest that sugar palm is a multipurpose palm species from which a variety of foods and beverages, timber commodities, biofibers, biopolymers and biocomposites can be produced. Recently, it is being used as a source of renewable energy in the form of bio-ethanol via fermentation process of the sugar palm sap. Although numerous products can be produced from sugar palm, three products that are most prominent are palm sugar, fruits and fibers. This paper focuses mainly on the significance of fibers as they are highly durable, resistant to sea water and as they are available naturally in the form of woven fiber, they are easy to process. Besides, the recent advances in the research of sugar palm fibers and their composites, this paper also addresses the development of new biodegradable polymer derived from sugar palm starch, and presents reviews on fiber surface treatment, product development, and challenges and efforts on properties enhancement of sugar palm fiber composites.

Monica Hanus et al. [51] studied the broad range of challenges faced by the construction industry, ranging from the performance of the materials to environmental and safety issues relating to materials and their properties. Recent developments in the various areas of nanotechnology show significant promise in addressing many of these challenges. Research and developments have demonstrated that the application of nanotechnology can improve the performance of the traditional construction materials, such as concrete and steel. Noteworthy improvements in concrete strength, durability and sustainability are being achieved with considerable use of metal/metal oxide nanoparticles and engineered nanoparticles (carbon nanotubes and carbon nanofibers), and environment-responsive anticorrosion coatings formed using nanoencapsulation techniques are
showing promise in laboratory settings. Developments in nanotechnology are also improving the accuracy and commercial viability of sensor-based structural health monitoring; a task rapidly gaining importance as the structures that comprise many countries’ most expensive investments are near the end of their design life. As energy usage worldwide continues to grow, a focus on the potential for nanotechnology developments to reduce energy consumption has become evident. Research demonstrates that nanotechnology can contribute to novel cooling systems, and improve the functionality of solar cells and insulation. A range of nanomaterials is also being used to add new functionalities, such as self-cleaning properties, to the traditional construction industry products, for example paint and cement. First generation products are available on the market and further advances are evident in the academic literature.

Taylor et al. [52] investigated the effects of fly ash on the fatigue resistance of cement mortars. Mortar mixes were prepared with similar compressive cube strengths using a range of fly ash contents up to 25%. Samples from these mixes were tested in a double torsion facility under cyclic loading and the rates of crack growth were measured, recorded and plotted against the applied stress intensities on log-log scales in $V—K$ diagrams. At later ages, the fly ash was found to increase the fatigue resistance and toughness. This was thought to be due to the spherical fly ash particles having a blunting effect. At greater ages the mixes containing fly ash were slightly less resistant to fatigue crack growth. Bond between the gel and the large fly ash particles was observed to be poor, resulting in their effectively acting as flaws that were now large in relation to the other flaws in the matrix which was reduced with continued hydration.

Murtuza Ali Syed et al. [53] made a study of the use turmeric spent (TS) as reinforcing filler to fabricate polypropylene (PP) green composite for load bearing and tribological applications. PP/TS composites were fabricated using varying amounts of TS viz, 10%, 20%, 30% and 40% (w/w) by twin screw extrusion method. The fabricated PP green composites were evaluated for physico-mechanical and tribological properties. Experimentally obtained tensile values were compared with the theoretically predicted values using different theoretical models. The tensile modulus of the composites increased from 1041 to 1771 MPa with the increase in
filler addition from 0 to 40 wt.%. Flexural strength and flexural modulus of composites were improved after incorporation of TS into PP matrix. The water absorption characteristics of the composites were determined. The effect of abrading distances viz., 150, 300, 450, and 600 m and different loads of 23.54 and 33.54 N at 200 rpm on the abrasive wear behaviour were studied using dry sand/rubber wheel abrasive test rig. The TS filler lowered the abrasion resistance of the PP/TS composites. The wear volume loss and the specific wear rate as a function of abrading distance and load were determined. The surface morphology of the tensile fractured green composites and their worn surface features were examined under scanning electron microscope.

Nicholas Cheremisinoff et al. [54] investigated the different types of resins and their properties. Properties of resins vary greatly and determine the conditions under which fabricating or molding a particular mixture can be done—for example, many resins generate volatiles during curing. As such, high-molding pressures are necessary to prevent byproducts from forming gas pockets in the product. Similarly, high-viscosity resins also require high pressures for molding to ensure thorough filling of the mold cavity. Low viscosity resins can often be molded at room temperature and pressure and provide no byproduct formation. Resins that can be used at low pressures are most often preferred for fiberglass-reinforced plastics (FRP) molding. Molding equipment at low pressure is less costly and simpler in design. In addition, high-molding pressure operations tend to reduce FRP product properties and high pressures tend to crush the fiberglass.

Rosana Gaggino [55] reported this work as contribution to decontaminating the environment, and to solving the housing shortage in our country. The technological products developed in this research are sustainable from the ecological, technical and economic points of view. The developed products were panels for housing and equipment. They were manufactured by recycling plastic materials from food, perfumery or cleaning packaging, and waste production from factories due to failures in sheet thickness or ink application. It, thus, contributes to decontaminating the environment, since most of this waste is buried in municipal land without any use, or accumulated and burned in landfills, causing environmental degradation.
2.2 MECHANICAL AND METALLURGICAL PROPERTIES

Arrakhiz et al. [56] investigated the use of plant fiber which requires the issue of compatibility between matrix and fibers. The effect of chemical modification (alkali treatment, etherification treatment and esterification treatment) on the Alfa fiber surface, and its impact on the mechanical and thermal properties of the composites were studied. To this end, the percentage of fibers was fixed at (20 wt. %), to evaluate the effect of each chemical modification in Alfa reinforced polypropylene (PP), based on the mechanical and thermal properties of composites. Composites containing chemically modified Alfa fibers were found to possess improved mechanical and thermal properties when compared to non-treated composites. The highest improvement in Young’s modulus was observed with esterified fibers, with a 35% increase. Results have shown that all the treatments investigated removed a part of non-cellulosic compounds from Alfa fibers, yielding increase in thermal and mechanical properties in composite. Mechanical gains were derived from Ester-modified Alfa. However, it should be noted that treatment with NaOH gave noticeable mechanical and thermal performances, while being the cheapest and most environmentally friendly way to perform.

Arrakhiz et al. [57] showed how high density polyethylene (HDPE) was compounded with chemically treated coir fiber using a heated two roll mill. Three chemical treatments denoting silane, sodium hydroxide (NaOH) and dodecane bromide (C12) were selected to improve the interface adhesion between the fibers and polyethylene matrix. The mechanical properties of these composites were evaluated and compared against those of the neat polymer and untreated fibers composites. Results have shown that composites obtained with treated fibers possess better mechanical properties than those of composites made with untreated fibers; the calculated Young’s modulus in the composites was higher for the alkaline treated fibers than the raw fibers and, the C12 composite also shows a significant tensile modulus when compared to the raw fibers reinforced polymer.

