CHAPTER 2

LITERATURE SURVEY

2.1 NATURAL FIBERS

The history of natural fiber reinforced polymer composites can be traced back to the advent of synthetic polymers in the early twentieth century. In 1850s, shellac was compounded with wood flour. Research on natural fiber composites has existed since the early 19th century but has not received much attention until late in the 1980's. During 1920s, 1930s and early 1940s, a good deal of research was carried out on natural fiber reinforced composites. Caldwell and Clay carried out their research work on natural fiber reinforced composites for lighter materials to be used in aircraft primary structures [31].

Composites, primarily glass but including natural reinforced composites are found in countless consumer products like boats, agricultural machinery and cars [32-34]. A major goal of natural fiber composites is to alleviate the need to use expensive glass fiber, which has a relatively high density and is dependent on non-renewable sources [32, 34].

Recently, car manufacturers have been interested in incorporating natural fiber composites into both interior and exterior parts. This serves a two-fold goal of the companies that is to lower the overall weight of the vehicle thus increasing fuel efficiency and to increase the sustainability of their manufacturing process [32]. Many companies such as Mercedes Benz, Toyota and DaimlerChrysler have already accomplished this and are looking to expand the uses of natural fiber composites.

2.2 CONSTITUENTS OF NATURAL FIBERS

Natural fibers primarily consist of cellulose, hemicelluloses, pectin and lignin (Figure 2.1). The individual percentage of these components varies with the different types of fibers. This variation can also be effected by growing and harvesting conditions.
Cellulose is a semi-crystalline polysaccharide and is responsible for the hydrophilic nature of natural fibers. Hemicellulose is a fully amorphous polysaccharide with a lower molecular weight compared to cellulose. The amorphous nature of hemicellulose results as partially water soluble and partially alkaline soluble solutions [34, 35]. Pectin, whose function is to hold the fiber together, is a polysaccharide like cellulose and hemicellulose. Lignin is an amorphous polymer but unlike hemicellulose, lignin is comprised mainly of aromatics and has little effect on water absorption [36, 37].

Cellulose, the most widespread organic molecule on Earth, is the major component of plant cell walls. Plants produce approximately 50 kilograms of cellulose daily for each person on Earth. It is a linear polymer made up of 10,000 to 15,000 glucose molecules bonded with glycosidic linkages, which is made with entirely of glucose. Cellulose molecules contain many polar hydroxyl groups, which allow them to interact with adjacent molecules to form fibers. These fibers are structurally strong and
resistant to chemical attack. Therefore wood products are widely used in construction and production of paper [39]. The various chemical constituents of specific natural fibers also vary considerably [40-45].

2.3 REVIEW OF NATURAL FIBER COMPOSITES

Han-Seung Yang; Douglas J. Gardner [46] have used Nano-sized cellulose fillers (cellulose nanofiber [CNF], microfibrillated cellulose [MFC]) and a micron-sized cellulose filler microcrystalline cellulose [MCC]) as fillers in polypropylene (PP) composites. They manufactured Cellulose-filled PP composite samples and examined morphological properties of fracture surfaces at different filler loading levels after mechanical testing. Scanning electron microscopy analysis results showed polymer stretching as the major component causing plastic deformation in fracture surfaces of CNF- and MCC-filled composites, whereas analysis of MFC-filled composites exhibited brittle deformation. They found considerable agglomeration beyond 6 wt% filler loading, and composites sustained considerable tensile and flexural strength up to 10 wt% filler loading, whereas tensile and flexural strength of MCC-filled composites were found to decrease continuously.

Chandramohan, D. and J. Bharanichandar[47] made their effort to utilize the advantages offered by renewable resources for the development of composite materials based on polymer and particles of natural fibers for conservation of natural resources. In their research, natural fibers like Sisal (Agave sisalana), Banana (Musa sepientum) and Roselle (Hibiscus sabdariffa), Sisal and banana (hybrid), Roselle and banana (hybrid) and Roselle and sisal (hybrid) are tried with bio epoxy resin using molding method. In their paper the optimum mixing of fiber and resin was achieved by using Taguchi method, and they have worked on tensile and hardness of Sisal and banana (hybrid), Roselle and banana (hybrid) and Roselle and sisal (hybrid) composite at dry and wet conditions.

