Chapter 2

LITERATURE REVIEW

2.1 EFFECT OF COMPATIBILIZER/ TITANATE COUPLING AGENT ON MECHANICAL PROPERTIES OF RICE HUSK POLYPROPYLENE (RHPP) COMPOSITES

2.1.1 RHPP Composites with Maleic Anhydride Polypropylene Compatibilizer (MAPP)

Compatibilizers are used to improve the interfacial adhesion between the hydrophobic polymer and hydrophilic filler. Coupling agents such as silane, titanate and zirconate are also effective. MAPP has been in wide use for improving the bonding between plastics and lignocellulosic materials.

Surface of rice husk was modified by maleated polypropylene and γ-amino propyl triethoxy silane. Both chemicals modify the rice husk surface through chemical reactions forming the strong ester and ether bonds. Surface modification of rice husk improves interfacial adhesion between rice husk and polypropylene [Fabbri et al., 2004]. Size reduction of rice husk was done by dry grinding and steam explosion. Samples were examined by X-ray photoelectron spectroscopy and Fourier transform infrared spectroscopy (FTIR) spectroscopy. Maleic anhydride polypropylene (MAPP) and amino propyltriethoxy silane (APS) were used to improve the bonding. Process of dry grinding give particulate segments, while steam explosion separate husk into fibrous components. Silane treatment result an increase in Si/O ratio for dry ground husk surface, whereas this ratio decrease for steam exploded rice husk. Ester and ether bonds were found in MAPP and APS treated husks. Method of preparation of rice husk particles has effect on interfacial adhesion between rice husk and thermoplastic matrix [Park et al., 2004].

Effect of maleic anhydride polypropylene (MAPP) on abrasive behavior of jute fiber reinforced polypropylene was studied. Improvement in wear resistance was observed in the composites by studying the surface microstructures of worn surfaces [Chan and Dwivedi, 2006]. Mechanical and morphological properties of
Rice husk polypropylene composites were studied by varying compatibilizing agent percentage (1, 3 and 5 wt%). There was increase in tensile strength by addition of compatibilizer without modifying the impact strength. Better interfacial bonding between rice husk and polypropylene by use of compatibilizer was verified by morphological tests [Yang et al., 2007].

Polypropylene can be reinforced by kraft pulp and coupling agent used was phenyl isocyanate, unblocked and phenol blocked derivatives of 4, 4′-methylenebis phenyl isocyanate (MDI). No significant change in mechanical properties of composites with different iso cyanates was noticed. Compared with mono reactive iso cyanates, use of MDI improve mechanical properties of pine fiber polypropylene composites considerably. DSC study shows slowing effect of MDI on crystallization kinetics of coupled composites due to mechanical anchoring onto the fiber surface [Gironès et al., 2008].

2.1.2 Rice Husk Polypropylene Composites without Compatibilizer

With the growing need of biodegradable materials, thermoplastics composites based on lignocellulosic materials (rice husk, wood flour, bagasse etc.) were developed. Popularly known as Green Composites, these materials are lower in cost, less abrasive, and have good mechanical properties. Initial attempt for the use of rice husk as filler in plastics was made in 1988 by using polyester resin [Chand et al., 1988]. Rice husk was used in polypropylene up to 40% for making composites. Yang et al., 2004 studied the tensile strength and impact strength of polymer composites by addition of rice husk. Decrease in tensile strength and impact strength was observed, however tensile modulus showed a positive trend due to lower elongation.

2.1.3 Rice Husk Polypropylene Composites with Titanate Coupling Agent

Modification of CaCO₃ was done by titanate coupling agent for improving interaction (chemical bonding). Photo acoustic spectroscopy (PAS) study indicates that interaction take place beneath the surface of CaCO₃ particles rather than on surface [Abu-Zeid et al., 1985]. Titanium dioxide was treated with titanate coupling agents containing caprate and lower carboxylates. Viscosities measurement was carried out by dispersing in di octyl phthalate. Lower the pKₐ of carboxylic acid of
titanate, lower is the viscosity of corresponding dispersion. Introduction of orientation of titanate onto the powder surface is helpful in understanding viscosities of dispersion by FTIR test [Mamoru et al., 1990].

Coupling agents such as titanate (LICA 38), zirconate (NZ 44) and silanes (PROSIL 2020 and PROSIL 9234) were used to reinforce rice husk ash (RHA) with polypropylene. Rice husk was used up to 40%, and processed on twin screw extruder. Better flexural modulus with higher rice husk loading was noticed in the composites whereas tensile strength, elongation at break and Izod impact strength decreased for most composites. PROSIL 2020 coupling agent increase the tensile strength whereas impact strength were enhanced by LICA 38 and PROSIL 9234 coupling agents [Fuad et al., 1995]. Mechanical properties of TiO$_2$ filled epoxy composite by use of silane and titanate were compared. Titanate modified composite have better Young's modulus and flexural strength than silane modified. Improvement in mechanical properties was observed due to strong interfacial bonding between filler and matrix. Scanning electron microscopy revealed better dispersion of surface modified filler particles and strong bonding between filler and matrix [Hussain et al., 1996].

Polypropylene was reinforced with short glass fiber mats, and mechanical properties were studied by using silane, N-β (N-vinylbenzylaminethyl)-γ-aminpropytrimethoxy silane hydrogen chloride (STS), and titanateisopropyl triisostearoyl titanate (TTS) coupling agents. Composite prepared with STS have better flexural strength and flexural modulus but TTS decrease the flexural strength and flexural modulus. When mixture of coupling agents was used, better impact absorption energy was found without reduction in flexural strength. Morphological study of fracture surfaces of composites was helpful in understanding interfacial phenomena of fracture surface of composites [Nam and Jyongsik, 1998]).

Polycarbonate (PC) was reinforced with potassium titanate by using methyl tri methoxy silane and tetra butyl ortho titanate coupling agents. No influence on thermal stability of PC was studied by addition of methyl tri methoxy silane. Glass transition temperature (T$_g$) and 5% weight loss temperature (T$_{5\%}$) of PC reinforced with tetra butyl ortho titanate were much lower than methyl tri ethoxy silane based PC. Use of methyl tri methoxy silane shift T$_g$ and T$_{5\%}$ to lowest temperatures. A synergistic effect between methyl tri methoxy silane and potassium titanate was noticed in degradation of PC during compounding process [Jiang and Tjong, 1999]. LICA 12
titanate coupling agent from Kenrich Petrochemicals was used to reinforce talc filled polypropylene. There was decrease in melt viscosity of filled PP by use of titanate. It was found that polypropylene (PP) molecules undergone chain scission and has broader molecular weight distribution (MWD). Plasticizing effect in the composites lowers tensile and flexural properties of composites.