Abdulkadir Gullu et al. [58] investigated the influence of silane coated glass fibers added to polypropylene (PP) and polyamide 6 (PA6) plastics. These plastics were reinforced with (15 and 30 wt %) silane coated glass fibers. For this purpose, a die was designed and manufactured to produce tension and notched impact species
using various injection parameters. Based on the results, the influence of the fiber reinforcement and injection parameters on the tensile strength and impact strength, PP and PA6 plastics reinforced with glass fiber exhibited improvement in their mechanical strength with the fiber reinforcement. However, improvement in the mechanical strength did not show a linear relationship with the fiber weight fraction on account of inhomogeneous fiber distribution and fiber fracture. In addition, the tensile strength increased with increasing injection feeding zone temperature and decreased with increasing injection speed and extruder screw speed. As the mechanical properties of the plastic matrix composite are heavily dependent on fiber weight/volume fraction and fiber length, these properties are determined and fiber length can be controlled according to its application areas. To obtain the longest fiber distribution, low screw and injection speed and big gate cross section should be selected.

Ishak et al. [59] observed that kenaf fiber has high potential to be used for composite reinforcement in bio composite material. It is made up of an inner woody core and an outer fibrous bark surrounding the core. The aim of this study was to compare the mechanical properties of short kenaf bast and core fiber reinforced unsaturated polyester composites with varying fiber weight fraction i.e. 0%, 5%, 10%, 20%, 30% and 40%. The compression moulding technique was used to prepare the composite specimens for the tensile, flexural and impact tests in accordance with the ASTM D5083, ASTM D790 and ASTM D256 respectively. The overall results showed that the composites reinforced with kenaf bast fiber had higher mechanical properties than kenaf core fiber composites. The results also showed that the optimum fiber content for achieving highest tensile strength for both bast and a core fiber composite was 20%wt. It was also observed that the elongation at break for both composites decreased as the fiber content increased. It can be concluded, the higher the cellulose content, the smaller the fiber diameter and the longer fiber significantly increases the mechanical properties of the composite.

Kumar et al. [60] discovered the possibility of obtaining relatively low dielectric constant bamboo-epoxy nano dielectrics with improved mechanical properties. The tensile strength of alkali-treated bamboo-epoxy nano composites with 3 wt% nano clay increased by 60% as compared to pure composites. It was
confirmed that the alkali and silane treatments with nanoclay filler improved the dielectric and mechanical properties of bamboo-epoxy composites.

Sun-young lee et al. [61] investigated the effects of chemical modification (silane coupling) and filler loading on the fundamental properties of the bamboo fiber (BF) filled polypropylene (PP) bio-composites. It was observed that the mechanical properties of the PP/BF composites, such as the tensile strength, flexural strength, and impact strength decreased as BF loading increased. However, the tensile modulus, flexural modulus, and water absorption were increased by the increase in the BF loading. The addition of aminopropyltrimethoxysilane (AS) and tetra methoxy orthosilicate (TMOS) after the alkali pretreatment for the BF increased all the tensile, flexural, impact strength, and water desorption of the resultant composites, resulting from the improved adhesion between the BF and PP matrix.

Venkata Subba Reddy et al. [62] observed that tensile properties of the hybrid composites increased with glass fiber content. These properties were found to be higher when alkali treated bamboo fibers were used in the hybrid composites. The elimination of amorphous hemi-cellulose with alkali treatment leading to higher crystallinity of the bamboo fibers may be responsible for these observations.

Singha et al. [63] studied the synthesis and mechanical properties of new series of green composites involving Hibiscus sabdariffa fiber as a reinforcing material in urea–formaldehyde (UF) resin based polymer matrix. The present work reveals that mechanical properties such as tensile strength, compressive strength and wear resistance etc of the urea–formaldehyde resin increase to a considerable extent when reinforced with the fiber. These SEM clearly shows the difference morphology of UF resin and respective fiber reinforced polymer composites. These results show that hibiscus sabdariffa fiber has immense scope in the fabrication of natural fiber reinforced polymer composites having a vast number of industrial applications.

Mei-po Ho et al. [64] investigated the mechanical properties and biodegradability of silk fiber reinforced Poly (lactic-acid) (PLA) composites. It was found that the Young’s modulus and flexural modulus of the composites increased with the use of silk fiber reinforcement while their tensile and flexural strengths decreased. This phenomenon was attributed to the disruption of inter- and intra-
molecular bonding on the silk fiber with PLA during the mixing process, and consequent reduction of the silk fiber strength. Moreover, bio-degradability tests showed that the hydrophilic properties of the silk might alter the biodegradation properties of the composites compared to that of a pristine PLA sample. Scanning electron micrographs helps to identify the fractured surfaces of silk/PLA composites with the fiber pull out compared with pure PLA.

Girones et al. [65] obtained thermoplastic starch (TPS) from industrial non-modified corn starch and reinforced this with natural strands. The influence of the reinforcement on the physical–chemical properties of the composites obtained by melt processing was analyzed. For this purpose, the composites reinforced with different amounts of either sisal or hemp strands were prepared and evaluated in terms of crystallinity, water absorption, thermal and mechanical properties. The results showed that the incorporation of sisal or hemp strands caused an increase in the glass transition temperature (Tg) of the TPS as determined by DMTA. The reinforcement also increased the stiffness of the material, as reflected in both the storage modulus and the Young’s modulus. The fragile fracture surfaces of the composites were studied with a scanning electron microscope. The composites were prepared with sisal, fibers appear not individually but forming large bundles similar to those of the raw material. Microphotographs also showed the effect of the fracture on the fibers. As expected for the efficiently reinforced composites, during the fracture process fibers suffered rupture instead of being pulled out. This observation is indicative of a good adhesion of the fibers to matrix. Materials with high fiber load presented some small voids in its matrix structure, especially in the case of the composites containing latex. The nature of these voids was not clear. However, absence of pulled-out fibers suggests that these but might be formed at the conformation of the material. The good adhesion showed in the SEM microphotographs, was transferred to the mechanical properties of the composites prepared, which were considerably enhanced by the presence of the reinforcing fibers.

Dhakal et al. [66] investigated the Hemp fiber reinforced unsaturated polyester composites (HFRUPE) subjected to low velocity impact tests. HFRUPE composites specimens containing 0, 0.06, 0.10, 0.15, 0.21 and 0.26 fiber volume
fractions (\(V_i\)) were prepared and their impact response compared with the samples containing an equivalent fiber volume fraction of chopped strand mat E-glass fiber reinforcement. Post-impact damage was assessed using scanning electron microscopy (SEM). A significant improvement in load bearing capability and impact energy absorption was found following the introduction of hemp fiber as reinforcement. The results indicate a clear correlation between the fiber volume fractions, stiffness of the composite laminate, impact load and total absorbed energy.