Lawrence T. Drzal, A. K. Mohantyand M. Misra [48] reviewed Natural/Bio-fiber composites as emerging viable alternative to glass fiber reinforced composites
especially in automotive application (Table 2.1). The combination of bio-fibers like Kenaf, Hemp, Flax, Jute, Henequen, Pineapple leaf fiber and Sisal with polymer matrices from both non-renewable and renewable resources was tried to produce composite materials that are competitive with synthetic composites with special emphasis on biofiber-matrix interface and novel processing methods [Figure 2.2].

Natural fiber reinforced polypropylene (PP) composites have attained commercial attraction in automotive industries because synthetic fiber – PP or polyester composites are not eco-friendly due to the petro-based source as well as non-biodegradable nature of the polymer matrix which will solve many environmental issues. They had also stated that the main advantage of using renewable materials is that the global CO$_2$ balance is kept at a stable level.

An article by Ing. Eva Akova [49] explains the recent developments on natural fiber reinforced polymer composites and experiments on polyester composites with hop fibers. He prepared two sets of composites one with 20gram and other with 45gram hop fibers and both were tested for their mechanical properties. He had concluded that both the samples produced similar properties with required industrial applications.

![Figure 2.2: Relative merits of natural fiber and glass fiber composites](image)

**Figure 2.2: Relative merits of natural fiber and glass fiber composites**

**Courtesy: CRC for Advanced Composite Structures**
The major car manufacturers like Volkswagen, BMW, Mercedes, Ford and Opel now use natural fiber composites in their applications [50].

**Table 2.1: Vehicle manufacturers and use of natural fiber composites (50)**

<table>
<thead>
<tr>
<th>Automotive manufactures</th>
<th>Model Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMW</td>
<td>Door Panels, Head Linear Panels, Seat Backs, Noise insulation panels, Moulded foot well lining.</td>
</tr>
<tr>
<td>AUDI</td>
<td>Seat backs, Sides, Door Panels, Spare tyre lining.</td>
</tr>
<tr>
<td>MARCENDES-BENZ</td>
<td>Trucks, Internal Engine Cover, Engine Insulation, Sun Visor, Interior insulation, bumper, wheel box, roof cover.</td>
</tr>
<tr>
<td>VOLKSWAGEN</td>
<td>Golf, Passat, Bora,Door Panels, Seat Backs, Furnishing panels</td>
</tr>
<tr>
<td>TOYATA</td>
<td>Door Panels, Seat Backs, tyre Cover</td>
</tr>
</tbody>
</table>

An experimental study has been conducted by Punyapriya Mishra & S. K. Acharya [51] to determine the abrasive wear behaviour of bagasse fiber reinforced epoxy composite in different directions, namely parallel orientation (PO), anti-parallel orientation (APO) and normal orientation (NO) by using a two body abrasion wear tester. Three different types of abrasives wear behaviour have been observed in the composites in three orientations and they found to follow the following trends: WNO < WAPO < WPO, where WNO, WAPO and WPO are the wear in normal, anti-parallel and parallel directions of fibres orientation, respectively. SEM results of wear tested samples show that in PO type samples the abrasion takes place due to micro ploughing, whereas in APO and NO type samples wearing process may be due to micro cutting of the samples. They evaluated the relationship of wear anisotropy with load and grit size. They further suggested that the method can be further extended to hybrid composite structures.

Khairiah Haji Badri et al [52] incorporated different sizes of EFB (empty fruit bunch) fibers of oil palm in poly urethane matrix and compared the properties of the composites with that of control foam. They found that compressive strength increased
by 11.1%, 11.6% and 29.1% for the 45-56μm, 100-160μm and 200-315μm fibre size, respectively. The 45-56μm fibre size at 5.5% fibre loading showed the maximum compression strength and modulus. Micrographs of the cellular structure of the EFB-filled polyurethane foam showed that the presence of the fibrous EFB of size 200-315μm torn the cellular structure, whereas the powder form of EFB filled structures of the cellular network enhanced the strength of the cells' wall. The overall increase in the compression stress and modulus for the refined EFB-filled composites shows the ability of the filler either in fibre or powder form to impart greater stiffness to the composites. They also suggested that ligno cellulosic materials with high moisture absorption and low microbial resistance lead to limitation in properties that need to be considered and corrected.

