

Comparative Analysis of Polymer Matrix Composites processed by Injection and Compression Molding

Sukhjinder Singh Sandhu^a and Ramandeep Singh^b,

^a Assistant Professor, Department of Mechanical Engg, S. B. S. S. T. C., Ferozepur, 152004, INDIA

^b Assistant Professor, Department of Mechanical Engg, S. B. S. S. T. C., Ferozepur, 152004, INDIA

ABSTRACT

Natural fibers are potentially a high-performance and non-abrasive reinforcing fibres source. Coir fibers are a byproduct derived from coconut fruit. Coir fibers are an agricultural waste extracted from the outer shell of coconut fruit and are abundantly available in southern India. In this study, mechanical properties of short coir fiber reinforced polypropylene composites fabricated by compression and injection molding process are examined. These were chopped to a length of 2-5 mm. The effect of fiber loading on the tensile and flexural properties of compression molded composites is evaluated and results indicate that there is no significant improvement with the addition of fibers from 3 to 15%. Whereas, injection molded specimens (PP/(15) Coir) have shown 58.75% and 25.82% increase in tensile and flexural strength respectively, compared to neat PP. The tensile and flexural modulus of injection molded composites also increased by 47.42% and 58.84% respectively as compared to neat PP. Hence, the tensile and flexural properties of the developed composites clearly indicate towards injection molding as a better fabrication process for short fiber reinforced composites compared to compression molding.

Key words: Sphere; Tangential Stress; Creep; Pressure Ratio.

1. Introduction

The use of natural fibers as reinforcement in composites is increasing day by day due to its best mechanical properties in the industrial area. Even though, there is a very large variety of fibers, matrices and manufacturing techniques used to produce natural fiber composites (NFC's).

1.1 Materials

Design and development of sustainable materials require the scientists and engineers to think beyond what constitutes the best material for any application. Now-a-days, due to depletion of natural resources, environmental responsiveness, economic considerations, and important technology breakthroughs, engineers are interested in proper utilization of renewable resources.

The knowledge of the structure of materials and their properties, which has been established over 150 years, has now empowered the engineers to design a variety of the materials with different characteristics. Therefore, various materials have been designed with desired properties, which meet the needs of our modern and complex applications, which also include alloys, plastics, glasses, and fibers.

Generally, solid materials are divided into three basic groups: metals, ceramics, and polymers. This classification is based on the properties (chemical, physical and mechanical etc.) and atomic structure, and mostly materials fall into one distinct group or another, yet there are also some intermediates, which are generally termed as alloys or composites.

The main purpose of the matrix is to bind the reinforcement together so that there can be proper bonding between the matrix and the raw material used. The matrix properties determine the resistance of Polymer Matrix Composites to most of the degradative processes that eventually cause failure of structures. These processes include impact damage, de-lamination, chemical attack, water absorption, and high-temperature creep. Thus, the matrix is typically the weak link in the Polymer Matrix Composite (PMC) structure. The matrix phase of commercial Polymer Matrix Composite can be classified as either thermoset or thermoplastic.

Classification of Polymer Matrices

1. Thermoset

2. Thermoplastic- crystalline and amorphous.

1.2 Composite Material

Composites are the intermediate materials made up of two or more distinct materials. Which are combined in such a way that it allows its constituents to remain distinct and identifiable. The main purpose of composites is to allow the developed materials to have properties of both the constituents often times covering the original material weaknesses. Composite materials have many advantages over conventional materials due to its light weight, also they cheaper than the conventional materials [1].

Composites have two (or more) chemically or physically distinct phases on a microscopic level, separated by a distinct interface, so that these phases are identifiable. The constituent which is continuous and is often present in greater quantity in the composites, is termed the matrix. Composites may have a ceramic, metallic, and polymeric' matrix. It is generally harder, stronger and stiffer than the matrix material. So the composites are the combination of the matrix and the fiber, where the fiber makes the composites stiffest (rigid) in order to resist the load and the matrix act as a binder which holds the fiber in place [2].

Classification of Composite Materials based on reinforcement

Composites are mainly classified into three types, particle reinforced composites, fiber reinforced composites and flake reinforced composites [3]. Classification of the composite materials based on their type of reinforcement is shown in the Figure: 1.1

Based on various combinations of reinforcement and matrix used, composites are again classified as Metal Matrix Composites, Ceramic Matrix Composites, Carbon-Carbon Composites and Polymer Matrix Composites.

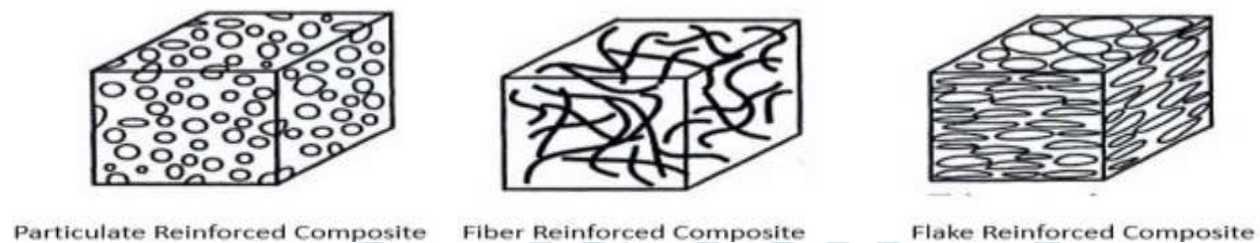


Figure 0.1: Diagram of classification of composites according to type of reinforcement used [3].

1.3 Polymer Matrix Composites

Polymer matrix composites consist of thermoplastic or thermoset matrix resins reinforced with fibers, which are much stronger and stiffer than the matrix. Polymer matrix composites are light in weight. Stronger, and stiffer than the unreinforced polymers, with the additional advantage of easy fabrication, suitable for mass production and their properties and form can be tailored to meet the needs of a desired application, which depends also on the manufacturing process. The properties of composite depend not only on the fiber reinforcements, but also on the polymer matrix. The characteristics of the interface between the fiber and the matrix, and the manufacturing process used to form the finished structure. The common fibers used are Glass fibers. Now-a-days particulated filler based polymer composites are in use, i.e. Carbon black, polymer nanocomposites and Graphene based.

As the cost associated with manufacturing of synthetic fibers is comparatively high, so use of natural fiber as reinforcement is increasing globally due to the cost, environmental and ecological aspects.

1.4 Natural Fibers

Fibers are small in diameters and their materials are generally polymers, natural or ceramics. Now these days there are two types of fibers used in engineering industries, first which are obtained from natural sources and some of which are made by man. In this research work short coir fiber is used (length 2-5 mm) in both injection and compression molding process.

- A) Fibers which are man-made are called man-made fibre. For Example- Glass Fibres, Aramid Fibres, Carbon fibres, Nylon, Acrylic etc.
- B) Fibres which are obtained from natural sources or are processed from natural sources are called natural fibres. For example- Hemp, Sisal, Cotton, Wool, Coir etc.