Anshida Haneefa et al. [67] observe that in the field of technical utilization of plant fibers, banana fiber-reinforced composites represent one of the most important areas. The influence of the fiber content, fiber loading, and hybrid effect on the mechanical properties such as tensile strength, Young’s modulus, elongation at break, and the flexural properties of the composites were evaluated. The volume fraction of glass fiber based on the total fiber content increased all the mechanical properties, except elongation at break. The tensile and flexural properties of composites were observed to have improved as the fiber loading (vol %) increased. On the other hand, lack of good interfacial adhesion and poor resistance to moisture absorption made the use of natural fiber-reinforced composites less attractive. Modification of the banana fiber improved the optimum fiber-matrix properties. Fracture behavior of the tensile failure samples were analyzed with scanning electron micrographs (SEM). It was clear from the SEM that the tensile failure was mainly due to fiber pull out. Chemical modifications such as alkali treatment, benzoyl chloride treatment and PSMA improved the tensile properties of the composite.

Raghavendra Rao et al. [68] studied the flexural, compressive properties of bamboo/glass fiber-reinforced epoxy hybrid composites. The effect of alkali treatment of the bamboo fibers on these properties was also studied. These hybrid composites were found to exhibit good flexural properties. The hybrid composites with alkali-treated bamboo fibers were found to possess higher flexural properties. The elimination of amorphous weak hemi-cellulose components from the bamboo fibers on alkali treatment may be responsible for this behavior.

Osorio et al. [69] developed a novel mechanical extraction process to obtain long bamboo fibers to be used as reinforcement in structural composites. A single-fiber tensile test at four different span lengths for the fibers of the bamboo species
Guadua angustifolia was performed. The strength values of 800 MPa and Young’s modulus of 43 GPa were obtained. Unidirectional bamboo fiber/epoxy composites (BFC) were produced with untreated and alkali-treated fibers to evaluate the effectiveness of the new reinforcing material. Flexural tests were performed with two fiber orientations (longitudinal and transverse). The longitudinal flexural strength was higher when untreated fibers were used while the treatment benefited the longitudinal flexural stiffness of the composite. Transverse strength increased at lower alkali concentrations, but the transverse three-point bending strength of untreated bamboo in epoxy was already quite high at around 33 MPa. The results illustrate that these bamboo fibers present a natural and renewable option to reinforce composites in several applications where glass fiber and traditional natural fibers are used nowadays.

Subhash Mandal et al. [70] investigated the effects of weight fraction and length of short bamboo and glass fibers on the flexural strength and inter-laminar shear strength (ILSS) of vinyl ester resin and unsaturated polyester (USP) resins. The bamboo fibers were isolated from the bamboo plant by treating them with dilute solution of sodium hydroxide (0.1 and 1N NaOH) for 72 h and then boiling them in a pressure cooker for 30 min. The fibers were separated, dried, and cut into 5 or 10mm lengths. Composites were fabricated using vinyl ester resin or USP resin as binders. The flexural properties of the glass/bamboo fiber reinforced vinyl ester resins were higher than those based on USP resins. This may be due to the better wetting of the fibers by VE resins with their low viscosity and the possibility of hydrogen bond formation with hydroxyl group on the bamboo fibers. Hybrid composites were fabricated using 50wt% of fibers. The wt% of the bamboo fibers in these hybrid composites was varied as 25, 50, and 75wt% of chopped glass fibers (5 mm). Replacement of 25wt% of glass fibers did not affect the flexural modulus and a marginal increase in ILSS was observed. However, replacement of 75% glass fibers by bamboo fibers resulted in a significant decrease in flexural strength, modulus and ILSS.

Smita Mohanty et al. [71] studied bamboo fiber-reinforced HDPE composites prepared by employing melt blending technique, followed by injection molding. A systematic investigation of the mechanical, dynamic, thermal, and morphological
behavior of the composites was carried out. It was observed that the tensile and flexural properties increased with the increase in the fiber loading from 10% to 30%, beyond which there was a decline in the mechanical strength of the composites.

Sultan Ozturk [72] investigated the mechanical properties such as tensile characteristics, flexural characteristics, impact strengths, and hardness of kenaf/phenol formaldehyde (PF), fiberfrax/PF, and kenaf/fiberfrax hybrid PF composites. The hybrid effect of kenaf and fiberfrax fiber on the tensile, flexural, impact strengths, and hardness was also investigated for the various ratios of kenaf/fiberfrax fiber loadings ranging between 1: 0 and 0: 1. The total fiber loading of the hybrid composites was 43 vol. %. The tensile, flexural strength and hardness of the composites increased with increasing fiber loading up to 43 vol. % and decreased above this value for kenaf/PF composites. With the addition of fiberfrax fiber, the tensile, flexural, and impact strengths of the kenaf/fiberfrax hybrid PF composites decreased linearly and the hardness of the composite increased.

Lukas Sobczak et al. [73] observe that Natural Fiber Composites (NFCs) and Wood Polymer Composites (WPCs) based on polypropylene (PP) have gained increasing interest over the past two decades, both in the scientific community and in industry. This study analyzes the current state of knowledge on the mechanical performance profiles of injection molded NFCs and WPCs unnotched impact strength values of all the other PP composites are reduced compared to neat PP, with PP–sgf exhibiting the least reductions, followed by PP–talc composites and NFCs, with WPCs revealing the most significant. In this context, it is known from the preliminary investigations that the notched impact properties of PP–sgf composites and PP composites with Tencel fibers may even exceed the values obtained with neat PP.

Nagalingam et al. [74] reveals that advanced composite, fiber-reinforced polymers (FRP), has been favored for certain aerospace, military, marine and automotive applications. Polymer nano composites containing layered silicates have attracted much attention. These exhibit increased modulus, decreased thermal expansion coefficient, increased solvent resistance and enhanced ionic conductivity when compared to the polymer alone. Eight different combinations of the composites FRP with nano clay (montmorillonite) were developed by layered manufacturing techniques (LM) and measured the mechanical properties were measured. The
measurement showed that the tensile strength, impact strength and fatigue life were highly increased. Particularly impact strength increases to 10 J/mm², with an addition of 10 wt% of nano powder.

Andrzej Bledzki et al. [75] prepared polyurethane-based composites reinforced with woven flax and jute fabrics with an evenly distributed micro void foam structure. The relationship between the resin-filled grade and the micro void content and the density was described. The influence of the type of reinforcing fiber, fiber and micro void content on the mechanical properties was studied. Increasing the fiber content induced an increase in the shear modulus and impact strength. However, increasing the micro void content in the matrix resulted in decreased shear modulus and impact strength. The woven flax fiber result in composites with better mechanical strength than the woven jute fiber composites.

Paul Wambua et al. [76] proposed natural fibers (sisal, kenaf, hemp, jute and coir) reinforced polypropylene composites, processed by compression moulding using a film stacking method. The mechanical properties of the different natural fiber composites were tested and compared. Kenaf, hemp and sisal composites showed comparable tensile strength and modulus results but as regards impact properties, hemp appeared to out-perform kenaf. The tensile modulus, impact strength and the ultimate tensile stress of kenaf reinforced polypropylene composites were found to increase with increasing fiber weight fraction. Coir fiber composites displayed the lowest mechanical properties, but their impact strength was higher than those of jute and kenaf composites.