2.4 REVIEW OFCOMPATIBILITY IMPROVEMENT STUDIES ON NATURAL FIBER COMPOSITES

Suwatthana Phrommedetch and Cattaleeya Pattamaprom [53] used the ashes of Rice husk and bagasse which were the prevalent industrial wastes from rice mills and sugar industries, respectively, as reinforcement in natural rubber. Since the surfaces of the ashes are hydrophilic, the compatibility with rubber is expected to be low. In their study, modification of natural rubber into maleated natural rubber (Figure 2.3) was proposed to improve the hydrophilicity of natural rubber and the compatibility with those agricultural waste and their reinforcing effects are compared to those of conventional reinforcing fillers, such as silica and carbon black. They had studied the effects of maleated rubber on degree of swelling, as well as, tensile strength of the rubber compounds. They found that the tensile strengths and moduli of maleated natural rubber composites filled with bagasse ashes were improved from those without maleic anhydride, together with lower degree of swelling. For rice husk ashes, even though their tensile strengths were comparable, the MNR composites gave significantly higher moduli than the composites of conventional natural rubber.
Figure 2.3: Tentative reaction between Maleic anhydride and Natural rubber during processing[53]

The results showed that the moduli of maleated composites using rice husk ashes and bagasse ashes as fillers were improved from the conventional composites. Nevertheless, the fact that MNR compounds still exhibited a long delayed onset of vulcanization compared to that of natural rubber, should be further improved.

M. Khalid et al [54] used maleic anhydride grafted polypropylene, MAPP (GR-205) as a coupling agent for the PP-cellulose (derived from oil palm empty fruit bunch fiber) and PP-oil palm empty fruit bunch fiber (EFBF) biocomposites. They prepared different sets of biocomposites by blending PP-cellulose and PP-EFBF at a fixed ratio of 70(wt%)/30(wt%) using brabender mixer at 180°C. MAPP was added at varying concentrations (2wt %, 3wt%, 5wt%, and 7wt%) during the blending. The effect of MAPP concentration on the mechanical properties such as tensile, flexural and impact strengths of both the biocomposites was studied. They found that 30 wt % filler (cellulose and EFBF) loading with 2wt% MAPP concentration gave the best results for the EFBF biocomposites. On the other hand there were no significant changes observed in the PP cellulose biocomposites properties on addition of MAPP. They also had stated that PP-cellulose biocomposite did not show significant changes in the mechanical properties indicating that the MAPP works well with the lingo cellulosic fibers. With the increase in the concentration of MAPP in the PP matrix above 2wt%
there is a substantial decrease in mechanical strength. They had also suggested that further testing should be done at still lower concentration of MAPP. They had concluded that, MAPP modified EFB fiber and PP matrix can be moulded into a value added and cost effective bio composite materials.

**Doaa I. Osman et al [55]** used kraft pulpas, a mechanical property modifier for the insulating oil–based polymer composites. They prepared an insulating oil which was blended with low density polymers [polyethylene (PE) and polypropylene (PP)] and Kraft pulp with different concentrations to manufacture composites. They determined the electrical properties (dielectric constant, energy loss and power factor) and mechanical properties (hardness and tear factor) for each blend. The addition of polymer (polyethylene and polypropylene) to the composite improves the electrical properties and hardness of the composites.

**Mohd Shahril Ezuan Mustapa [56]** had reported about the effects of coupling agent and impact modifier on the mechanical properties of polypropylene rice husk composites. They used both Ethylene 1-octene copolymers (EOC) and maleic anhydride grafted polypropylene (MAPP) as the impact modifier and coupling agent respectively. These compounds were melt blended using twin screw extruder and then injection moulded into standard test samples. They observed improvement of 35% in flexural strength with the addition of 4wt% of MAPP into the composites with 30wt% rice husk.