Table 0.1: Properties of natural fibres [4]

Properties	Unit	Coir	Flax	Hemp	Jute	Ramie	Sisal
Density	g/m ³	1.25-1.5	1.4	1.48	1.45	1.5	1.26-1.33
Diameter	µm	100-450	100	25	60	40-50	100-300
Cellulose content	%	36-43	62-72	67-75	59-71	68-76	60-67
Hemicellulose Content	%	0.2	16-18	16-18	12-13	13-14	10-13.9
Lignin Content	%	41-45	2-2.5	2.8-3.3	11.8-12.9	0.6-0.7	8-12
Microfibrillar angle	deg	30-45	10	6.2	7-9	7.5-12	10-20
Tensile Strength	Mpa	105-175	800-1500	550-900	400-800	500-870	600-700
Young's Modulus	Gpa	4-6	60-80	70	10-30	44	38
Elongation at break	%	17-47	1.2-2.4	1.6	1.16-1.8	1.2	3.64-5.12
Moisture Absorption	%	10	7	8	12	12-17	11

1.5 Synthetic Fibers

Synthetic fibers can be made from synthesized polymers or small molecules. The compounds that are used to make these fibers generally come from raw materials such as petroleum based chemicals or petrochemicals. The most commonly used synthetic fibers are Glass fibers, Carbon fibers, Aramid fibers and Basalt fibers.

Synthetic fibers are used due to their various properties, which are essentially required in engineering industries, i.e. Heat sensitivity, chemical resistivity, less degradability, Low moisture absorbency, electrostatic, flame resistance, high melting point and maintainability.

1.6 Injection Molding

Injection molding is a manufacturing process for producing parts by injecting a material into a mold at high temperature and pressure. Injection molding can be performed with almost any type of materials including metal, glass, elastomers thermoset and most common thermoplastic polymers. Material, generally in granule form, is fed into the hopper. Which goes to heating barrel by some mechanical means, mixed thoroughly in the barrel, then (breed into a mold cavity by mechanical or hydraulic means, where it cools and solidifies in the shape of the mold cavity).

Injection Molding Machine

With injection molding, granular plastic (pellets) is fed through a hopper into a heated barrel. As the granules are slowly pushed forward by a screw-type plunger, the plastic is forced into a heated chamber called the heating barrels where it is melted. As the plunger advances, the melted plastic is forced through a nozzle, allowing it to enter the mold cavity through a gate and runner system. The mold remains at a set temperature so the plastic can solidify almost as soon as the mold is filled.

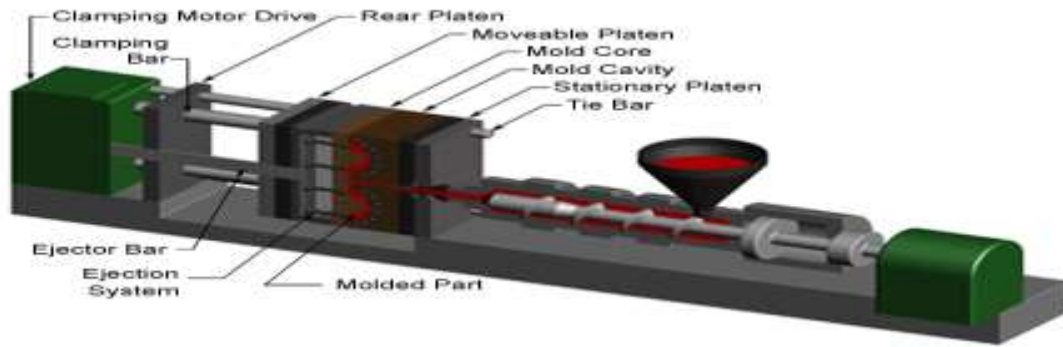


Figure 0.2: Basic structure of injection molding machine [38]

Salient characteristics of injection molding process

1. It's a closed molding process.
2. The process is suitable for both thermoplastic and thermosetting polymers based on the short fiber reinforced composites.
3. Best suitable for producing composites parts with high accuracy in size and shape.
4. Mainly suitable and more profitable for mass production of identical products in larger volume.

1.7.2 Injection Molding Cycle

The main stages of an injection molding cycle are the injection stage, which is followed by holding and plasticizing stage, and then the final stage that is the ejection of the molded part. After the completion of the third stage, the mold is closed and the cycle starts over again.

Stage 1: Injection stage

In this stage, the nozzle of the extruder is pushed towards the sprue bushing of the mold when the mold is closed. The screw, which is stationary in this stage, is pushed forward toward the nozzle so that the melt, which is in front of the screw, is forced into the mold cavity through the nozzle.

Stage 2: Holding and Plasticizing Stage

Once the mold is completely filled, then screw remains in its position and static for some time to keep the melt in the mold under pressure. This time, for which the pressure is applied, is called the "holding time" and applied pressure is termed as "holding pressure".

Stage 3: Ejection Stage

Once the melt in the mold sufficiently solidifies and able to retain its shape, mold plates opens and the part is ejected with the help of ejector pins. After ejection, the mold closes again and then the next cycle starts accordingly.

1.7 Compression Molding Machine

Compression molding process can be used for both thermoplastic and thermoset polymers. In compression molding machine, the base plate stay in a fixed position, but the upper plate is movable shown in Figure: 1.3. Reinforcement and matrix used are placed in the metal mold and the entire assembly is kept inside the compression molder. Heat and pressure is applied as per requirement of the composite for a definite period of time. The material placed in between the molding plates melts due to the application of pressure and heat and gets the shape of the mold cavity with the high dimensional accuracy which depends upon the mold design. Curing of the composite can be carried out either at room temperature or at some elevated temperature. After curing, the mold is opened and composite product is removed.

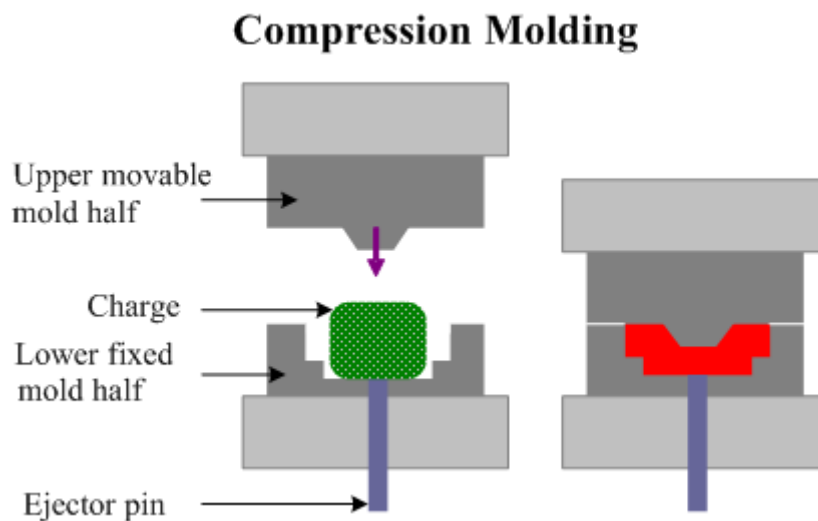


Figure 0.3: Basic structure of compression molding machine

Compression molding process involves the following steps-

- A pre-weighed amount of a polymer mixed with additives and fillers i.e. charge is kept in the lower half of the mold. A charge may be in the form of pellets, powders, sheet laminates etc. The charge is usually pre-heated prior to placement into the mold. Preheated polymer becomes softer, resulting in shortening the molding cycle time.
- Upper half of the mold moves downwards pressing on the polymer charge and forcing it to fill the mold cavity. Mold, equipped with a heating system provides curing of polymer (if thermoset is processed).
- The mold is opened and the part is removed by means of the ejector pin.