Shen et al. [77] studied the correlation between the macro hardness and the tensile strength of particle reinforced metal matrix composites. Contrary to monolithic metals, a simple relationship between hardness and tensile strength was not found. The reinforcement fraction and matrix strength appear to play an important role in influencing the behavior of the composite under hardness and tensile loading conditions. The different loading modes of the tensile test compared to the hardness test, along with the local increase in particle concentration directly underneath the indenter during indentation, result in a significant overestimation of the tensile strength by the hardness test, especially when the matrix strength was relatively low.
Sujeet Sinha et al. [78] investigated the scratch and normal hardness characteristics of polyamide 6/nano-clay composite. It was found that the weight percentage (wt %) of nano-clay greatly affected the scratch properties of the composite because of the intercalated structure of the nano-clay in the composite for higher clay loading. The scratch hardness, computed using the scratch width data, decreased while the scratch force increased as the wt% of nano-clay particles added into the composite increased. On the other hand, normal hardness increased and so did the yield strength and the elastic modulus when the percentage of nano-clay was increased in the composite.

Kamal Kar [79] investigated the effects of rubber hardness on the properties of fiber-reinforced plastic (FRP) composites in order to find out the optimum composition of rubber mold used in the rubber pressure molding (RPM) technique. Burn test, tension test, interlaminar shear test and interlaminar fracture toughness tests were conducted on the FRP composites to measure the void content, presence of delamination, tensile strength, inter laminar shear strength and inter laminar fracture toughness. The results were compared with the FRP composites made by conventional technique to evaluate the performance of RPM technique. It was observed that the laminates produced by RPM technique with different filler content in the natural rubber mold showed significant improvement in the mechanical properties except interlaminar shear strength.

Hongyan Chen et al. [80] observed that moisture absorption was a major concern in the case of natural fibers used as reinforcement in structural composites. In this study bamboo strip as a kind of natural material was used to reinforce vinyl ester resin. The moisture absorption behavior of the bamboo strips and their adhesion to vinyl ester resin at different levels of relative humidity (RH) during specimen fabrication were investigated. To improve the moisture resistance and the adhesion to vinyl ester resin under high RH conditions, the bamboo strips were subject to different chemical treatments, such as alkaline, pre-alkaline and acetic anhydride, pre-alkaline and potassium permanganate, and pre-alkaline and silane. The study of the equilibrium moisture content of the modified bamboo strips showed that it was slightly increased by alkaline treatment, while it was reduced by the other three methods, especially by acetylation due to its well-known esterification. The
interfacial shear strength (IFSS) by pull-out test was greatly improved after the modification and it decreased steadily as the fabrication RH levels increased for both the untreated and treated samples. At high level RH (80% RH), IFSS was almost negligible except acetylated specimens. The results indicated that the severe negative impact on the IFSS by fabrication RH levels was not so considerable if the bamboo strips were subjected to acetylation as pretreatment. The interlaminar shear strength values based on short-beam shear test of unidirectional bamboo strip mats/vinyl ester resin composites were well consistent with IFSS data.

Pradeep et al. [81] studied the mechanical and water absorption behavior of the bamboo-glass mat (strand and woven) reinforced epoxy and polyester laminate composites. The hybridization with glass mat increased the mechanical and water resistant properties of the hybrid composites. The increase in properties was higher in the woven glass mat reinforced hybrid composites compared to the strand mat. For both the epoxy and polyester matrix composites, when two layers of the strand glass mat were used, the mechanical properties increased, but with three layers it showed a decrease in value. With woven glass mat reinforcement, the mechanical properties increased as the number of glass mat layer was increased. Addition of glass fiber resulted in the reduction of water absorption by the epoxy and polyester bamboo composites. Water absorption was reduced with increase in the glass fibers in the composite.

Sun-Young Lee et al. [82] investigated bamboo fiber (BF) filled polypropylene (PP) composites, manufactured by melt compounding and injection molding. Tensile modulus, impact resistance, and creep improved as BF loading increased. However, the tensile strength and water desorption were decreased by the increase in BF loading. The addition of maleated polypropylene (MAPP) as a coupling agent increased the tensile strength and modulus. The loading of MAPP also improved the water desorption, impact resistance, and bamboo fiber dispersion into neat PP matrix, while lowering creep.

Pradeep Kushwaha et al. [83] investigated the chemical surface modification of woven bamboo mat with maleic anhydride, permanganate, benzoil chloride, benzyl chloride, and pre-impregnation. These modified fibers were used as reinforcements in epoxy and polyester matrices. The effects of fiber modification on
the tensile, flexural, impact, and water absorption properties of the composites were investigated. After benzoylation of the bamboo fiber, the water absorption was 16% for the bamboo-epoxy composite compared to 41% by untreated bamboo-epoxy composite. The water absorption by benzylated bamboo reinforced polyester composite was 16.8% compared to 51% by untreated bamboo-polyester composite. Pre-impregnation improved the mechanical and water resistant properties of both epoxy and polyester-based composites.

Mariatti et al. [84] studied the properties of unsaturated polyester reinforced with banana and pandanus woven fabric. Both of the composite systems were fabricated by vacuum bagging technique. Flexural, impact, and water absorption properties were investigated as a function of total fiber volume fraction. It was observed that the water absorption test showed that woven pandanus fabric composites increased the overall water uptake more than the woven banana fabric composites. This might be due to the higher hemicellulose content and the defects existed in the composite system.

Suhara Panthapulakkal et al. [85] reveal that hemp fiber is one of the inexpensive and readily available bast natural fibers and hemp-fiber reinforced polymer composite products have gained considerable attraction for automotive interior products. In this study the moisture absorption of short hemp fiber and hemp-glass hybrid reinforced thermoplastic composites was analyzed to know if it was suitable for outdoor applications. The water absorption properties and its effect on the tensile properties of hemp and hemp/glass fiber hybrid polypropylene (PP) composites prepared by an injection molding process. The effect of hybridization on the water uptake and the kinetics of moisture absorption of the hemp fiber composites were evaluated by immersing the hybrid composite samples in distilled water at different temperatures, of 40, 60 and 80°C. The composites showed a Fickian mode of diffusion; however, a deviation was observed at higher temperature and it may be attributed to the microcracks developed at the interface and dissolution of the lower molecular weight substances from the natural fibers. Equilibrium moisture content (Mm) showed that water uptake of 40 wt% hemp fiber reinforced PP composites was the highest and incorporation of glass fiber decreased the water uptake significantly (40%). Equilibrium moisture content was found to be
independent of temperature, while diffusion coefficient (D) was increased with temperature. The effect of water absorption on the tensile properties of the composites showed that there was a significant reduction in strength and stiffness. It was observed that hybridization with glass fibers did not have any significant effect on the strength properties of the aged samples. The tensile properties of the re-dried aged samples showed an increased retention of strength properties after drying; however, a complete recovery of the properties was not achieved. This indicated that water absorption was not a physical process and permanent damage occurred to the composite after aging.