In many of the studies PP, Cellulosic fibers and MAPP pellets or powders are added in situ into twin-screw extruder and compounded at 200°C [61]. There is no conclusive or direct evidence of ester links between fibers and maleated polypropylene. There is no strong reason to assume that the anhydride groups on maleated polypropylene may have played a role on the strength of the properties of composites.

**Muhammad Yasina et al [57]** have produced medium and high density fiber boards from rice wheat straw fillers, binders like amino and phenol formaldehyde resins and adhesives such as poly isocyanate. This study will help in efficient utilization of
wheat and rice straw as an alternate resource for the industrial manufacture of particleboards and fiber boards. They had suggested that further research is required to make progress in utilization of wider range of lingo cellulosic raw materials for composites and in technologies of their economic manufacturing to eliminate the question of availability of feedstock. Such research should particularly concentrate methods to improve the surface activation of refined ligno-cellulosic material to reduce the water absorption and to improve mechanical strength of fiber boards.

![Diagram of Manufacture of Straw Medium Density Fiber board](57)

According to Huda et al. [58] the flexural properties of the PLA composites were significantly higher as a result of reinforcement by wood fiber in the matrix material. Compared with those of the neat resin the incorporation of WFs gave rise to a considerable increase in the storage modulus and a decrease in the tan \( \delta \) values, in DMA analysis and increase in the heat deflection temperature of the composites.

In another similar study based on PLA/silk fiber biocomposites by Cheung et al. [59] the mechanical and thermal properties of a silk fiber/PLA biocomposite were studied. The tensile property test revealed that the modulus of elasticity and ductility of the biocomposite were substantially increased to 53% and 39% respectively as compared with neat PLA. In the morphological studies using SEM analysis there is good interfacial bonding between the silk fibers and PLA matrix, which reflects that there is good wettability of the resin during injection and extrusion processes.
Ramakrishna Malkapuram et al [60] had reviewed on various natural fiber reinforced polypropylene composites. They had explained the mechanism of reaction between maleic anhydride co-polymer composites, which in turn can be divided into two steps; first step is the activation of copolymer by heating, preceded by the esterification of cellulose, leading to better wettability and interfacial bonding.

Suarez et al. [61] studied the mechanical and morphological behaviour of composites prepared from PP with MAPP and saw dust coated up to 22.4 wt% MAPP. The tensile properties of composites with up to 10% MAPP have not improved. This was attributed to the poor filler/matrix adhesion. The addition of MAPP content to the PP composites produced better adhesion of saw dust to PP matrix and an increase in the tensile strength. SEM was performed to analyse the tensile fracture surfaces and the interfacial fiber/matrix adhesion.

2.5 REVIEW OF HYGROSCOPICITY OF NATURAL FIBER COMPOSITES

All the cellulose derivatives are hydrophilic in nature; hence all the natural fibers absorb moisture. Usually moisture content in natural fibers varies between 5 wt%-15 wt%. Reinforcement of these natural fibers into the polymer matrix will decrease the mechanical strength and lead to the variation in dimensional stability. Therefore before incorporating these fibers as reinforcement they should be properly processed, dried and stored at the optimum temperature condition.

Sisal and coconut coir reinforced epoxy composites were subjected to water immersion tests and the effects of water absorption on their mechanical properties were studied by Girisha et al [62]. The percentage of moisture uptake increased as the fiber volume fraction increased because of the high cellulose content of the fiber. The tensile and flexural properties of natural fiber reinforced epoxy composite specimens were found to decrease with increase in percentage moisture uptake. Moisture induced degradation of composite samples was observed at elevated temperature. The water absorption pattern of these composites at room temperature was found to follow Fickian behavior, whereas the water absorption properties at higher temperature did not follow Fick’s law.
Pradeep Upadhyaya et al [63] studied the effect of water absorption on mechanical properties of hybrid fiber reinforced polypropylene composites. These hybrid filler (wood flour and wheat husk)-polypropylene composites specimens containing 30% and 40% fiber weight were prepared by melt blending process. Water absorption tests were conducted by immersion of specimens in distilled water at room temperature for different time durations (24h, 48h, 72h, 96h, 120h, 144h, 168h, 192h). The tensile, flexural and impact properties were investigated before and after water absorption.