Better impact and elongation properties were observed in the composites by incorporation of coupling agent [Leong et al., 2000]. Polyester was reinforced by plant fiber, which was acetylated and modified by coupling agents such as γ-methacryloxy propyl tri methoxy silane or neo pentyl (diallyl) oxy tri (dioctyl) pyro-phosphate titanate. Acetylated fiber exhibit superior bio resistance followed by silane. Both un modified and modified titanate composites showed considerable loss in tensile and impact properties [Khalil and Ismail, 2000]. Calcium carbonate is widely used filler with polyolefin matrix to decrease the cost. Formation of large agglomerates in the polymer matrix was seen which affect the mechanical properties of composites considerably.

Coupling agents such as Lica 09, Lica 01, zirconates ZN 12, and 1:1 mixture of Lica 12 and Lica 01, were used in blend of PP/high density polyethylene (HDPE) (80/20 wt ratio) with filler percentage up to 30%. These coupling agents improve mechanical properties of PP/HDPE/CaCO₃ composites, and each one is responsible for the specific action. Lica 01 improve Young’s modulus (0.7 wt%) and elongation at break at various concentrations (0.3 and 0.7 wt%), ZN 12 results higher elongation at break. Considerable improvement in impact strength was observed with mixture of Lica 12 and Lica 01 (1:1) [González et al., 2002]. Kraft pulp was used in polypropylene for making composites by using coupling agents such as MAPP and poly ethylene imine (PEI). PEI degrades the cellulose to form new chromospheres, whereas no noticeable discoloration was observed in composites modified with MAPP [Orden et al., 2007].

2.1.4 Rice Husk Polypropylene Composites with Silane (and others)

Coupling Agents

Wood fiber can be used with cement for making the composites. Surface treatment of wood fiber with coupling agents gives reinforcing effect with higher fracture energy and flexural strength [Coutts and Campbell, 1979]. Addition of coupling agent results better dispersion of filler in polymer matrix with higher
rigidity. Pyrolysis gas chromatography (PGC) and FTIR techniques are very useful in studying interaction of silane with inorganic fillers [such as Mg(OH)₂ and CaCO₃]. PGC study showed that chemisorbed amount of silane increase with time and temperature [Yang et al., 2003]. Microstructure and dielectric behavior of epoxy/BaTiO₃ composites was studied with silane coupling agent. Mixing process was facilitated by diluting the epoxy resin in tetra hydro furan solvent. Methoxy silane was applied onto ceramic particles and films were prepared by dipping technique. Resulted films have good dielectric properties and are strongly dependent on silane concentration [Ramajo et al., 2007].

Polypropylene was modified with an organo silane coupling agent and filler used was wood flour. Composites were also coupled by maleic anhydride, which was prepared in the laboratory. It was found that silane has higher reactivity towards PP chains. Better interfacial adhesion between fibers and polymer matrix was noticed with silane modified composites compared with maleated polypropylene coupled composites[Nachtigall et al.,2007]. Hydroxyapatite/biopolymer interface interactions were studied with three polymers: polyethylene (PE), polyamide (PA) and poly lactic acid (PLA) for biomedical applications. The interactions of polymers on hydroxyl apatite (HA) crystallographic planes (0 0 1), (1 0 0) and (1 1 0) by use of silane was examined. It was found that HA (1 1 0) has highest binding energy with these polymers because of its higher planar atom density than that of HA (0 0 1) and (1 0 0). Use of silane increases binding energy between PE and HA, but not for PA/HA and PLA/HA systems [Zhang et al., 2009].

Glass flakes were used as reinforcement in polypropylene and effects of amino silane and titanate was studied on mechanical properties of composites. Glass flakes modified with amino silane resulted higher stiffness compared with titanate modified. Residual stresses in polymers were studied by thermal expansion hysteresis. Ultrasonic velocity measurements are effective in assessing the various surface treatment processes responsible for promoting interfacial adhesion [Broughton et al., 2010]. Bonding between cellulose and polypropylene can be improved by adding poly ethylene imine (PEI) as a coupling agent. Higher tensile strength and elongation at break results due to formation of imine and amide bonds in interfacial region of composite [Orden et al., 2007]. Rice husk surfaces were modified by steam and sodium hydroxide (NaOH) treatments. Surface functional groups properties were evaluated by using the phenol formaldehyde (PF) resins.
Improvement in the interfacial bonding of rice husk and resin was revealed by higher modulus of elasticity. Higher steam temperature results in better mechanical properties in composite. Untreated rice husks exhibit higher thermal stability compared with NaOH treated rice husk. Degradation of rice husk by concentrated NaOH decreases its thermal stability [Ndazi et al., 2007].

Wood plastic composites (WPCs) are the promising materials which contain plant fiber and thermoset/thermoplastic as matrix. Biobased composites thus prepared have better mechanical strength, good acoustic performance, low density, reduced fuel consumption, passenger safety and shatter proof performance under extreme temperature conditions required for automobile applications [Ashori, 2008].

2.2 EFFECT OF PROCESS PARAMETERS ON MECHANICAL PROPERTIES OF RICE HUSK POLYPROPYLENE (RHPP) COMPOSITES

Plastics are widely used for making bio composites by utilizing lignocellulosic materials such as wood flour, rice husk, jute, coir and sisal and bagasse [Satyanarayana et al., 1990]. Natural fibers reinforced polypropylene (PP) composites were made by compression molding technique. Kenaf, hemp and sisal based composites have comparable tensile strength and modulus but hemp outperforms kenaf in impact strength. Tensile modulus, impact strength and ultimate tensile stress of kenaf reinforced composite increase with fiber weight fraction. Coir fiber based composite have lowest mechanical properties but better impact strength than jute and kenaf based [Wambua et al., 2003]. Rice husk polypropylene composites were prepared and compatibilizer/coupling agent was used to improve adhesion between rice husk and polymer. Use of compatibilizer/coupling agent improves tensile strength but impact strength show no positive result with higher coupling agent/compatibilizer loading [Yang et al., 2004, 2007].

2.2.1 Effect of Addition of Fillers on Properties of Rice Husk Polypropylene Composites

Effect of various fillers such as magnetite, talc, glass fibers and strontium ferrite on cooling behavior of polypropylene was studied on an injection molding machine. Cooling curve has different merging sections affected by pressure, and
thermal diffusivity of materials. Thermal diffusivity of composite is dependent on alignment of filler and interconnectivity of filler particles. Thermal diffusivity is highest for talc filled PP (30 vol%) but shortest cooling time was observed for copper filled PP (35 vol%). Strong anisotropic properties of talc filled PP allow to design composite with predefined maximum heat flow capability to transport heat in a preferred direction [Weidenfeller et al., 2005].