Wang et al. [86] show that the moisture absorption of natural fiber plastic composites is one major concern in their outdoor applications. The purpose of this study is to introduce percolation theory into this field and conduct some preliminary work. First, two new concepts, accessible fiber ratio and diffusion-permeability coefficient, were defined; secondly, a percolation model was developed to estimate the critical accessible fiber ratio; finally, the moisture absorption and electrical conduction behavior of the composites with different fiber loadings were investigated. At high fiber loading when accessible fiber ratio was high, the diffusion process was the dominant mechanism; while at low fiber loading close to and below percolation threshold, percolation was the dominant mechanism. The over-estimate of accessible fiber ratio led to discrepancies between the observed and model estimates.

Abdelmouleh et al. [87] investigated the composite material based cellulose fibers (raw or chemically modified) as reinforcing elements thermoplastic matrices were prepared and characterized, in terms of mechanical performances, thermal properties and water absorbance behaviour. Four different cellulose fibers with different average lengths were used, namely avicel, technical, alfa pulps and pine fibers. Two thermoplastic polymers, i.e. low density polyethylene and natural rubber, were employed as matrices. Cellulose fibers were incorporated into the matrices, as such or after chemical surface modification involving three silane coupling agents, namely c-methacryloxypropyltrimethoxy (MPS), c mercaptoproyltrimethoxy (MRPS) and hexadecyltrimethoxy-silanes (HDS). For composites, the equilibrium
water uptake was found to depend on the treatment of the fibers. For all the composites, the water absorption was found to increase with immersion time.

Dhakal et al. [88] investigated hemp fiber reinforced unsaturated polyester composites (HFRUPE) which were subjected to water immersion tests in order to study the effects of water absorption on the mechanical properties. HFRUPE composites specimens containing 0, 0.10, 0.15, 0.21 and 0.26 fiber volume fraction were prepared. Water absorption tests were conducted by immersing the specimens in a de-ionised water bath at 25°C and 100°C for different time durations. The tensile and flexural properties of the water immersed specimens subjected to both aging conditions were evaluated and compared alongside dry composite specimens. The percentage of moisture uptake increased as the fiber volume fraction increased due to the high cellulose content. The tensile and flexural properties of HFRUPE specimens were found to decrease with increase in percentage moisture uptake. Moisture induced degradation of the composite samples was significant at elevated temperature. The water absorption pattern of these composites at room temperature was found to follow Fickian behaviour, whereas at elevated temperatures it exhibited non-Fickian.

Rassmann et al. [89] studied on the mechanical and water absorption properties of kenaf fiber reinforced polyester laminates manufactured by resin transfer moulding. Varying processing conditions were considered as alternatives to fiber treatments, thereby potentially avoiding additional cost and complexity in the manufacturing process. Laminates were produced by altering fiber moisture content, mould temperature and mould pressure following injection. Tensile, flexural, impact and water absorption tests were conducted. Processing conditions were found to have little effect on the properties. Examinations using a scanning electron microscope showed that all the laminates failed by fiber pull-out.

Andrzej et al. [90] prepared abaca fiber reinforced PP composites using a high speed mixer followed by injection moulding with 30 wt.% of fiber load. Prior to the composite production, the fibers were modified by fungamix and natural enzyme. The effects of modification of the fiber were assessed on the basis of morphology and thermal resistance as well as on the mechanical, thermal and environmental stress corrosion resistance properties of the resulting composites. Coupling agent
(MA-PP) was also used with unmodified abaca fiber to observe the coupling agent effect on the resulting composites properties. The moisture absorption of the composites was found to be reduced 20–45% due to modification. The tensile strength was found to be 5–45% and flexural strengths increases to be 10–35% due to modification. Modified fiber composites found to better resistance in acid and base medium.

Alix et al. [91] applied Silane (Si) and styrene (S) treatments on flax fibers in order to improve their adhesion with a polyester resin and to increase their moisture resistance. The water sorption and permeation kinetics of the composites were correlated with the water sorption behaviour of the untreated and treated fibers. An increase of the water barrier effect was observed in the treated fibers-based composites in comparison with the untreated ones. This was related to the shift-down of water solubility and to a decrease in the water diffusivity in treated fiber-based composites. In the case of (S) treatment, the presence of styrene increased the moisture resistance of the treated fibers and made compatible the fibers and the matrix. In the case of (Si) treatment, a good hydric fiber/matrix interface was obtained due to cross linking reactions and hydrogen bonding between water molecules and free hydroxyl groups of (Si) treated fibers. In order to interpret water permeation behaviour of the composite films, a simple illustrated model was suggested and represented by a schematic view.

Bin Wei et al. [92] reinforced epoxy resins with basalt fibers and glass fibers respectively and they were treated with a seawater solution for different periods of time. Both the mass gain ratio and the strength maintenance ratio of the composites were examined after the treatment. The fracture surfaces were characterized using scanning electron microscopy. The tensile and bending strengths of the seawater treated samples showed a decreasing trend with treating time. In general, the anti-seawater corrosion property of the basalt fiber reinforced composites was almost the same as that of the glass fiber reinforced ones. Based on the experimental results, possible corrosion mechanisms were explored, indicating that an effective lowering of the Fe^{2+} content in the basalt fiber could lead to a higher stability for the basalt fiber reinforced composites in a seawater environment.
Khondker et al. [93] investigated the mechanical properties of aramid/nylon and aramid/epoxy composites and their relationships to the fiber/matrix interfacial adhesion and interactions. With the increase in the processing time, tensile modulus and strength of aramid/nylon composites have increased and decreased respectively. Furthermore, scanning electron microscopic observations clearly indicated that longer molding time had resulted in stronger adhesion property between fiber and matrix. Aramid/nylon knitted composites revealed comparable strength property in the course direction, albeit they had inferior tensile strength in the wale direction when compared to that in aramid/epoxy composites. In aramid/nylon knitted composites, while tensile modulus exhibited an increasing trend, there were clear drops in tensile strengths with longer molding time. This indicates that there could be an optimum molding condition at which maximum tensile properties can be obtained. Aramid/nylon knitted composites exhibited relatively better interfacial bonding properties than Aramid/epoxy composites, which suffered fiber/matrix debonding.

Alain Bourmaud et al. [94] carried out microscopic and tensile tests to determine the mechanical behavior of PP and PLLA/reed fiber composites. This study has allowed to place the mechanical properties of reed fibers between those of sisal and hemp fibers. Optical microscopic observations exposed the short length and the poor aspect ratio of the reed fibers used. Complementary SEM pictures showed an improvement of the bonding between fibers and matrix with the addition of PP-g-MA or PLA-g-MA and the poor dispersion of reed fiber into composites by showing important number of bundles. Tensile tests highlighted important improvement of the tensile modulus and a decrease of the tensile strength at yield with the addition of vegetal fibers. The presence of maleated matrix induced an improvement of the modulus and strength for PP/reed composites.