To determine the moisture pickup of aspen fiber/polypropylene composites Roger M. Rowell [64] and his co-workers made several different levels of aspen fiber (30% to 60% by weight) polypropylene composites both with and without the addition of a coupling agent (maleic anhydride grafted polypropylene, MAPP). These composites were tested using short and long term water soaking, boiling water, cyclic liquid water and oven drying, and under various relative humidity conditions. It was observed that as the level of fiber increases, the rate and extent of thickness swelling and moisture sorption increased as compared to pure polypropylene. But the presence of MAPP decreased the extent of swelling and moisture pickup. This may be due to the increase in compatibilization resulting from more contact between hydrophilic fiber and hydrophobic plastic. Further, they reported that moisture absorption in fiber-thermoplastic composites leads to dimensional instability and biological attack.

A similar study with polypropylene/sisal fiber (SF) composites using a pre-coating technique was conducted by C.P.L Chow et al [65]. In their research work the composite specimens were subjected to hot water immersion treatment at 90°C for different durations. The effects of the immersion treatment on the tensile and impact fracture characteristics were investigated. The apparent weight gain and weight loss curves were drawn. It was found that both the tensile modulus and tensile strength of the SF/PP composites decreased continuously with increasing water immersion time. On the contrary, the Izod impact strength increased initially with immersion treatment. After reaching the maximum impact strength, it was found to decrease with further increase in immersion time. These contradictory behaviours between the tensile and impact properties were explained by the plasticization of the SF/PP interface and the swelling of the reinforcing sisal fibers.
2.6 SURVEY ON BIODEGRADATION IN POLYMERIC COMPOSITES

Synthetic polymers play a vital role in day to day activity and also in many branches of industry especially in packaging industry. But, they have an undesirable influence on the environment and cause problems with waste management. Thus, there is a need to substitute such polymers with polymers which can be degraded easily. Therefore, there is an increasing interest for developing biodegradable polymeric materials and composites. Biodegradable materials degrade into biomass, carbon dioxide and methane. In the case of synthetic polymers, microbial utilization of its carbon backbone as a carbon source is required [68].

The biodegradation process can be divided into two types

- **Aerobic biodegradation:**
  - \( \text{Polymer} + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} + \text{biomass} + \text{residue(s)} \) (1)

- **Anaerobic biodegradation:**
  - \( \text{Polymer} \rightarrow \text{CO}_2 + \text{CH}_4 + \text{H}_2\text{O} + \text{biomass} + \text{residue(s)} \) (2)

![Figure 2.5: Polymeric biodegradation under aerobic and anaerobic condition [69]](image)

Behjat et al [70] had studied the biodegradation on several blends of cellulose derived from bast part of kenaf (Hibiscus cannabinus) plant, with different thermoplastics like low density polyethylene (LDPE) and high density polyethylene (HDPE), prepared by a melt blending machine. It was observed that biodegradability of
the bio-composites made up using PEG was superior to those of the bio-composites fabricated without PEG, due to the improved wetting of the plasticizer in the matrix polymer. The results were also supported by the scanning electron microscopy (SEM). It had been suggested that the successful biodegradability test can be continued with more percentage of cellulose and PEG; however, it may weaken the mechanical properties of the composites.

Starch grafted polyethylene (PE), was successfully synthesized by graft copolymerization method using benzoyl peroxide as the radical initiator by Inderjeet Kaure et al [71] and its biodegradation studies were carried out by soil burial test. Microanalysis of the soil containing the samples was carried out after a specified number of days. An increase in the colonies of microorganisms with increasing number of days was observed. Effect of degradation of the grafted samples buried in soil and urea enriched soil on the growth of plants was studied and it was found that the plants grow normally in the soil containing the grafted material. Specification was made that the synthesis of starch grafted polyethylene will be beneficial in making best use of polyethylene without the risk of environmental pollution as clear from the consistent growth of plants.