A number of processes can be used for the fabrication of composite products. But compression and injection molding processes are the two most important processes which are being used commercially. Therefore, the present experimental investigation aims at comparing the mechanical properties of composites fabricated by the two processes.

2.0 Literature Survey

Literature review gives us an idea that how we can think of the future proposed work, by reading the research done earlier. Therefore, our main objective is to find out the research gaps in the literature and opportunities for putting in research efforts. Also, the focus of this literature review is to establish a research ground based on experimental and scientific knowledge available in the area of polymer matrix composites.

Srinivasababu et al. [5] determined the tensile properties of various natural fiber reinforced composites. Different composites with okra, sisal and banana fiber were prepared by using hand lay-up method. **Debabrata Debnath [6]** presented his work on the development of polymer matrix composite (epoxy resin) using bagasse fiber as reinforcement using hand lay-up process with volume fractions 10%, 15% and 20% and to study its mechanical properties at cryogenic temperature. **Yosuff et al. [7]** studied the mechanical properties of short oil palm fibre reinforced epoxy composites in their experimentation. Empty fruit bunch (EFB) (with four different volume fractions of 5%, 10%, 15% and 20% vol) was selected as the reinforcement and epoxy as the matrix to fabricate the composite by hand lay-up techniques. **Rafeeq et al. [8]** carried an experiment on natural fiber extracted from the date palm tree and coconut shell particle filler were used as reinforcement for epoxy matrix composites. Epoxy composite specimens reinforced with date palm fibers, coconut shell particle filler, and date palm fibers/coconut shell particle filler hybrid respectively were fabricated by hand lay-up technique.

2.1 Thermoset Matrix Composites with Synthetic Fiber Reinforcement

Abdel-Magid et al. [9] examined the properties of an E-glass reinforced epoxy composite before and after mechanical loading and moisture conditioning. Results indicated that moisture and mechanical loading affects the mechanical properties i.e. modulus, strength, and strain of the composite material. When conditioning at room temperature for shorter durations, a slight increase in strength and a slight decrease in modulus were observed: but with conditioning for longer durations, reduction in strength was noticed. **Hasim Pihili [10]** studied the effects of resin content on the wear of woven roving glass fibre reinforced epoxy composites and glass fibre-polyester resin composite materials under dry conditions. Tests were conducted for two different speeds, at two different loads. The weight loss was measured and wear in the experiments was determined. **Lopresto et al. [11]** evaluated the possibility to replace glass fibres with Basalt fiber. Mechanical tests were carried out on laminates which were reinforced with E-glass and basalt fibre, which were fabricated through vacuum bag technology. The results obtained were compared and higher young modulus, higher compressive and bending strength, high impact force and energy were observed in Basalt based laminates. **Varga et al. [12]** developed and used new additives for enhancing the bonding properties between reinforcement and matrix and to get better characteristics

of glass fibre reinforced polyester composites. Two different reinforcements (chopped glass fibre and glass woven fabric) have been used and investigated. **Han et al. [13]** observed that strength is increased by 34.0% when carbon fibers are treated with the coupling agent. The result has shown that the by adding coupling agent, improvement in the compatibility and interfacial bonding between the reinforcement and matrix can be achieved.

2.2 Studies on Thermoplastic matrix and Natural Fiber Reinforcement

A lot of publications were made on injection molding of thermoplastics, using different reinforcements and different thermoplastic matrix, but the most work is done on Polypropylene (PP) and Poly Lactide (PLA). Referred to data available on scopus, out of 4494 papers published on injection molding of thermoplastics, 2895 papers are only with polypropylene. The main reason of using polypropylene as matrix material in most of the cases is its low cost, better mechanical properties and moldability, it also accounts for more than half of all the plastic materials used in automobiles and almost everywhere due to its recyclability too.

Yu Dong et al. [14] evaluated the mechanical, thermal properties and biodegradability of PLA/coir fiber bio-composites with and without alkali treatment. **Oksman et al. [15]** reported that flax fiber reinforced PLA composites with 30-40% reinforcement; strength was comparatively 50% higher than to flax reinforced polypropylene composites. An increase in the stiffness from 3.4 to 8.4 GPa was observed in the composite.

Shih et al. [16] used recycled fiber from disposable chopsticks with PLA as matrix to fabricate green composites by melt-mixing process. **Bajpai et al. [17]** compared the mechanical properties of various natural fibers with PLA as reinforcement which were fabricated by different processes. **Shibata et al. [18]** revealed the effect of injection temperature on thermal degradation and porosity of the bagasse reinforced polypropylene composites fabricated by injection molding process. It was observed that above 185°C, incomplete filling of cavity can occur and this incompleteness will increase with the increase of injection temperature. **Bledzki and Faruk [19]** experimented on wood fiber reinforced polypropylene composites fabricated by injection molding and compression molding process with hardwood and softwood fibers. An investigation was done on the influence of different processing parameters and additives on mechanical properties of the composites. **Akil et al. [20]** revealed that the tensile and flexural properties depend not only on the type, orientations, content and form of kenaf fiber in kenaf reinforced polymer composites but also on the type of blending/plasticizer used.

Murtuza and Akheel [21] made an attempt to use turmeric spent as filler to fabricate polypropylene green composite and it was observed that the tensile modulus of composites increased from 1041 to 1771 MPa with the increase in filler addition from 0 to 40 wt.%. Flexural properties of composites were also improved after reinforcement of turmeric spent into PP matrix. **Hemmati and Garmabi [22]** showed in

their experiment that the fire retardancy is another proficiency concern of the composites. Bagasse reinforced polypropylene composites were fabricated with additives including flame retardants, ultraviolet (UV) stabilizer, and antifungal and colouring agents. The addition of the flame retardant, which decomposed at high temperature could result in the NFC with a significant decrease in burning rate (up to 98%) compared to the composite without flame retardant. **Ochi [23]** also reported that the tensile and flexural strength increase linearly when fiber content is increased up to 50% in kenaf reinforced PIA composites, which proved that kenaf fiber exhibit higher mechanical properties as compared to other natural fibers, when reinforced with PLA. **Sawpan et al. [24]** worked on flexural properties of chemically treated random short and aligned long hemp fibre reinforced polylactic acid (PLA) and unsaturated polyester composites were also investigated over a range of fibre content (0-50 wt%). **Bledzki et al. [25]** made an experimental work on hard wood fibre reinforced polypropylene composites. The composites were fabricated by using various processes (Extrusion-injection molding, Mixer-injection molding, Compression molding and direct Extrusion) process with 30 wt. % and 50 wt. % fibre contents. It was observed by the experimentation that extrusion and injection molding process delivered the best mechanical and physical properties in maximum cases, when compared to other fabrication processes.