Nicolas Ali Libre et al. [95] undertook a study to improve the ductility of pumice lightweight aggregate concrete by incorporating hybrid steel and polypropylene fibers. The changes in the mechanical properties and also bulk density and workability of pumice lightweight aggregate concrete due to the addition of hybrid steel and polypropylene fibers were studied. The properties investigated were flexural, tensile strength, splitting tensile strength and toughness of hardened
concrete. Nine concrete mixtures with different volume fractions of steel and polypropylene fibers were tested. A large increase in the flexural ductility and energy absorption capacity due to the addition of steel fibers was observed. Polypropylene fibers, on the other hand, caused a minor change in the mechanical properties of the hardened concrete especially in the mixtures made with both steel and polypropylene fibers. These observations provide insight into the benefits of different fiber reinforcement systems to the mechanical performance of pumice lightweight aggregate concrete which is considered to be brittle. These results provide guidance for the design of concrete materials with reduced density and enhanced ductility for different applications, including construction of high-rise, earthquake-resistant buildings.

Axel Nechwatal et al. [96] proposed that all composite models contained the Young’s modulus or the tensile strength of the reinforcing fibers. Therefore, the essential prerequisite to come to an agreement between the theoretical approaches and the practical results is the exact measurement of these parameters. Some aspects of the measurement of the natural fiber E-modulus are discussed. Furthermore a new process to produce long fiber reinforced thermoplastic granules is presented. These long fiber granules can be processed by conventional plastic equipment.

Joung-Man Park et al. [97] evaluated the untreated and the treated Jute and Hemp fibers reinforced different matrix polypropylene-maleic anhydride polypropylene copolymer (PP-MAPP) composites by a micromechanical technique combining with acoustic emission (AE) and dynamic contact angle measurement. For the statistical tensile strength of Jute and Hemp fibers, bimodal Weibull distribution was fitted better than the unimodal distribution. The acid–base parameter on the interfacial shear strength (IFSS) of the natural fiber composites was characterized by calculating the work adhesion, Wa. The effect of alkaline, silane coupling agent on natural fibers was obtained with changing the MAPP content in PP-MAPP matrices. Alkaline treated fibers caused the surface energy to be higher due to the removal of the weak boundary layers and thus increasing surface area, whereas the surface energy of silane treated Jute and Hemp fibers decreased due to the blocked high energy sites.
Wassamon Sujaritjun et al. [98] reveals that natural fibers have recently become attractive to researchers, engineers and scientists as an alternative reinforcement for fiber reinforced polymer composites. This paper is focused on the tensile properties of natural fiber reinforced polylactic acid composites. The untreated and flexible epoxy treated bamboo fiber, vetiver grass fiber and coconut fiber were used as reinforcement for PLA biocomposites. The stiffness of the untreated biocomposites increased significantly with increasing of fiber content. However, the tensile strength decreased with the increasing of fiber content. The flexible epoxy surface treatment reduced the stiffness of all the composites while it considerably increased the tensile strength when compared with the untreated composites. In addition, it can be seen that the effects of flexible epoxy treated on the tensile strength improvement were dependent upon the type of natural fiber. The tensile strength of bamboo fiber and coconut fiber reinforced PLA composites were significantly improved by the flexible epoxy surface treatment. Unlike the other combinations, vetiver grass fiber reinforced PLA composite showed less improvement in tensile strength when compared with the other natural fibers. Bamboo fiber proved to be the most effective reinforcement compared to other reinforcements.

Herrera-Franco et al. [99] studied the mechanical behavior of high density polyethylene (HDPE) reinforced with continuous henequen fibers (Agave fourcroydes). Fiber-matrix adhesion was promoted by fiber surface modifications using an alkaline treatment and a matrix pre impregnation together with a silane coupling agent. The use of the silane coupling agent to promote a chemical interaction, improved the degree of fiber matrix adhesion. However, it was found that the resulting strength and stiffness of the composite depended on the amount of silane deposited on the fiber. A maximum value for the tensile strength was obtained for a certain silane concentration but when using higher concentrations, the tensile strength did not increase. Using the silane concentration that resulted in higher tensile strength values, the flexural and shear properties were also studied. The elastic modulus of the composite did not improve with the fiber surface modification. The elastic modulus, in the longitudinal fiber direction obtained from the tensile and flexural measurements, were compared with the values calculated using the rule of mixtures. It was observed that the increase in stiffness from the use of henequen
fibers was approximately 80% of the calculated values. The increase in the mechanical properties ranged between 3 and 43%, for the longitudinal tensile and flexural properties, whereas in the transverse direction to the fiber, the increase was greater than 50% with respect to the properties of the composite made with untreated fiber composite. In the case of the shear strength, the increase was of the order of 50%. From the failure surfaces it was observed that with increased fiber matrix interaction the failure mode changed from interfacial failure to matrix failure.

Supranee Sangthong et al. [100] treated sisal fiber by admicellar polymerization with a poly(methyl methacrylate) film coating in order to enhance the interfacial adhesion of the fiber/polymer composite for mechanical property improvement. Properties of the admicellar-treated sisal fiber were investigated by measuring its moisture absorption and electrostatic charge. Thermal stability study by thermogravimetric analysis and film identification by FTIR was also carried out. The treatment was shown to improve the tensile and flexural properties, impact strength, and hardness of the composite. SEM micrographs of the tensile fracture surface of sisal/unsaturated polyester composites also showed interfacial adhesion improvement of the composite prepared with admicellar-treated sisal.

Nina Graupner et al. [101] described the production and the mechanical characteristics of composites made completely of renewable raw materials. Composites of different kinds of natural fibers like cotton, hemp, kenaf and man-made cellulose fibers (Lyocell) with various characteristics were processed with a fiber mass proportion of 40% and poly (lactic acid) (PLA) by compression moulding. Additionally, composites were made of fiber mixtures (hemp/kenaf, hemp/Lyocell). The composites were tested for tensile strength, elongation at break, Young’s modulus and Charpy impact strength. Their characteristics varied markedly depending on the characteristics of the raw fibers and fiber bundles and fiber mixtures used. While kenaf and hemp/PLA composites showed very high tensile strength and Young’s modulus values, cotton/PLA showed good impact characteristics. Lyocell/PLA composites combined both high tensile strength and Young’s modulus with high impact strength. Thus, the composites could be applied in various fields, each meeting different requirements.
Anuar et al. [102] reported on the development of thermoplastic elastomer composite reinforced with 20 vol.% kenaf fiber. Two types of impact modifier were blended with polypropylene (PP) namely; thermoplastic natural rubber (TPNR) and polypropylene/ethylene–propylene–diene–monomer (PP/EPDM). Both the composites were produced via double melt blending method using Haake internal mixer before they were compression moulded. The ratio of thermoplastic: elastomer was 70:30 for both polymer blends. Due to incompatibility between matrix and reinforcement, maleic anhydride polypropylene (MAPP) was added as in the case of treated composite. It was found that the tensile strength for TPNR was about 12% higher than the PP/EPDM matrix. The presence of kenaf fiber (KF) and MAPP, however, significantly increased the tensile strength of the PP/EPDM composite by approximately 81% while only 55% increment attained in TPNR–KF–MAPP as compared to unreinforced TPNR. Apart from that, flexural properties and impact strength are greatly improved for treated kenaf fiber composite. This shows that KF imparted its tensile strength to the PP/EPDM system with good interaction provided by the compatibilizer agent. Scanning electron micrographs (SEMs) revealed that the improvement achieved in mechanical properties was due to the interaction between both matrix systems and kenaf fiber.