2.2.2 Effect of Various Processes on Properties of Rice Husk Polypropylene Composites

Effect of electron beam treatment was studied in making wood fiber reinforced polypropylene composites. Beam creates active sites on polymer matrix and improvement in mechanical properties (modulus of elasticity, flexural strength and tensile strength) and thermal tolerance of composites was compared with conventional wood fiber PP blends, and PP [Czvikovszky, 1996]. Thermoplastic composites can be prepared by water-assisted injection molding technology. Reciprocating injection molding machine was used for short glass fiber filled polypropylene composites. Processing parameters such as short shot size and water injection delay time were critical in affecting properties of composites. Composites prepared by water assisted injection molding have lower cycle time than molded by gas assisted injection molding. Glass fibers in molded parts are oriented in flow direction of polymer melt in water injection molding process [Liu and Chen, 2004]. Effect of processing method and fiber size on the properties of wood reinforced plastic composites was studied. Fibers of different length to diameter (L/D) ratios were used and processed by injection and extrusion processes. Composite prepared by injection molding have better mechanical properties and lower water absorption than made by extrusion process.

L/D ratio of fiber has positive effect on mechanical properties and water absorption characteristics [Migneault et al., 2009]. Composite samples prepared by twin screw extruder have better tensile strength and hardness than single screw extruder but Izod impact strength is independent on the type of process. Scanning electron microscopy (SEM) show better dispersion of rice husk in composites prepared by twin screw extruder [Yang et al., 2006]. Polypropylene and high density polyethylene (HDPE) were reinforced with curaua fibers and processed on twin screw extruder. Higher screw speed of extruder lowers the aspect ratio of fibers resulting
lower reinforcing effect. PP based composites are less affected by screw speed than HDPE based [Mano et al., 2010].

2.2.3 Effect of Process Conditions/Parameters on Properties of Rice Husk Polypropylene Composites

Effect of casting pressure was studied on mechanical properties of wood fibers based portland cement. Higher casting pressure results better flexural strength of composites [Coutts and Warden, 1990]. Unidirectional (UD) and multidirectional (MD) polypropylene composites reinforced with flax, were prepared using maleic anhydride polypropylene (MAPP) compatibilizer. Boiled flax and flax with varying retting degree were used as reinforcement and influence of different process time and temperature on mechanical properties of composites was analyzed. Boiled flax combined with MAPP give best results in unidirectional composites. Contrary to UD composites, flax treatment does not improve the properties of MD composites [Velde and Kiekens, 2003]).

PP nano composites were prepared and effect of processing conditions on nano composites structure (intercalated or exfoliated) was observed. Lower processing temperature improves apparent melt viscosity and shear stress of polymer. PP nano composites prepared with maleated compatibilizer have exfoliated structure and better mechanical properties [Modesti et al., 2005]. Wheat straw (WS)/recycled polyethylene (PE) was used in free isocyanate group (NCO) terminated urethane prepolymer (UPs) and cross linked by polymeric diphenyl methane diisocyanate. It was found that properties of composites such as internal bonding (IB) strength after being soaked in boiling water for 2 hr, modulus of rupture (MOR), modulus of elasticity (MOE) and 24 hr thickness of swell improve significantly with higher CA contents and composites densities [Wang et al., 2009].

For marine application, accelerated aging was performed on high density polyethylene (HDPE), by immersing in synthetic sea water at various temperatures (23 ± 3, 70 and 90°C). There was decrease in mechanical properties such as elastic modulus and tensile strength. Degradation of polymer was dependent on aging temperature and aging cycle (immersion duration) [Guermazi et al., 2009]. Highly oriented polypropylene (PP) tapes can produce self reinforced composites. PP tapes
have lower density, higher dimensional thermal stability with increasing draw ratio, and change appearance from transparent to opaque [Alcock et al., 2009].

Effect of process parameters such as pressure and temperature on mechanical properties of polypropylene–hydroxyapatite was studied in presence of silanated and unsilanated hydroxyapatites. Higher pressure improve density, crystallinity, melt flow index (MFI), ultimate tensile strength, and Young’s modulus. Parameters such as pressure and temperature have less effect on mechanical properties of silanated hydroxyapatite composites than unsilanated hydroxyapatite. Ductile to brittle fracture was seen with higher pressure and temperature in this process [Younesi and Bahrolololoom, 2009]. Curaua fibers were used to reinforce polypropylene (PP) and high density polyethylene (HDPE) matrices. Higher screw rotation speed (SRS) and aspect ratio of fibers result lower flexural strength and tensile strength of composites. PP composites are less affected by change in SRS compared with HDPE based [Mano et al., 2010].

Wood polymer composites can be oriented by drawing process. Composites with significantly better stiffness and strength were obtained by using soft and hard woods. Decrease in moduli of drawn filled composites was compared with unfilled polypropylene, but no change in specific moduli was noticed. Types of wood particles have marginal influence on mechanical properties of die drawn composites [Poleć et al., 2010]. Effect of injection molding parameters such as melt temperature, packing pressure, cooling time and injection pressure on the mechanical properties of acrylonitrile butadiene styrene (ABS) was studied. Mold of two different thermal conductivities was used in the experiment. Mechanical properties such as elasticity module, tensile strength and tensile strain at yield, tensile strain at break, flexural modulus and Izod impact strength (notched) were studied as per ASTM test procedures [Ozcelik et al., 2010].

Effect of temperature on mechanical properties of polypropylene-hydroxyapatite (PP–HA) biocomposites produced by hot press molding was studied. Effect of temperature and pressure on the mechanical properties such as ultimate tensile strength, Young’s modulus and impact strength was studied by using sensitivity analysis. Sensitivity of mechanical properties with respect to pressure is more than temperature in hot pressing process, tensile strength in particular [Younesi and Bahrolololoom, 2010]. Effect of addition of organo clay to polypropylene/ethylene
propylene diene monomer (PP/EPDM) blends was studied by characterizing the mechanical properties. Composites were processed by twin screw extruder and maleic anhydride grafted polypropylene was used as compatibilizer. Higher nano clay (NC) content and shear rate result better tensile strength and modulus in the composites. NC content does not affect overall impact strength, but it first increase with shear rate, then decrease [Hejazi et al., 2011].