Samia Sultana Mir et al. [26] investigated the effects of fibre treatment and fibre contents on physico mech. properties of basic chromium sulfate (CrSO_4) and NaHCO_3 (Sodium hydrogen carbonate) salts treated coir reinforced Polypropylene bio-composites. For both raw and chemically treated coir reinforced Polypropylene composites, the tensile strength initially increases and then decreased with further increase in fibre content. **Aurrekoetxea et al. [27]** studied the effect of injection molding induced morphology on fracture behaviour of virgin and recycled PP matrix polypropylene. Results shows that the virgin polypropylene has higher micro-hardness values than the recycled one. **Han-Seung et al. [28]** examined the effect of compatibilizing agents on mechanical properties using rice-husk flour as reinforcing filler and matrix polypropylene (PP). Four levels of filler loading were taken i.e. 10, 20, 30, 40 wt% and three levels of compatibilizing agent contents 1, 3, 5 wt%. Without using compatibilizing agent the developed composites give less tensile properties due to poor interfacial-bonding between the filler and the matrix polymer. **Rout et al. [29]** investigated that the surface modification of coir fibres shows better mechanical properties using 2% alkali treated coir composites show better tensile strength i.e 26.80 MPa whereas 5% alkali treated coir composites show better flexural i.e 60.4 MPa and impact strength (634.6 J/m). Also the tendency of water absorption decreases due to surface modification of the fibers. SEM micrograph shows good adhesion between the matrix and fibers.

2.3 Thermoplastic Matrix Composites with Synthetic Fiber Reinforcement

Moriwaki [30] used a direct injection molding process, in which, instead of using extrusion first for mixing of fiber with the matrix, composite parts are molded by injection molding directly using a dry blend of the

resin and reinforcement. It was found that this method was more effective and better mechanical properties are observed, when compared to two step process, under higher % of reinforcement. Also, it was concluded that the extrusion process used can break the long fibers in short ones and a two step process can deteriorate the properties of glass fiber, which may lead to poor mechanical properties.

J.L. Thomason [31] revealed the mechanical properties of long and short glass fibre-polypropylene injection molded compounds. This allowed comparison of the mechanical properties of long and short fibre reinforced composites by using the same matrix at the same fibre properties, and also the effect of fibre diameter in short fibre compounds. The composites were prepared with a reinforcement of 40 vol%. At the same fibre diameter and fibre content long fiber polypropylene composite gives meaningful improvements in tensile and flexural properties, notched and unnotched impact resistance. The effect of lowering the fibre diameter in SF-PP resulted in increase of both, but notched impact and modulus were found unaffected by reducing diameter. **Sousa et al. [32]** carried experimentation on high density polyethylene and short carbon fibers using an injection molding process. Two types of HDPE granules of different MFI (Melt Flow Index) were used as matrix material with 20% carbon short fiber for two different composites. It was observed that the two composite materials produced by compounding injection molding exhibit distinct mechanical properties. Lower viscosity HDPE composite exhibited more stiffness, improved strength and better impact performance. **Chifor et al. [33]** carried experimentation on mechanical and physical properties, such as tensile strength, elongation at break, modulus of elasticity, melt flow rate (MFR), and electrical and thermal conductivities of composites with high density polyethylene matrix reinforced with 30% Al powders. The experimental data obtained from the work were found in good accordance with the theoretical data. Ultimate tensile strength (UTS) and elongation at break found to be decreased with increasing Al powder content, but the modulus of elasticity increased. **Wang and Ying [34]** studied the thermal, tensile and dynamic mechanical properties of injection molded short carbon fiber in polypropylene matrix. In the experiment, carbon fibres were cut into short ones and mixed with polypropylene (PP) fibers. Three concentrations of SCF, 5, 15 and 25 w%, were used. Composites with good uniform dispersion of SCF in PP matrix were prepared via melting compounding in a twin-screw extruder followed by injection molding. **Hirano et al. [35]** studied the effect of fiber length and adhesion of fiber and matrix in carbon fiber reinforced polypropylene composites. The interfacial properties were quantified in terms of the interfacial shear strength, Mechanical properties and impact resistance were evaluated. Composite strength and impact resistance were improved while increasing IFSS and when using short fibers, but impact strength improves with decreasing interfacial shear strength. **Nevin and Ayse [36]** used to melt mixing method for fabrication of carbon fiber reinforced polyamide 6 composites, to illustrate the effects of fiber length and content, on the mechanical, thermal and morphological properties of carbon fiber reinforced polyamide composites. The maximum numbers of fiber were detected in the range of 0-50 μm , while

mechanical test results showed the increase in tensile strength by increasing the carbon fiber content. Modulus and hardness values also increased with carbon fiber reinforcement.

2.4 Identified Gaps

A lot of work has been carried out by various researchers, in the field of FRCs, which have been manufactured by various processes, i.e. compression molding, extrusion, injection molding etc. But still the optimum levels of process parameters for various processes have to be established for NFRCs by performing experiments at various combinations of parameters. Also the processes used in the experiments are not well elaborated in most of the publications, i.e. optimum parameters etc. Working conditions and time consumed in the work has not also been mentioned. Therefore, it seems difficult to get the consistent results practically, which are shown in the publications. The basic characteristics of matrix and reinforcement also vary from place to place and time by time, but the comparison work in publications has been done on a standard basis, which seems inappropriate. In general, the process used in most of the experiments, the combination of the process and material used are not easily and commercially available and are also quite costly, therefore, to use them, one has to be careful and specific. Also, using this cost factor will increase drastically instead of decreasing. Most of the research work reported the use the modified natural fibers. Various treatments have been used to modify the properties of the natural fibers before using them as reinforcement in polymer matrices. Maximum research efforts have been noticed in the broad area of compression molding, resin transfer molding etc. of NFRCs.

Hence, not much work has been reported by keeping important factors such as, product cost, simplicity, feasibility, availability, environment etc. in context of NFRCs.

Still the identification and availability of natural fibres and their cost in different geographic regions evoke that a lot of research and development work has to be done for proper utilization of available resources of natural fibres. These gaps and the future potential in the work already done, help us to identify the opportunities for performing research work.

2.5 Objective of the present Work

- Fabrication of natural fibre reinforced composites by injection and compression molding processes.
- To study the effect of fiber (short coir fiber) loading on composites processed by compression molding.
- To study the mechanical properties like flexural and tensile strength of the developed composites.