Ku et al. [103] investigated the tensile properties of natural fiber reinforced polymer composites. Natural fibers have recently become attractive to researchers, engineers and scientists as an alternative reinforcement for fiber reinforced polymer (FRP) composites. Due to their low cost, fairly good mechanical properties, high specific strength, non-abrasive, eco-friendly and bio-degradability characteristics, they are exploited as a replacement for the conventional fiber, such as glass, aramid and carbon. The tensile properties of natural fiber reinforce polymers (both thermoplastics and thermosets) are mainly influenced by the interfacial adhesion between the matrix and the fibers. Several chemical modifications are employed to improve the interfacial matrix–fiber bonding resulting in the enhancement of the tensile properties of the composites. In general, the tensile strengths of the natural fiber reinforced polymer composites increase with the fiber content, up to a maximum or optimum value, and then the value will then drop. However, the Young’s modulus of the natural fiber reinforced polymer composites increase with the increase in fiber loading. Mathematical modelling was also mentioned. It was
discovered that the rule of mixture (ROM) predicted and the experimental tensile strength of the different natural fibers reinforced HDPE composites were very close to each other. Halpin–Tsai equation was found to be the most effective equation in predicting the Young’s modulus of the composites containing different types of natural fibers.

Joseph et al. [104] prepared a composite consisting of polypropylene reinforced with short sisal fibers by melt-mixing and solution-mixing methods. In the melt-mixing technique, mixing parameters were optimised by varying the mixing time, rotor speed and chamber temperature. A mixing time of 10 min, rotor speed of 50 rpm and a mixing temperature of 170°C were found to be the optimum mixing conditions. The tensile properties of the melt-mixed and solution-mixed composites were compared. Under optimum mixing conditions, the melt-mixed composites showed better tensile properties than those of the solution-mixed composites. The influence of the fiber length, fiber loading and fiber orientation on the mechanical properties of PP/sisal composites was evaluated. The fiber breakage and damage during melt-mixing were analysed from fiber-length distribution curves and optical photomicrographs. The effect of the chemical treatment on the tensile properties of sisal/PP composites was investigated. Treatments with chemicals such as sodium hydroxide, maleic anhydride, urethane derivative of PPG, and permanganate were carried out to improve the bonding at the fiber/polymer interface. It was observed that all the treatments enhanced the tensile properties of the composites considerably, but to varying degrees.

Shinichi Shibata et al. [105] made a study on bio-based polymer composites made from kenaf, bamboo and biodegradable resin, which was a corn starch base were fabricated with press forming. The relationship between fiber Young’s modulus and flexural modulus in the composites was investigated. The Young’s modulus of each fiber was measured to predict the flexural modulus in the composites. The flexural modulus in the composites was predicted by Cox model, which incorporates the effect of the fiber compression. The flexural modulus increased with increase in the fiber content. In the case of kenaf, the flexural modulus in the experimental was in good agreement with the experimental, while in the case of bamboo, the difference between experimental and calculation was large. This is because Young’s modulus in
bamboo was estimated considerably lower than the actual modulus due to the partial breakage of bamboo during the single fiber tensile test. The flexural modulus in unidirectional fiber composite made a good agreement with the predicted. However, the flexural modulus in the cross ply composite was considerably lower than the predicted. This is because less fiber movement during hot pressing resulted in the resin segregation and the movement made the fibers less wetting with resin.

Nam Kim et al. [106] evaluated the exact element stiffness matrix is newly presented in order to perform the spatially coupled stability analysis of the thin-walled composite beams with symmetric and arbitrary laminations subjected to a compressive force. For this, the general bifurcation-type buckling theory of thin-walled composite beam was developed based on the energy functional, which is consistently obtained corresponding to semi tangential rotations and semi tangential moments. A numerical procedure is proposed by deriving a generalized eigenvalue problem associated with 14 displacement parameters, which produce both complex eigenvalues and multiple zero eigenvalues. Then, the exact displacement functions are constructed by combining eigenvectors and polynomial solutions corresponding to non-zero and zero eigenvalues respectively. Consequently, exact element stiffness matrices are evaluated by applying member force–displacement relationships to these displacement functions. As a special case, the analytical solutions for the buckling loads of unidirectional and cross-ply laminated composite beams with various boundary conditions are derived. Finally, the finite element procedure based on Hermitian interpolation polynomial is developed. In order to verify the accuracy and validity of this study, the numerical, analytical, and the finite element solutions using the Hermitian beam elements are presented and compared with those from ABAQUS’s shell elements. The effects of fiber orientation and the Wagner effect on the coupled buckling loads are also investigated intensively.

Hee Sun Kim et al. [107] reported experimental studies on reinforced concrete (RC) beams retrofitted with new hybrid fiber reinforced polymer (FRP) system consisting carbon FRP (CFRP) and glass FRP (GFRP). The objective of this study is examine effect of hybrid FRPs on structural behavior of retrofitted RC beams and to investigate if the different sequences of CFRP and GFRP sheets of the hybrid FRPs have influences on the improvement of strengthening RC beams.
Toward that goal, 14 RC beams are fabricated and retrofitted with hybrid FRPs having different combinations of CFRP and GFRP sheets. The beams are loaded with different magnitudes prior to retrofitting in order to investigate the effect of the initial loading on the flexural behavior of the retrofitted beam. The main test variables are sequences of attaching hybrid FRP layers and magnitudes of preloads. Under loaded condition, beams are retrofitted with two or three layers of hybrid FRPs, and then the load increases until the beams reach failure. The test results conclude that the strengthening effects of hybrid FRPs on ductility and stiffness of RC beams depend on the orders of FRP layers.

Naderian [108] developed a semi-analytical finite strip method for the prediction of the torsional and flexural buckling stresses of composite FRP columns under pure compression. Numerical finite strip results will be compared with those obtained from closed-form equations for doubly symmetric open thin-walled FRP sections. The accuracy of the proposed finite strip method in determining critical flexural and torsional stresses of FRP columns will be assessed. Among the composites, FRP columns with doubly symmetric open sections, buckling behavior of the stiffened and unstiffened FRP cruciform sections will be evaluated and case studies performed. The effect of the material properties and longitudinal stiffeners applied at the end of the web-plate and flange-plate on buckling modes of composite FRP cruciform sections is also observed.

Mahesh Hosur et al. [109] carried out a systematic study to investigate mechanical properties of 2D nanophased braided carbon/epoxy composites. SC-15 epoxy with three types of braided fabrics: ±45°, 0/±45°, and 0/±60° was used to fabricate composite laminates using vacuum assisted resin infusion molding (VARIM) process. Low-velocity impact (LVI), ultrasonic nondestructive evaluation (NDE) and 3-point bend flexure studies were carried out on biaxial and triaxial braided samples. Impact parameters like peak load and absorbed energy were calculated. All the LVI tested samples were then subjected to ultrasonic c-scan testing to determine the damage size. From the results it was seen that laminates sustained the impact load without any damage at 10 J, a little damage at 20 J and more damage at 30 J. From the ultrasonic tests it was seen that the biaxial ±45° laminates had the lowest damage. Flexural test showed the highest flexural strength
and stiffness for triaxial $0^\circ/\pm 45^\circ$. An investigation was also carried out to improve the properties of the braided laminates by introducing Nanomer® I-28E nanoclay, a surface modified montmorillonite mineral, into SC-15 epoxy matrix. Different weight percentages of nanoclay were dispersed in SC-15 epoxy. Highest properties were obtained for the samples with 1% by weight of nanoclay reinforcement.