2.3 EFFECT OF KAOLIN ON MECHANICAL PROPERTIES OF RHPP COMPOSITE

2.3.1 Kaolin with other Polymers

High density polyethylene (HDPE) can be modified by kaolin and bond strength, impact strength, shear modulus were studied. Morphological changes in polyethylene at volume and surface levels were observed with silane coupling agent when used with kaolin [Gähde et al., 1977]. Kaolin is used extensively as filler in paper industry and improves appearance, smoothness, brightness, opacity, and printability of paper. Decrease in strength of coated and filled paper was observed with decrease in particle size of filler. Higher coating void volume decreases the strength [Bundy and Ishley, 1991]. Poly vinyl acetate (PVAc) films were prepared by using surface treated CaCO₃ fillers. Acid base interaction affects calcite dispersions and mechanical properties in PVAc matrix. Elongation at break and tensile strength of the composites are dependent on filler quantity, dispersion quality and adhesion at polymer/filler interface [Kovaevi and Ceroveki, 1997].

Blend of polypropylene (PP) with virgin and recycled high density polyethylene (r-HDPE) (80/20) was prepared with functionalized and non-functionalized ethylene propylene rubber (EPR). Calcium carbonate (30 wt%) was used (untreated or treated) along with titanate coupling agent. Mechanical studies of PP/HDPE/EPR blends show that functionalization was not effective. Blends of PP/HDPE/EPR with treated or untreated filler were compared with recycled HDPE reinforced with untreated filler. Slight increase in elongation at break but lower Young’s modulus and impact strength were observed in the composites. It is due to the action of recycled HDPE and EPR as a plastifier in these blends. Treated calcium carbonate does not improve the mechanical properties of composites.
Recycled HDPE can be used with PP and non functionalized EPR (nf-EPR), with untreated calcium carbonate filler [Albano et al., 2000]. Polymer composites can be prepared by using epoxy resin matrix and silicon carbide (SiC) filler particles. Mechanical properties were studied by micro hardness measurements. Hardness value increase from 210 to 640 MPa with increases in SiC volume percentage from 7 to 45 [Krumova et al., 2001]. Rheometry, spectroscopic analysis and relaxation time are useful in studying structure and molecular dynamics of calcium carbonate filled low density polyethylene (LDPE). With addition of filler, increase in rigidity but decrease in mobility in its crystalline regions took place. Use of filler makes crystal structure less perfect and reduces size of crystallites [Nowaczyk et al., 2004]. Recently, there is greater emphasis on utilization of layered silicate and carbon nano tube reinforced polymer nano composites.

Filler aspect ratio, particle size, particle/matrix interface adhesion and particle loading affect the stiffness, strength and toughness of composites [Fu et al., 2008]. Difference in properties of organic and inorganic materials (compatibility, chemical reactivity, surface properties, and coefficient of thermal expansion), lead to weaker bonding between them. Adhesion promoters, or coupling agents modify the interface between an organic polymer and an inorganic filler chemically and physically to form strong cohesive bond. Adhesion promoter not only alters physical and chemical forces at the interface but act as glue to improve the adhesion. Organo silane coupling agents are very effective as adhesion promoters. Other methods such as oxidation and abrasion of the inorganic substrate were used to increase bonding surface area between the materials [Myer, 2011]. Poly tetra fluoro ethylene (PTFE) was reinforced with ultrafine kaolin particulates and tested by a reciprocating tribometer under pressure of 7.5 MPa. Increase in the friction coefficient and wear resistance of the composites was compared with unfilled PTFE [Xiang and Gu, 2006].

Flame resistance of low density polyethylene (LDPE)/ethylene propylene diene rubber (EPDM) blends was improved by using nano-kaolin and nano-HAO (hydroxyl aluminum oxalate). Both materials exhibit excellent synergistic effects on flame retardancy of LDPE/EPDM blends. It was studied that use of nano-HAO mainly affects degradation of composites chemically. It was further studied that nano-kaolin mainly affects the transfer process physically by aggregating with nano-HAO [Chang et al., 2007]. Natural rubber (NR) was reinforced with kaolin modified with
sodium salt of rubber seed oil (RSO-Na) and its effect on physico mechanical properties of vulcanizates was examined. Tensile strength and tear resistance of composites increase with filler loading, but optimum results were achieved at 8 phr (part per hundred part of resin) of modified kaolin. Higher storage modulus was observed with modified kaolin with reduction in swelling index. At 8 phr of modified kaolin, higher cross liked density, better reinforcement, and improvement of failure properties of NR vulcanizates was observed [Yahaya et al., 2009].

Stiffness of styrene butadiene solid rubber modified with kaolin powder was studied and is related with yield stress of kaolin dispersion in liquid poly butadiene. Kaolin powder dispersed in solid rubber matrix, acts as an additive which reduce random movement of poly butadiene chains [Lagazzo et al., 2010]. Natural rubber (NR) was reinforced by silane modified kaolin (SMK), precipitated silica (PS) and their mixed compound additions (SMK + PS). On characterization, it was studied that kaolinite particles were finely dispersed into natural rubber and arranged in parallel orientation. Resultant composite have outstanding mechanical properties, excellent gas barrier properties and higher thermal stability. Gas barrier properties of composite modified with SMK and PS was better than PS modified. Decrease in nitrogen permeability of NR/SMK composite by addition of kaolin took place. Significant improvement in properties was possible due to parallel kaolinite particles which restrict free movement of rubber chains and retard diffusion of gas molecules [Zhang et al., 2010].

2.3.2 Kaolin with Polypropylene

Rice husk polypropylene composites can be modified by kaolin and processed by compression molding process [Prasad et al., 1991]. Use of mineral fillers in thermoplastics enhances the mechanical properties but lower impact strength. Ultrafine fillers were surface treated with stearic acid or cationic treatment with quaternary ammonium in suspension. Higher impact strength was obtained with quaternary ammonium due to better particle dispersion in matrix and finer crystalline structure as studied by thermal analysis [Mareri et al., 1998]. Four different types of kaolin (K₁, K₂, K₃ and K₄) from various origins were used. Kaolinite is the principal mineral in kaolin but other minerals like Illite, Muscovite and Quartz are also present in small quantity. Thermal study indicates that Mullite is first formed at a temperature
as low as 1100°C [Ghorbel et al., 2008]. Mechanical and thermal properties of polypropylene modified with kaolin were studied by using 3-(trimethoxysilyl) propyl methacrylate as a coupling agent. Kaolin polystyrene particles were synthesized via in situ polymerization and have better mechanical and thermal properties due to better dispersion of kaolin in PP matrix [Zhao et al., 2011].