Comparative analysis of the composites developed by injection as well as compression molding process.

3.0 Results and Discussion

In this chapter results obtained from the mechanical and morphological examination are mentioned and discussed.

3.1 Mechanical Properties and Analysis

Flexural and tensile testing results of the composites fabricated by compression molding process at various fibers loadings are given in Table 4.1. A graphical representation of the average values of tensile and flexural results is given in Figure 4.1 and 4.2.

Table 3.1: Tensile and flexural properties of coir fiber reinforced composites (compression molding process)

S No.	% Reinforce ment	Tensile Strength (MPa)	Tensile Modulus (MPa)	Flexural Strength (MPa)	Flexural Modulus (MPa)
1	3	17.035	768.041	37.543	1006.570
2	3	17.755	802.412	37.575	1091.512
3	3	17.153	760.683	38.893	1046.570
4	5	17.988	795.751	38.564	1087.178
5	5	18.153	781.122	37.637	1146.585
6	5	18.055	722.710	38.123	1193.474
7	10	19.550	747.268	38.002	1122.809
8	10	19.201	787.997	36.988	1117.663
9	10	18.988	725.551	38.849	1133.923
10	15	19.971	722.962	37.838	1248.860
11	15	19.778	827.829	37.868	1352.207
12	15	20.655	875.113	38.647	1350.351

The response Table for the mean values of tensile strength, tensile modulus, flexural strength and flexural modulus of compression and molding process are shown in Table 4.2 and graphical representation is shown in Figure 4.1

Table 3.2: Mean values of tensile and flexural properties for compression molded specimens

S No.	% Reinforcement	Tensile Strength (MPa)	Tensile Modulus (MPa)	Flexural Strength (MPa)	Flexural Modulus (MPa)
1.	3	17.231	777.045	36.147	705.113
2.	5	17.899	766.768	38.132	760.683
3.	10	18.442	753.679	38.998	747.268
4.	15	20.101	808.631	39.565	808.634

Table 3.3: Tensile and flexural properties for injection molded specimens

S No.	% Reinforcement	Tensile Strength (MPa)	Tensile Modulus (MPa)	Flexural Strength (MPa)	Flexural Modulus (MPa)
1.	15	21.813	862.544	41.901	1322.641
2.	15	22.176	886.856	44.037	1275.462

3.	15	22.576	896.542	45.153	1288.116
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Mean values of tensile strength, tensile modulus, flexural strength and flexural modulus for injection molding process are shown in Table 4.4 and graphical representation is shown in Figure 4.3 and 4.4.

Table 3.4: Mean value of tensile and flexural properties for injection molded specimens

S No.	% Reinforcement	Tensile Strength (MPa)	Tensile Modulus (MPa)	Flexural Strength (MPa)	Flexural Modulus (MPa)
1.	15	22.183	881.980	43.697	1295.406

Tensile and flexural strength of composites fabricated by compression molding process at four levels of fiber loading i.e. 3%, 5%, 10%, 15%. It is observed from the Figure 4.1, as the percentage of coir is increasing, the tensile strength increase, but there is a marginal change in flexural strength.

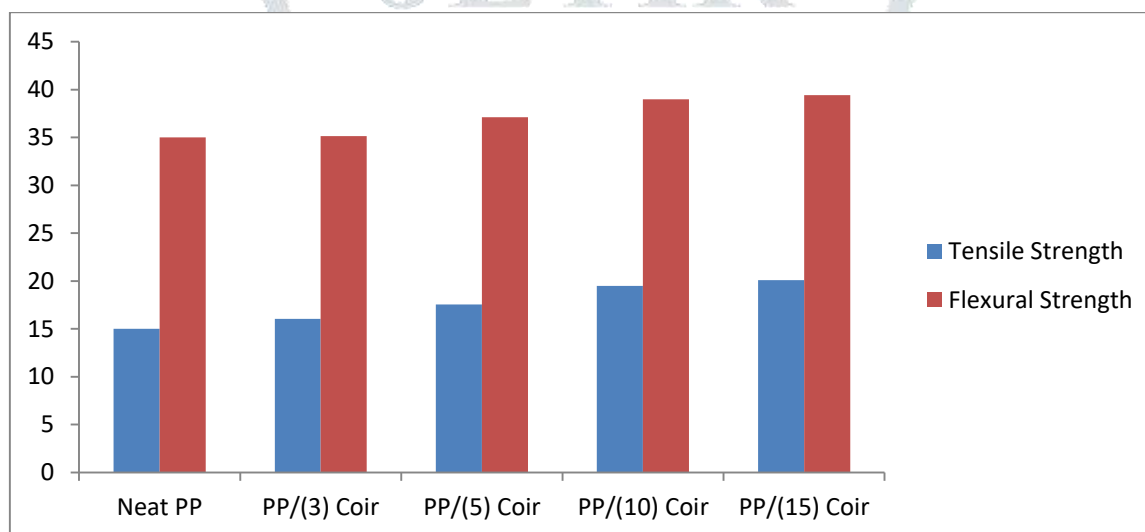


Figure 3.1: Tensile strength and flexural strength of the composites developed by compression molding process.

The tensile and flexural strength of PP, PP/(3)coir, PP/(5)coir, PP/(10)coir and PP/(15)coir composites fabricated by compression molding is given in Figure 4.1. It can be observed that with an increase in the coir concentration the tensile strength marginally increases. However, in case of flexural properties, the flexural strength increases with the addition of coir fibers compared to neat PP, but the effect of fiber concentration is not visible. The marginal or negligible increase in the tensile and flexural strength indicates towards low interfacial bonding between the hydrophobic PP and hydrophilic coir fibers. The addition of compatibilizer might have improved the strength of the developed composites. Also, the fiber distribution and orientation of the coir fibers within the developed composites might have reduced the tensile and

flexural strength. SEM examination of the compression molded PP/(15)Coir shown in Figure 4.5, clearly indicates towards the presence of voids and fiber pullouts as the major reason for composite failure under tensile loading. The tensile and flexural modulus of the compression molded specimens is given in Figure 4.2 The addition of natural fibers into a polymer matrix usually results in a significant increase in the tensile modulus of the developed composites. However, in the present study the modulus of the developed composites showed a marginal increase with the increasing fiber loading. This marginal increase in the modulus of the compression molded composites can be attributed to the low interfacial bonding between PP and coir fibers, presence of voids and improper distribution of fibers within the developed composites.