Sui et al. [110] prepared polypropylene (PP) composites reinforced using a novel plant fiber, sunflower hull sanding dust (SHSD), using a twin-screw extruder. Thermal and mechanical properties of the SHSD/PP composites were characterized and compared to an organically modified clay (organo-clay)/PP composite. Differential scanning calorimetry (DSC) analysis showed that the crystallization temperature and the degree of crystallinity of PP exhibited changes with the addition of SHSD and organo-clay. The mechanical properties of the PP were enhanced with the addition of SHSDs. Both the flexural strength and flexural modulus of the PP composites containing 5% (w/w) SHSD were comparable to that of the 5% (w/w) organo-clay reinforced PP. Scanning electron microscope (SEM) observation showed that no obvious agglomeration of SHSD existed in the PP matrix. Compared to the neat PP and organo-clay/PP, the SHSD/PP composites exhibited a relatively decreasing rate of thermal degradation with increase in temperature. The experimental results suggest that SHSD, as a sunflower processing byproduct, may find promising applications in composite materials.

Sreekala et al. [111] investigated hybridization of oil palm fiber with glass fiber in order to achieve superior mechanical performance. The reinforcing effect of glass in phenol formaldehyde resin is evaluated at various glass fiber loadings. Tensile strength, tensile modulus and flexural strength increase with an increase in fiber loading. However, elongation at break and flexural modulus are found to decrease beyond 40 wt.% fiber loading. Impact strength and the density of the composites showed similar trends. Compared to the gum sample, the hardness of the composites decreased by glass fiber reinforcement. The hybrid effect of glass fiber and oil palm empty fruit bunch (OPEFB) fiber on the tensile, flexural and impact response of the composites was investigated. Randomly oriented glass and OPEFB fiber mats were arranged as interlayers to enhance the hybrid effect. The overall performance of the composites was improved by the glass fiber addition. Impact
strength shows great enhancement by the introduction of a slight amount of glass fiber. The density of the hybrid composite decreases as the volume fraction of the OPEFB fiber increases. Hardness of the composites also showed a slight decrease on an increased volume fraction of OPEFB fiber. Scanning electron micrographs and optical photographs of the fractured surfaces were taken to study the failure mechanism and fiber/matrix interface adhesion. The experimental results were compared with theoretical predictions. The hybrid effect of glass and OPEFB fiber was also calculated.

Wiphawee Nuthong et al. [112] proposed that modification was required for more practical applications due to the brittleness of PLA polymer. The improvement of the impact properties of PLA is an addition of fillers or reinforcements. Bamboo fiber, vetiver grass fiber and coconut fiber were used as alternative reinforcements in PLA composites. Injection molded of the untreated and flexible epoxy treated the composites at various reinforcement content was prepared. The impact strength of the natural fiber reinforced PLA composite decreased with an increase of fiber content. The maximum reduction in the impact strength was 23.8, 27.3 and 56.2% for bamboo fiber/PLA, vetiver grass fiber/PLA and coconut fiber/PLA composites, respectively. The flexible epoxy surface treatment improved the impact property of the bamboo fiber/PLA and coconut fiber/PLA composites when compared to the untreated composites. Unlike the other combinations, treated vetiver grass fiber/PLA composite showed less improvement in impact strength when compared with the other natural fibers. Bamboo fiber proved to be the most effective reinforcement among all studied reinforcements.

Raghavan et al [113] evaluated the potential of super elastic shape memory alloy (SMA) fibers to enhance the damping capacity and toughness of a thermoset polymer matrix. A single-fiber winder was designed and built to manufacture a pre-form consisting of 102 lm diameter SMA fibers aligned parallel to each other. This pre-form was loaded to varying amounts of pre-strain and impregnated with vinyl ester to manufacture SMA fiber composites with 20% fiber volume fraction. The composites were tested using a Differential Scanning Calorimeter (DSC) and a Dynamic Mechanical Analysis (DMA), to evaluate the improvement in the damping capacity of the polymer matrix due to the SMA fibers. Tensile and instrumented
impact testing were carried out to evaluate improvements in the mechanical properties and toughness of the composites. Appreciable improvement was observed in damping, tensile, and the impact properties of the polymer matrix due to reinforcement with superelastic SMA fibers, highlighting the advantages of their use in polymer composites.

Enfedaque et al. [114] developed cementitious composite material made up of a cement mortar matrix and chopped glass fibers. Due to its outstanding mechanical properties, GRC has been widely used to produce cladding panels and some civil engineering elements. The impact failure of cladding panels made of GRC may occur during production if some tool falls onto the panel, due to stone or other objects impacting at low velocities or caused by debris projected after a blast. The impact failure of a front panel of a building may have not only an important economic value but also human lives may be at risk if broken pieces of the panel fall from the building to the pavement. Therefore, knowing GRC impact strength is necessary to prevent economic costs and putting human lives at risk.

One-stage light gas gun is an impact test machine capable of testing different materials subjected to impact loads. An experimental program was carried out, testing GRC samples of five different formulations, commonly used in building industry. Steel spheres were shot at different velocities on square GRC samples. The residual velocity of the projectiles was obtained both using a high speed camera with multiframe exposure and measuring the projectile’s penetration depth in molding clay blocks. Tests were performed on the young and artificially aged GRC samples to compare GRC’s behavior when subjected to high strain rates. Numerical simulations using a hydrocode were made to analyze which parameters were most important during an impact event.

GRC impact strength was obtained from test results. Also, GRC’s embrittlement, caused by GRC aging, has no influence on the GRC impact behavior due to the small size of the projectile. Also the, glass fibers used in GRC production only maintain GRC panels’ integrity but have no influence on GRC’s impact strength. Numerical models have reproduced accurately impact tests.
Masud Huda et al [115] reveal that natural/bio-fibers are replacing synthetic reinforcements traditionally used for the preparation of the environmentally friendly composites. Composite materials are also replacing conventional materials in various fields due to their ease of processability. Chopped glass fiber- and recycled newspaper cellulose fiber (RNCF)- reinforced poly(lactic acid) (PLA) composites were processed using a full size twinscrew extruder and an injection molder. Additionally, a glass-reinforced polypropylene (PP) composite was compounded and molded, and compared to PLA/RNCF and PLA/glass fiber composites. The tensile and the flexural moduli of RNCF- reinforced composites were significantly higher when compared to the virgin resin. The morphology, evaluated by scanning electron microscopy, indicated uniform dispersion of both the fibers in the PLA matrix.