### 2.4 EFFECT OF VARIOUS ADDITIVES ON MECHANICAL PROPERTIES OF RICE HUSK POLYPROPYLENE (RHPP) COMPOSITES

#### 2.4.1 Talc modified Rice Husk Polypropylene Composites

Polypropylene (PP) was reinforced with talc and mechanical properties were studied. Talc reinforced composites have higher stiffness, fracture toughness and yield stress was dependent on temperature and strain rate [Zihlif and Ragosta, 1991]. Varying percentage (up to 40 wt%) of talc was used to reinforce polypropylene and composites were processed by extrusion process. Silane was used as coupling agent to improve the affinity between filler and PP matrix. Configuration of crystalline phase of PP and nucleating activity of mineral was examined [Alonso et al., 1997]. Talc based polypropylene composites were injection molded using different processing conditions. Talc content or processing conditions do not affect the nucleation and thermal properties, except melt flow index (MFI).

Effect of processing conditions such as mold and melt temperature was studied. Densification of amorphous PP phase at high mold temperature, and improved homogenization at high melt temperature was observed in PP composites [Guerrica et al., 1998]. Titanate coupling agent was used to improve bonding between talc and polypropylene. It helps to reduce melt viscosity of filled PP but better dispersion was observed by use of coupling agent. Tensile strength and flexural strength decrease whilst impact strength and elongation improve by addition of coupling agent [Wahet et al., 2000]. Polypropylene (PP) was compounded with talc, rice husk and mechanical properties were studied. Increase in Young’s modulus and flexural modulus was studied, whereas yield strength and elongation at break decrease with increase in filler loading for both types of composite.
On comparing rice husk and talc based composites, it was found that rice husk based composite exhibit lower yield strength, Young’s modulus, flexural modulus, and higher elongation at break than talc based [Premalal et al., 2002]. Some of the disadvantages of polypropylene are poor stability to gamma (γ) irradiation, which may impede its growth in commercial use. Effect of talc and low dose γ irradiation on properties of composites was studied [Denac et al., 2003]. Polypropylene was reinforced with talc or calcium carbonate or hybrid fillers, and processed by injection molded process. Specimens were subjected to natural weathering for 6 months. There was deterioration in mechanical properties due to physical and chemical degradation in the composites. Hybrid filled PP composite have better retention of mechanical properties. Process of hybridization in hybrid filled PP increase resistance to severe environmental degradation despite the degradation of surface of composite [Leong et al., 2004].

Chicken eggshell (ES) is an industrial byproduct which contains 95% calcium carbonate. It was used as bio filler in polypropylene composites along with talc and calcium carbonate. Young’s modulus (E) of composite improves with ES content, as compared with all types of carbonate fillers. ES composites have lower E values than talc based. Better mechanical properties were obtained due to better ES/matrix interface related to geometric ratio of ES particles similar to talc particles [Toro et al., 2007].

2.4.2 Calcium Carbonate modified Rice Husk Polypropylene Composites

Mechanical properties of composites can be improved by enhancing interfacial adhesion which is dependent on area of interface and strength of interaction. Size of interface is related to specific surface area of filler, and strength of interaction on surface treatment. Polypropylene composites were prepared with various filler loadings by using tri alkoxy silane and stearic acid coupling agents. On comparison, it was found that use of amino functional silanes increase strength of interaction considerably, whereas stearic acid reduce surface tension of filler resulting decrease in tensile strength of composite [Demjén et al., 1998].

Calcium carbonate was used with polyolefin to decrease costs and its effect on mechanical properties was studied. Use of Lica 01 coupling agent increases the Young’s modulus at 0.7 (wt %). Lica 01 when used with Lica 12 increase the impact
strength of PP/HDPE blend considerably [González et al., 2002]. The influence of particle size and surface treatment of filler particles (with and without stearic acid) on impact strength of CaCO$_3$ polypropylene composites was studied. Prepared composites show higher modulus but lower yield stress with higher filler content. Differential scanning calorimetry study revealed that particle content and its size have no influence on melting temperature/thermal properties. Coating of stearic acid on particle surface has significant effect on impact strength due to better dispersion of CaCO$_3$ particles with polymer matrix. Therefore notched Izod fracture energy improves from 2 to 40–50 kJ/m.

The smaller particle sizes (<0.7 μm) and higher filler loading (>20 vol %), lower the toughening efficiency of the composites [Zuiderduin et al., 2003]. The internal friction and relative elastic modulus of polypropylene (PP) filled with nano calcium carbonate particles were studied in temperature range of 150°K – 400°K. The peak associated with glass transition and a small peak (α' peak) associated with pre melting process in crystalline parts of PP was observed around 290°K and 370°K, respectively. With increasing content of nano filler, apparent activation energy of α peak decreases, and after passing a minimum of 4.7 e.v. at 4 vol%, it increases. Peak temperature has a maximum of 289 °K at same filler fraction, and highest tensile strength, flexural strength of PP were obtained around this [Li et al., 2004]. Polypropylene (PP) was reinforced with calcium carbonate nano particles (5, 10 and 15 wt%) and samples were compression molded. Scanning electron microscopy (SEM) revealed that nano particles of CaCO$_3$ were dispersed uniformly but with a different level of coalescence. Parallel plate rheometer showed that rheological moduli of nano composites increase with nano filler concentration but this increase was greater in high frequency region. Further, complex viscosity of nano composites also increases with nano filler concentration. It was concluded that rheological behavior of nano composites is more sensitive to nano particle concentration at low frequencies [Karamipour et al., 2011].

2.4.3 Mica modified Rice Husk Polypropylene Composites

Mica is important filler in plastics with advantages of high modulus and low cost compared with glass flakes, clay, aluminum diboride and silicon carbide. It is a
platelet type material and full utilization of planar reinforcing properties of mica is in sheet materials [Maine and Shepherd, 1974]. Coupling of CaCO₃ with polypropylene (PP) can be improved by using amino functional silane coupling agents. Amino functional silanes bond strongly to surface of the filler. FTIR analysis demonstrated the oxidation of polymer at higher processing temperature. Carbonyl groups thus formed enter into chemical reactions with amino functionality of silane, which result in strong amide bonds [Demjén et al., 1999].