Polyvinyl alcohol / corn starch blend films were prepared using the solution casting method by N. A. Azahari, N. Othman and H. Ismail [71] and the biodegradability of the films was investigated based on enzymatic absorbency in water and acidic solution as well as by burial in soil and compost. The tensile properties were also examined. Film structure was characterised by scanning electron microscopy. Compared to film without corn starch, the films containing corn starch were found to be more highly biodegradable by enzymes as well as in soil and compost. However, the results from the tensile and elongation at break tests showed that strength decreased as the corn starch content increased. The morphology study revealed the distribution of corn starch in the polyvinyl alcohol.

Hee-Soo Kim et al [73] carried out experiments on the biodegradability of bio-flour filled biodegradable poly (butylene succinate) (PBS) bio-composites in natural and compost soil. The percentage weight loss and the reduction in mechanical properties of
PBS and the bio-composites in the compost soil burial test were significantly greater than those in the natural soil burial test. The biodegradability was enhanced with increasing bio-flour content.

Sanjay K. Nayak et al [74] studied the degradation and flammability behaviour of PP/banana(BF) and glass fiber based composites. Further, BFPP composites exhibited higher degradation tendency as compared to the virgin polymer as well as the hybrid composites. Extent of biodegradation in the irradiated samples showed increased weight loss in the BFPP samples thus revealing effective interfacial adhesion upon hybridization with glass fibers.

Kh. Mumtahenah Siddiquee et al [75] focussed their study towards the fabrication of jute polymer composites, biodegradation and the investigation of an optimum method of biodegradation. Polyethylene and Polypropylene were reinforced with 5wt%, 10wt% and 15wt% of fiber. Degradation behaviour of composites was studied in terms of percentage weight loss.

- It was found that degradation rate follows the sequence of:
  - Compost > Weather > Soil burial
- Compost show better degradation rate because of following reasons
  - Microorganism accelerates the degradation process.
  - Controlled environment.
  - Temperature

2.7 OUTCOME OF LITERATURE SURVEY

Most of the research works on natural fiber composites have been carried out with thermosetting plastics because of easy processing methods and few with thermoplastics [8, 15]. Further polyolefin, especially polyethylene and polypropylene are produced in larger quantities in India and utilised for packaging applications leading to
the generation of more consumer waste. Therefore thermoplastic polyolefin, especially polypropylene (PP) was chosen as a matrix material in the present work.

With respect to the reinforcement material only few works have been reported on corn husk and sea weeds as reinforcing filler with PP, and hence this was chosen as a reinforcing material in the present study and the effect of these fillers on various properties of polypropylene composites are also studied.

Literature reported with respect to banana fiber are mostly based on the stem fiber, which can be extracted easily but the banana fruit trunk part was thrown away after harvesting the riped banana fruits. In the present study the fibers derived from the fruit trunk part was used as another source of reinforcing material for the polypropylene composite. Further, there is a large gap in the findings with respect to coffee grounds residue as reinforcing filler, which was also chosen for the present study.

2.8 SCOPE AND OBJECTIVES OF THE PRESENT RESEARCH WORK

- Utilization of biodegradable agricultural waste such as corn husk, sea weeds, banana fiber and spent coffee ground in the development of composites.
- Choice of polypropylene as the matrix material for preparation of the composites because of its huge commercial availability.
- To evaluate and report the efficient processing methods and their relationship with varying percentages of filler as reinforcement.
- To study the characteristics of polypropylene composites in terms of various physical parameters essential for their acceptance as marketable products.
- To study the effect of reinforcing fillers on the biodegradation of polypropylene composites.
Scientific objectives

- To find out the percentage composition of moisture, ash, fat, protein and carbohydrate content present in the reinforcing fillers by chemical testing methods.