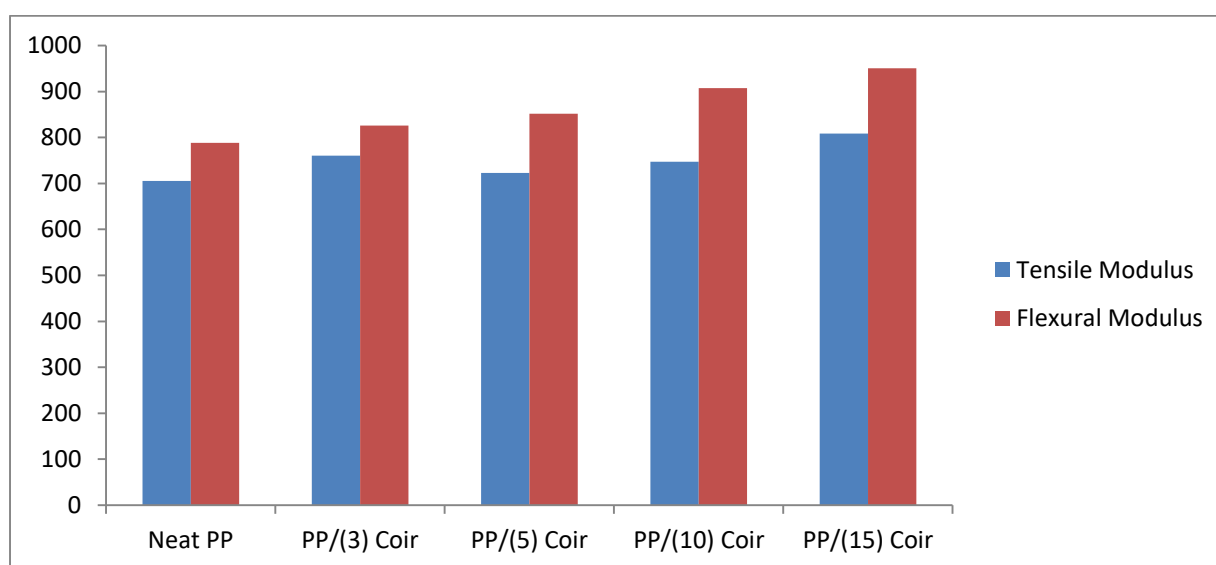


Figure 3.2: Tensile modulus and flexural modulus of the composites developed by compression molding process

Tensile and flexural strength and tensile and flexural modulus of 15% coir fiber reinforced PP fabricated by injection and compression molding process is compared in Figure 4.3 and 4.4 respectively. It can be clearly observed that the composites developed using an injection molding process exhibits better strength and modulus as compared to compression molded specimens. The improvement in the properties of injection molded specimens can be attributed to better distribution and orientation of fibers compared to compression molded specimens. The better orientation and distribution of fibers within the molded specimens ensure better stress transfer between fibers and the matrix and increases its load bearing capacity. Also, during the injection molding process, the matrix and fibers are melt blended before injection, which might lead to improved interfacial bonding between them. Moreover, the time required for injection molding process is negligible as compared to compression molding process. This means during the injection molding process the natural fibers and matrix are subjected to higher temperatures for a very short time/interval preventing their degradation.

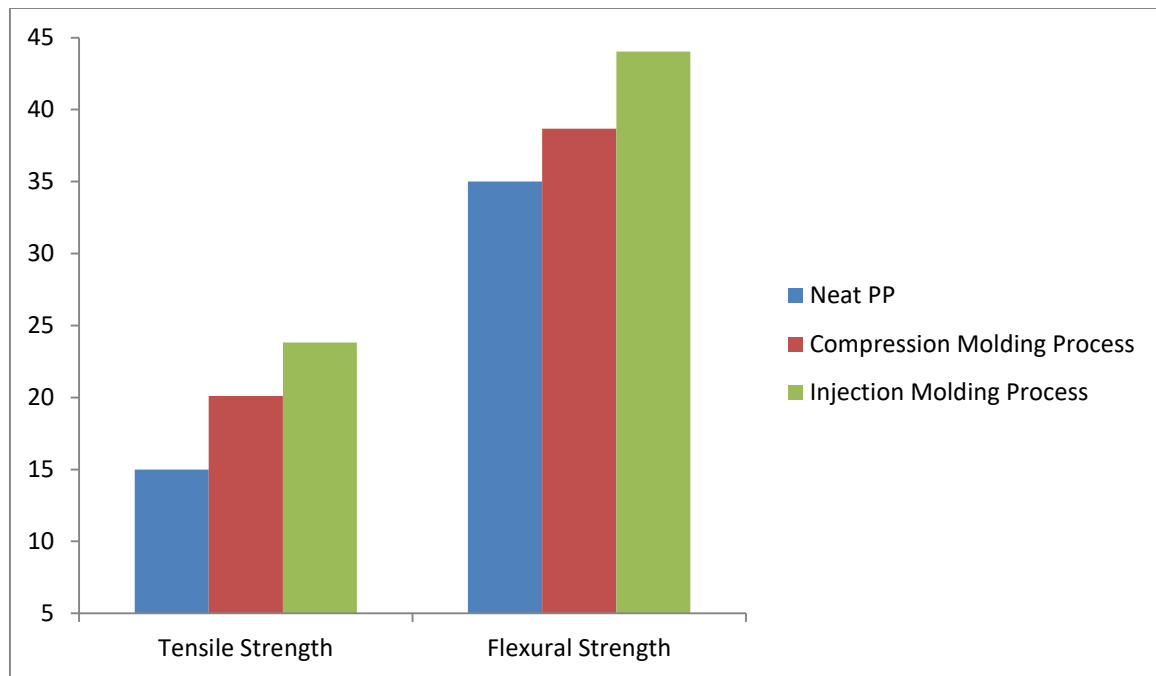


Figure 3.3: Tensile and flexural strength of injection and compression molded specimens