Poly urethane elastomers were reinforced with mica and alumina tri hydrate (ATH) and optimum amount of filler was analyzed for obtaining good mechanical properties. Properties such as tensile strength, hardness, abrasion resistance and flammability were studied to explore new applications of these composite materials [Pinto et al., 2001]. Mica was used in poly ether ketone ketone in combination with glass fiber for making composites. For composites with 30 wt% of total fillers, highest tensile strength was observed at filler containing 50 wt% of mica. Partial replacement of glass fiber by mica lowers the coefficient of friction and wearing rate of composites [Gan et al., 2001]. Nylon 6 nano composite was made by exfoliation of mica, potassium sericite (K⁺-SE), K⁺-SE was modified with dodecyl ammonium salt (DDA) by ion exchange process. Addition of small quantity of organically modified SE with 2.1 silicate (wt%) improve flexural strength and heat distortion temperature of nano composite. Degree of exfoliation, aspect ratio and dispersion homogeneity of silicate platelets determine the properties of nano composites [Uno et al., 2009].

2.4.4 Wollastonite modified Rice Husk Polypropylene Composites

The nature of stearic acid and poly methyl methe acrylate (PMMA) adsorption onto wollastonite has been studied from basic, neutral and acidic organic solvents. Maximum adsorption of stearic acid or PMMA take place with non polar solvent, and it decrease with higher acidity or basicity of solvent. Increased acidity or basicity of solvents leads to a monolayer or a fraction of monolayer coverage. Mechanical properties such as tensile strength and impact strength of stearic acid treated wollastonite are better when compared with untreated. Stronger interfacial bonding was seen between stearic acid and wollastonite [Rao et al., 1998]. Glass fiber can be replaced by natural fibers and wollastonite whiskers to reinforce polyester dough molding compounds.
Coupling agents used were neo pentyl (diallyl) oxy, tri (dioctyl) pyrophosphato titanate and gamma methacyloxy propyl tri methoxy silane. Wollastonite was used up to 50 wt % in an unsaturated polyester resin and showed positive result because of its micro structural features. It was found that sisal fibers (11 wt%) in wollastonite based polyester and glass fibers (3 to 5 wt%) in sisal wollastonite polyester give optimum results. Polyester dough molding compound with sisal/wollastonite gives satisfactory results in composites [Singh et al., 2003]. The strain rate sensitivity of polypropylene and wollastonite filled polypropylene was analyzed and found that both materials are strain rate sensitive resulting change in micro mechanisms of deformation and modes of fracture. Craze tearing and brittle mode of fracture was seen in polypropylene (PP), while wedge, ridge-tearing, fibrillation and brittle fracture were noticed in wollastonite based polypropylene [Dasari et al., 2004].

Tensile loading rate and evolution of microstructure during plastic deformation of isotactic polypropylene (PP), talc modified PP and wollastonite modified PP were studied. Both unreinforced and reinforced materials were sensitive to tensile loading rate (strain rate), change in micro mechanism of plastic deformation and mode of fracture. Plastic deformation in isotactic PP was characterized by craze tearing and brittle mode of fracture, while talc and wollastonite modified PP was characterized by wedge, ridge-tearing, fibrillation, and brittle fracture [Hadal and Misra, 2004]. Performance of wollastonite fiber and chopped glass fiber reinforced hybrid polypropylene composites was evaluated. The composite thus prepared has good mechanical properties, surface finish and low cost. Higher tensile, flexural, and impact properties in filled polypropylene were noticed compared with unfilled PP [Himani and Purnima, 2010].

2.4.5 Zirconium Oxide modified Rice Husk Polypropylene Composites

Zirconium oxide based aromatic polyamide composites were prepared by sol gel process. Thin cast films obtained were transparent, tough, and yellow in color. Gradual increase in tensile strength result with increase in zirconium content (up to 10%). Maximum strain at break point increases initially but decreases with further addition of zirconia. Glass transition temperature increases with zirconia content and thermal decomposition temperature of hybrid material was 450°C [Rehman et al., 1997]. α-Zirconium phosphate based poly vinyl alcohol nano composites were prepared by
solution casting method. With increase in loading of e-α-ZrP, tensile strength and elongation at break increase by 17.3% and 26.6% respectively. Optimum film properties were found at 0.8 (wt%) of e-α-ZrP. Mechanical and thermal properties of these composites were superior compared with unfilled material [Yang et al., 2009]. Ultrahigh molecular weight polyethylene (UHMWPE) was reinforced with zirconium, which has excellent corrosion resistance and biocompatibility. Samples were compression molded and zirconium (20 wt%) based composites show significant reduction in wear resistance compared with unfilled polymer while maintaining toughness. These composites are suitable for orthopedic applications [Plumlee and Schwartz, 2009].

2.5 CHEMICAL PROPERTIES OF RICE HUSK POLY-PROPYLENE (RHPP) COMPOSITES

2.5.1 Dissolution, Water Absorption and Mass Swelling of Rice Husk Polypropylene (RHPP) Composites

Dissolution of polypropylene in solvents depends on both polymer and solvent. Experimental conditions such as temperature and degree of stirring have effect on dissolution of PP. Rate of dissolution can be related with rate of penetration of polymer by solvent molecules [Blackadder and Poidevin, 1978]. Film samples of isotactic polypropylene were immersed in tetra chloro ethylene at temperatures (95°C-100°C) and dissolution of polypropylene took place in solvent. Solubility of polymer was dependent on crystalline, amorphous phases and various molecular weight fractions [Drain et al., 1983]. White rice husk ash (WRHA) was used with natural rubber (NR)/linear low density polyethylene (LLDPE) blends by using polypropylene ethylene acrylic acid (PPEAA) as a compatibilizer. Properties such as tensile strength, hardness, and mass swell were investigated. With higher loading of WRHA in NR/LLDPE blends, better tensile modulus and hardness was observed but decrease in tensile strength, elongation at break and mass swell was found.

With increase in compatibilizer content, higher tensile strength, hardness, and elongation at break results with lower mass swell [Ismail et al., 2001]. Increase in thickness swelling and water absorption of rice husk composites took place compared with wood based composites (particle board and fiber board) and solid wood. Mechanical properties of composites decrease with filler loading, but still composites
have an acceptable mechanical strength suitable for general purpose applications such as interior of bathrooms, wood decks, food packaging [Yang et al., 2006]. Chopped rice husk (CRH) up to 40% was used in polypropylene and processed on co-rotating twin screw extruder. Maleic anhydride was used as compatibilizer and mechanical properties, water absorption were studied. Increase in tensile strength and flexural modulus of composites was observed but with lower elongation at break and energy at break. Water absorption experiments showed an increase in diffusion coefficient with CRH loading [Nouri et al., 2006].