- To determine the different functional groups present in the reinforcing fillers used for reinforcement, by using FTIR analysis.

- To develop polypropylene composites with varying weight percentages of reinforcing fillers using extruder and mould them into standard test specimens.

- To determine and evaluate the mechanical, thermal and morphological characteristics of the composites developed.

- To study the moisture resistance of the composites by water absorption test.

- To carry out biodegradation behaviour of the composites by aerobic standard composting conditions as per ASTM D 5338 method.

The present work is divided into nine chapters including introductory chapter (Chapter 1), survey of literature (Chapter 2), chapter explaining experimental theme of the work (Chapter 3), results and discussion with respect to four different fillers (Chapter 4, 5, 6 and 7), biodegradation study (Chapter 8) and conclusions (Chapter 9) as per the prescribed format.

Chapter 1 gives a brief introduction about polymer composites and their classification, properties, applications, advantages and disadvantages and its problems after end use. It also discusses about raise in attention towards natural fiber composites which had gained importance as commodity plastic and recent advancements in polymer composites and their new challenges and opportunities.

Chapter 2 presents a detailed literature of natural fiber composites, its hydrophilic nature, innovative modifications required to improve their compatibility of
natural fiber with polymer matrices. Subsequently, outcome of literature survey, the scope and objectives of the present work are also discussed.

**Chapter 3** gives the materials and methods for the determination of composition of fillers, development of composites and characterization techniques such as physiochemical methods FT-IR, water absorption, thermal properties (DSC and TGA), mechanical properties (tensile strength, modulus, percentage elongation at break, impact strength and hardness) and morphological properties.

**Chapter 4** discusses the development and characterisation of corn husk polypropylene composite by varying the weight percentages (10wt%, 20wt% and 30wt%) of corn husk into the PP matrix. This was done to find out the effect of reinforcing filler content on the bio-composites in the absence of compatibilizer (or) coupling agent. The tensile properties are found to be decreased when compared to that of neat polypropylene due to the weak interfacial bonding between the matrix and the fiber. The thermal, water absorption and morphological structure of polypropylene/corn husk composites are analysed using TGA, DTA and SEM analysis. A comparative aspect of reinforcement into polymer matrix and composition of filler is explained based on the results obtained from FT-IR analysis.

**Chapter 5** presents the development of seaweed polypropylene composite by varying the weight percentages (10wt%, 20wt% and 30wt%) of reinforcing filler into the PP matrix. Two different non edible seaweeds (red and brown seaweed) were utilized in the present study. Comparative aspect of reinforcing filler content was explained using mechanical, thermal and morphological properties. Functional group present in the seaweed composite and that of neat polypropylene were compared using FT-IR analysis.

**Chapter 6** deals with the development of untreated and treated banana fruit stem fibercomposites. The chapter presents the effect of chemical treatment on the developed bio-composites. The bio-composites were characterized and tested for FT-IR, DSC, TGA, tensile strength, impact strength, hardness, and water absorption
analysis with reference to neat polypropylene matrix. The homogeneous dispersion of reinforcement in polypropylene was studied through SEM analysis.

Chapter 7 illustrates the development of new type of particulate bio-composite with spent coffee grounds residue. Compounding of the matrix with filler and compatibilizer (MAPP) was carried out in two steps, one with constant reinforcing filler and varying compatibilizerto optimize the percentage of compatibilizer and the other with varying reinforcing filler percentage, to find the effect of filler content on the bio-composites. Mechanical, thermal, morphological of both the composites have been analysed and enumerated. Effect of compatibilizer on the interface has been evaluated and discussed. Morphological studies have been reported and discussed.

Chapter 8 enlightens the influence of coffee ground filler and banana fiber on the biodegradation of polypropylene composites through soil burial method. Further ASTM D (5338-98) was adopted to study the aerobic biodegradation under controlled compost conditioning method for both banana fiber and coffee grounds composite (30wt%). The results were reported graphically with reference to the positive standard (Cellulose). SEM analysis reveals the extent of biodegradation.

Chapter 9 presents the comparative summary and conclusions of all the preceding Chapters.