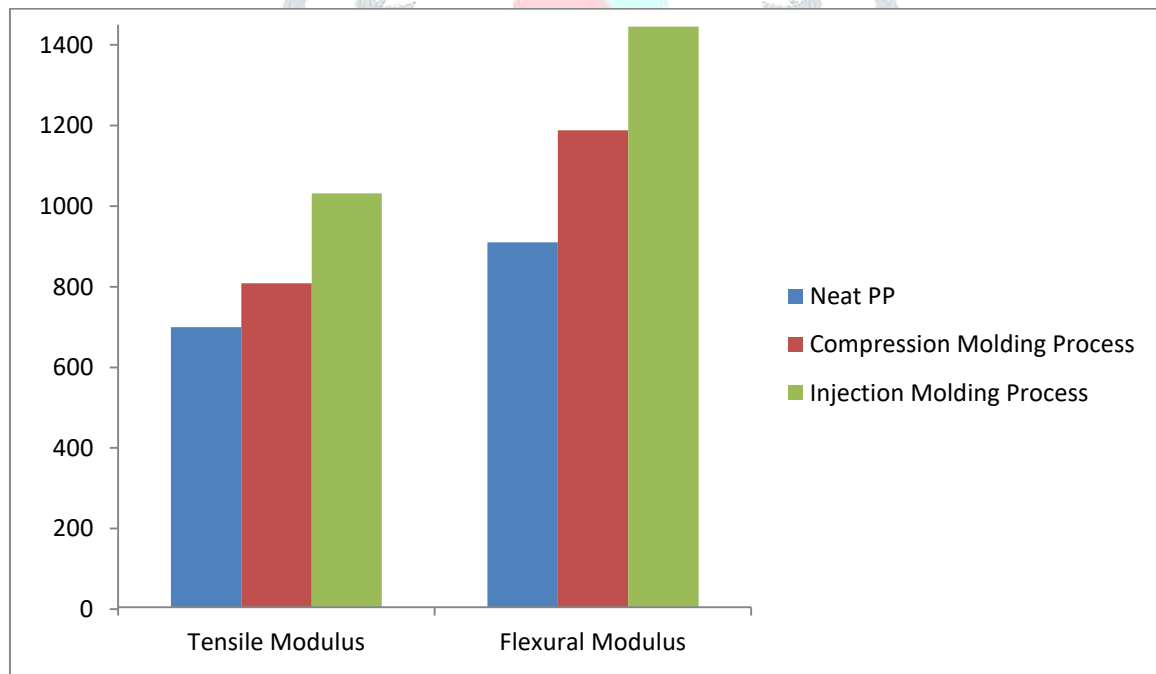


Figure 3.4: Tensile and flexural modulus of injection and compression molded specimen

3.2 Morphological Analysis of Fractured Specimens

SEM images of fractured composites are shown in Figure 4.5 and 4.6 for both compression and injection molded composites respectively, which provide an idea about the fracture mechanism of the fabricated

composite under tensile loading. The proper adhesion level, good bonding characteristics and less agglomeration will definitely enhance the mechanical properties of the composites. From SEM micrograph, matrix cracking, fiber fracture and fiber pull outs were observed as modes of composite failure.

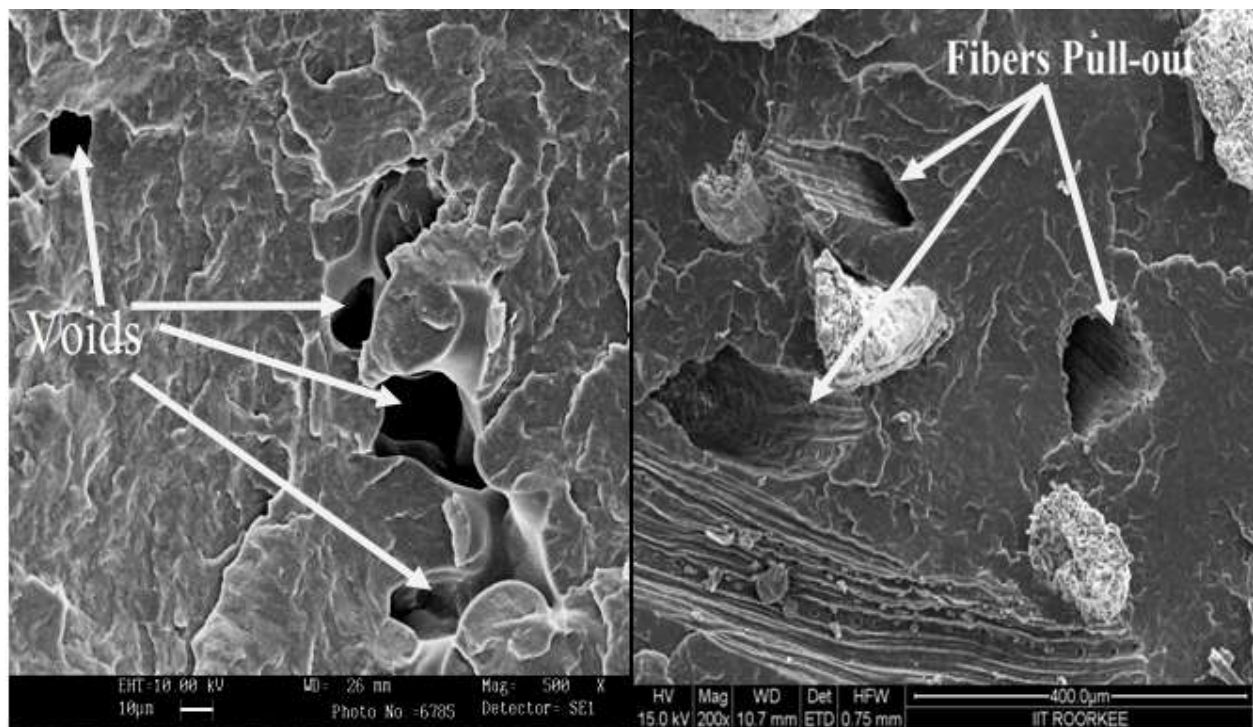


Figure 3.5: SEM images of the failed test specimens fabricated by compression molding process.

From Figure 4.5, it can be observed that composite failure occurred due to poor interfacial bonding between the matrix PP and coir fiber, fibers pull out, the presence of voids and improper fiber distribution. It has also been noticed that the surface of the pulled out coir fibers was clean (free from the matrix) after testing, indicating towards low interfacial bonding between the fiber and the matrix.

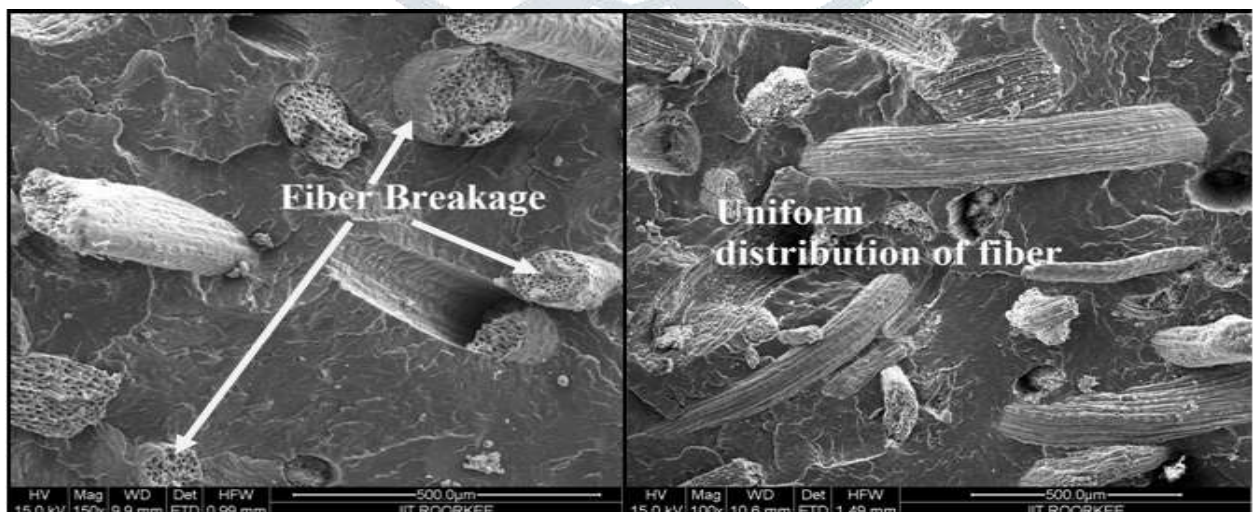


Figure 3.6: SEM images of the failed test specimens fabricated by injection molding process.