2.5.2 Effect of Chemicals on Rice Husk Polypropylene Composites

Use of high processing temperature in polypropylene results thermal oxidative degradation. Antioxidants such as 2,6-di-tert-butyl-4-methyl phenol (BHT) and 4,4'-di-“2-[(3,5-di-tert-butyl-4-hydroxy phenyl) methylene] hydrazine carbothioamido” biphenyl ether. 4,4'-di-“2-[(3,5-di-tertbutyl-4-hydroxy phenyl) methylene] hydrazine carbothioamido” biphenyl ether with 0.05% loading stabilize the polypropylene. Change in thermal (melt flow index, heat deflection temperature), and mechanical properties (tensile strength, impact strength, and flexural strength) was seen by addition of antioxidants [Raja et al., 1996]. Demixing pressure for polypropylene solutions in n-pentane was determined in temperature range (410 °K to 480°K). PP is completely miscible in n-pentane at pressures above 10 MPa.

It was studied that in presence of carbon dioxide, higher pressures are required for complete miscibility [Kiran and Xiong, 1998]. Methyl methacrylate (MMA) was grafted onto isotactic polypropylene (iPP) film by free radical polymerization by using supercritical carbon dioxide which acts both as solvent and swelling agent. Grafting level and morphology of product can be controlled by soaking time, pressure and concentrations of MMA and benzoyl peroxide in the fluid phase [Liu et al., 2002]. Introduction of chlorine atoms and sulfoxide groups into polyethylene bring it to elastomers nature over a wide temperature range. Presence of these groups introduces vulcanization which brings reversibly deforming, solvent resistant properties in the products. It is also possible by means of chemical reactions, to lose their viscoelasticity of polymer so that it becomes thermoplastic at ambient temperature [Halasa et al., 2005].
Rice husk surface can be modified by steam, sodium hydroxide (NaOH) treatment and mechanical properties were studied by bonding with phenol formaldehyde resin. Composite prepared with untreated and ground rice husks were compared. It was found that NaOH treatment improve the interfacial bonding as revealed by an increase in modulus of elasticity. Although steam treatment does not change the outer surface functional groups, still an increase in mechanical properties of composite was observed. Thermal stability of untreated rice husk was better than treated rice husk [Ndazi et al., 2007]. Polypropylene was reinforced with palm and coir fibers and processed on single screw extruder and injection molding. To improve compatibility, fibers were treated with benzene diazonium salt. Higher mechanical properties of treated fiber reinforced composites was noticed compared with untreated composites. Coir fiber composites has better mechanical properties than palm fiber based [Haque et al., 2009].

Effect of storage aging and acid immersion on tensile strength, flexural strength, modulus of elasticity and elongation at break of E-glass fiber reinforced polyester was studied. Storage aging reduces the tensile strength, flexural strength, modulus of elasticity and elongation at break of the plastic samples. When dipped in HCl, storage aged samples show decrease in mechanical properties due to degradation of fiber/matrix interfacial bond [Bagherpour et al., 2009]. Polypropylene was reinforced with abaca, which was chemically treated with benzene diazonium salt. Tensile strength of both raw and chemically treated abaca based PP composites decrease with higher filler content. Scanning electron microscopy (SEM) analysis revealed better interfacial bonding between treated filler and matrix [Rahman, 2009]. Coir filled polypropylene composites were prepared and chemically treated with o-hydroxy benzene diazonium salt. Chemically treated coir composites have better mechanical properties than untreated ones. Tensile strength of both raw and treated composite decrease with higher filler content [Islam et al., 2010]. High density polyethylene (HDPE) was reinforced with rice husk which was modified to improve the compatibility. Mercerization of rice husk was carried out with NaOH solution, followed by acetylation. Better adhesion of rice husk with polymer matrix results in higher flexural strength and impact strength of composites [Fávaro et al., 2010].
2.6 THERMAL PROPERTIES OF RICE HUSK POLYPROPYLENE (RHPP) COMPOSITES

2.6.1 Melting Behavior/Degradation of Rice Husk Polypropylene Composites

Crystallization behavior of polypropylene was studied by differential scanning calorimetry. Multiple fusion endotherms were obtained and this phenomenon was dominated by crystal imperfections at lower crystallization temperatures ($T_c \leq 400^\circ K$). On heating, crystallized fraction undergoes reorganization resulting crystals of greater degree of perfection (which melt at higher temperature). At higher crystallization temperatures ($T_c > 400^\circ K$), inbuilt defects in molecular chain dominate and multiple endotherms exits due to presence of crystalline species with different degrees of crystal disorder [Yadav and Jain, 1986]. Differential scanning calorimetry (DSC) was used to study melting behavior of oriented isotactic polypropylene, when extruded in solid phase. With extrusion ratio greater than four, two melting peaks were observed.

Lower temperature peak shift to higher temperatures with increase in extrusion rate as studied in DSC test. These peaks present in melting zone of crystalline species have different degrees of crystal disorder [Yadav and Jain, 1987]. Dilatometric study was utilized to study crystallization and melting behaviors of stereo block isotactic polypropylene (iPP). It was studied that chain microstructure plays significant role in melting behavior and related with crystal thickness [Candia and Russo, 1991]. Pyrolysis of polypropylene was carried out in wide temperature range (45°C – 580°C). Data obtained confirm to a first-order fit at temperatures of less than 404°C with activation energy of $98.3 \pm 3.1$ kJ/mol. At higher temperatures, the data again fit the pseudo first order reaction with an activation energy of $327.9 \pm 8.6$ kJ/mol. Lower activation energy obtained at lower temperatures was due to scission of weak links in the polymer. Higher activation energy was associated with random scission throughout the polymer [Chan and Balke, 1997]. Thermal degradation studies of poly vinyl chloride (PVC), polyethylene terephthalate (PET), and low density polyethylene (LDPE) was carried out to study the liquefaction temperature. Thermal degradation of single polymer was different when compared with mixture of polymers. Presence of swelling agent such as tetralin has influence on the degradation rate and product distribution [Murty et al., 1996].
Thermal analysis and Fourier transform infrared spectroscopy (FTIR) were used to study kinetics and mechanisms of thermal degradation of polymers. Thermal degradation of PMMA was initiated by a mixture of chain ends and random chain scission initiation, followed by depolymerization. Pre-oxidation of polymer on storage at room temperature leads to random scission. At higher temperatures, reduction in molecular weight was due to depolymerization of ends of polymer chain. Thermal degradation of PMMA produces char, amount of which increases with increase in concentration of end groups and temperature [Holland and Hay, 2001]. Thermal analysis and Fourier transform infrared spectroscopy were used to study thermal degradation of polyethylene terephthalate (PET), polyethylene isophthalate and polydiethylene glycol terephthalate, prepared in laboratory. It was found that diethylene glycol and isophthalate units present in polyester promote the thermal degradation through higher chain flexibility and favorable bond angles. There was formation of non-volatile residue on degradation which contains interconnected aromatic rings [Holland and Hay, 2002(a)]. Thermal degradation of polyvinyl acetate was studied by thermal analysis and fourier transform infra-red (FTIR). Elimination of acetate groups increase with the process of degradation and was dependent on concentration of unsaturated groups in polymer chain.

Additional process of elimination was activated by double bonds adjacent to acetate unit in polyvinyl acetate [Holland and Hay, 2002(b)]. Thermal decomposition of natural fibers such as wood, bamboo, agricultural residue, and bast fibers was studied by dynamic TGA. Approximately 60% of thermal decomposition in most fibers occurs from 215°C to 310°C. Apparent activation energy was in the range of 160-170 kJ/mol for most of selected fibers throughout the processing range [Wu et al., 2008]. Thermo gravimetry (TG) and differential scanning calorimetry techniques are very useful in studying catalytic degradation of low and high density polyethylene. Catalysts used were based on transition metals supported on zeolite Y and results were compared with pure materials. Transition metals such as vanadium, zirconium and nickel, supported on NaY or HY have different degrees of efficiency. These catalysts promote the degradation process of polyethylene with varying efficiencies [Coelho et al., 2010]. Thermal analysis techniques were helpful in studying degradation of pure polymers such as polyethylene, polypropylene, polystyrene and poly methyl metha acrylate in different atmospheres. Rate constants
based on the sum of several temperature dependent first order processes were calculated by thermo gravimetry and compared with several heating rates.

Propagation of oxidation and depolymerization to monomer explain the differences in kinetic behavior of examined polymers [Rychlí et al., 2011]. Thermal behavior of two biodegradable aliphatic polyesters such as poly propylene azelate [PPAz] and poly propylene sebacate [PPSeb] was studied by thermo gravimetric analysis (TGA). PPAz has its highest decomposition rate at 411.3 °C, while PPSeb at 413.6 °C. Decomposition of both polymers took place, mainly through β-hydrogen bond scission and α-hydrogen bond scission as studied by mass ion detection method. Decomposition products such as aldehydes, alcohols, allyl, diallyl, and carboxylic acids were obtained [Chrissafis et al., 2011].

2.6.2 Thermal Properties of Rice Husk Polypropylene Composites

Differential scanning calorimetry (DSC) is an important tool to study thermal behavior of polymers. Measurement of specific heat, glass transition temperature, melting, crystallization characteristic and thermal stability was possible by this instrument [Ghijsels and Waals, 1980]. Thermo gravimetry and differential thermal analysis is very useful in understanding the thermal stability of poly vinyl chloride [Manley et al., 1985]. PVC/cis-PBR blends modified by PBR in 0–50 wt% were studied for thermal properties. Thermo gravimetric analysis of blends indicates that all blends are more stable than PVC and stability increase with PBR content. Three parameters namely threshold degradation temperature (D_T), temperature at which rate of degradation was highest (D_M) and glass transition temperature (T_g) were measured to study the thermal stability [Naqvi and Sen, 1991]. Thermo gravimetric and differential scanning calorimetric analysis was carried out for flax and hemp fibers. Good thermal stability was required for consolidation process of composite materials [Wielage et al., 1999].

Effect of blend ratio, crosslink level and initiating system was studied on thermal degradation of natural rubber/polystyrene (NR/PS) interpenetrating polymer networks (IPNs). The thermo gravimetric analysis (TGA) shows better stability of IPNs compared with pure components. There was improvement in initial decomposition temperature and temperature for 50% decomposition (T_{50}) with increase in concentration and cross linker level of plastic phase. Better mechanical
strength of IPNs aged for 72 hr at 100°C was noticed due to cross linking on post curing [Mathew et al., 2001]. Thermal characteristics of polypropylene/polyethylene (PP/PE) blend were studied by thermo gravimetric analysis (TGA) and differential scanning calorimetry (DSC). DSC test is valuable for analyzing melting and crystallinity behavior of blend, whereas TGA for degradation study. An empirical relationship can estimate the overall crystallinity percent from blend ratios and densities of pure components. Calculation of crystallinity by this method eliminates graphical integration process on determining areas under curves of thermograms.

Effect of temperature on induction time of PP/PE blend was studied, and it follows the trend of Arrhenius equation [Wong and Lam, 2002]. Synthesis and processing conditions affect structure of thermoplastic polyurethane (TPU) elastomers. Quality deviations observed from one production to another, influence the structure of material in batch process. Synthesis and process conditions can control the properties of TPU. Melting behavior and residual crystallinity after processing depend on stoichiometry and processing conditions as studied by DSC study [Frick and Rochman, 2004]. Polypropylene was reinforced by layered silicate (montmorillonite) with MAPP as compatibilizer and thermal properties were studied. Composites show tactoid, intercalated and exfoliated structures side by side with different dominant states which depend on type of clay and processing conditions. System behaves as multi component blends rather than binary blends because organic ions not only change the mixing behavior, but affect the material properties also [Tidjani et al., 2003]. Thermo gravimetric analysis (TGA) was used to study thermal behavior of liquefied wood (LW) with low density polyethylene (LDPE), high density polyethylene (HDPE), and polypropylene (PP) composites. HDPE based composites have better thermal stability than PP based. Melting temperature of polymers decrease with increase of LW loading. Enthalpy of virgin polymers decreases by addition of LW [Doh et al., 2005].

Microscopic and macroscopic properties of thermoplastic polyurethane (TPU) samples in hard and soft segments were analyzed. Higher glass transition temperature and lower angle of rebound result with increase in hard segment content at the same molecular weight soft segments. Higher molecular weight of soft segment at same content of hard segments reduces glass transition temperature and angle of rebound [Voda et al., 2006]. Five samples of poly vinyl chloride (PVC) were obtained at
different polymerization temperatures and influence of microstructure on thermal degradation behavior was studied. TGA study was used to detect two independent weight loss steps in dehydro chlorination process. Syndio tacticity tendency of PVC was seen due to relative contribution of these two steps [Gonzalez et al., 2006].

Polypropylene was reinforced with fully exfoliated montmorillonite (MMT) and thermo oxidative/thermal stability was studied by DSC and TGA methods. Weight loss from TGA and enthalpy changes from DSC in a temperature range (from room temperature to 500°C) was noticed. Thermal degradation of polypropylene nano composites in oxygen free atmosphere was strongly inhibited up to temperature of 420°C in contrast to pristine polypropylene which degrades at 300°C. Lower sensibility to thermal oxidation of nano composites was correlated with lower oxygen permeability which results from an increased diffusion path for oxygen as well as volatile decomposition products [Golebiewski and Galeski, 2007].