It has been observed that composites developed by injection molding process show better distribution of fibers compared to compression molded specimens. In the SEM analysis of injection molded specimens (Figure 4.6), more number of fiber breakages were observed compared to compression molded specimens indicating towards uniform fiber-matrix mixing and improved interfacial bonding between the fiber and matrix.

4.0 Conclusions:

Natural fiber reinforced PP composites were successfully developed using compression and injection molding technique. The following conclusions can be drawn from the present experimental investigation:

- 1) Upto weight 15% of fiber loading of coir fiber reinforced PP composites was successfully developed using compression molding process.
- 2) With further increase of fiber concentration fiber agglomeration and improper distribution was observed.
- 3) Hence, the short coir fibre reinforcement to 15 wt % is optimal for compression molding process.
- 4) The composites developed with varying fiber concentration using compression molding process shows negligible increase in tensile and flexural properties, this could be due to lower interfacial bonding and non-uniform distribution and orientation of the coir fibers within the developed composites.
- 5) The tensile strength of injection molded and compression molded specimens increased by 58.75% and 34% respectively compared to neat PP. Flexural strength of injection molded and compression molded specimens increased by 25.82% and 10.51% respectively.
- 6) Similarly tensile modulus of injection molded and compression molded specimens increased by 47.42% and 15.52% respectively compared to neat PP. Flexural modulus of injection molded and compression molded specimens increased by 58.84% and 30.60%.
- 7) The injection molded specimens resulted in better tensile and flexural properties compared to compression molded specimens. The improvement in the properties of injection molded specimens is due to better distribution and orientation of fibers compared to compression molded specimens.
- 8) The better orientation and distribution of fibers within the molded specimens ensure better stress transfer between fibers and the matrix and increases its load bearing capacity. Also, during the injection molding process the matrix and fibers are melt blended before injection, which might lead to improved interfacial bonding between them.

Therefore the injection molding process is the best process compared to the compression molding process, also it requires very less time for the fabrication of composites, useful for mass production and intricate parts can be easily developed.

4.1 Applications

By observing the different characteristics of the developed composites by injection and compression molding process, the composites fabricated by injection molding process can be used in mainly those application areas as it gives good mechanical properties, where there is a requirement of good flexural properties. It has been observed that in automobile engineering industries, the components, which are made up of polypropylene, are subjected to mainly flexural loading. The same properties are desirable in case of furniture and other domestic products. The examples of components, where the developed material configuration can be used for are: Automobiles: Dashboard, Steering wheel, Buttons, Bumper, Interiors etc. Household items: Table, Chairs, Door and door panels, laptop body and covers etc.

REFERENCES

- [1] Jones, R.M. *Mechanics of Composite Materials*, Taylor and Francis Inc. (1999). 31-33.
- [2] Verma, D., Gope, P. C., Shandilya, A., Gupta, A., and Maheshwari, M. K. "Coir fibre reinforcement and application in polymer composites" *A Review, Journal of Material and Environment Science*, 4 (2013) 263-276.
- [3] PrakashReddy, B., Satish, S. and ThomasRenald, C.J. "Investigation on Tensile and Flexural Properties of Coir Fiber Reinforced Isophthalic Polyester Composites" *Composites Part B: Engineering*, 42(6) (2007) 1648-1656.
- [4] Annamalai, K., Patil, R., Arjun, C. and Pillarisetti. "Influence of e-glass and graphite particle on Al-356 alloy composite produced by vortex method" *International Journal of Engineering Science and Technology*, 3 (2011) (2).
- [5] N. Srinivasababu, K. Murali Mohan Rao, J Suresh Kumar, "Experimental determination of tensile properties of okra, sisal and banana fiber reinforced polyester composites" *Indian Journal of Science and Technology*, 2 No. 7 (July 2009) ISSN: 0974- 6846.
- [6] Debabrata Debnath "Mechanical behavior of bagasse fiber epoxy composites at liquid nitrogen temperature" *Thesis- NIT Rourkela*.
- [7] Mohd. Yusoff, Mohd. Zuhri, Mohd. Sapuan Salit, Napsiah Ismail, Riza Wirawan "Mechanical properties of short random oil palm fibre reinforced epoxy composites" *Sains Malaysiana*, 39(1) (2010) 87-92.
- [8] Sewench N. Rafeeq, Inaam M. Abdulmajeed, Areej Riyadh Saeed, "Mechanical and thermal properties of date palm fiber and coconut shell particulate filler reinforced epoxy composite" *Indian Journal of Applied Research*, 3 (2013) Issue : 4.
- [9] Beckry Abdel-Magid, Saeed Ziaee, Katrina Gass, Marcus Schneider "The combined effects of load, moisture and temperature on the properties of E-glass/epoxy composites" *Composite Structures*, 71 (2005) 320-326.

- [10] Hasim Pihtili, "An experimental investigation of wear of glass fibre-epoxy resin and glass fibre-polyester resin composite materials" *European Polymer Journal*, 45 (2009) 149-154.
- [11] V. Lopresto, C. Leone, I. De Iorio, "Mechanical characterisation of basalt fibre reinforced plastic" *Composites: Part B*, 42 (2011) 717-723.
- [12] CS. Varga, N. Miskolczi, L. Bartha, G. Lipoczi "Improving the mechanical properties of glass-fibre-reinforced polyester composites by modification of fibre surface" *Materials and Design*, 31 (2010) 185-193.
- [13] Han Song Hee, Hyun Ju Oh, Hyun Chul Lee, Seong Su Kim, "The effect of post-processing of carbon fibers on the mechanical properties of epoxy-based composites" *Composites: Part B*, 45 (2013) 172-177.
- [14] Yu Dong , Arvinder Ghataura , Hitoshi Takagi , Hazim J. Haroosh , Antonio N. Nakagaito, Kin-Tak Lau "Polylactic acid (PLA) biocomposites reinforced with coir fibres" *Journal of Composite Materials*, 63 (2014) 76–84.
- [15] Oksman K, Skrifvars M and Selin JF. Natural fibers as reinforcement in poly lactic acid (PLA) composites. *Compos Sci Technol*, 63 (2003) 1317-1324.
- [16] Shih YF, Huang CC and Chen PW. Biodegradable green composites reinforced by the fiber recycling from disposable chopsticks. *Material Science Engineering*, 527 (2010) 1516-1521.
- [17] Pramendra Kumar Bajpai, Inderdeep Singh and Jitendra Madaan, "Development and characterization of PLA-based green composites: A review" *Journal of Thermoplastic Material*, 101.177 (2012) 1-30.
- [18] Shinichi Shibata, Rahman M. Bozlur, Isao Fukumoto, Yasuyuki Kanda, "Properties of Bagasse/polypropylene Injection Molding composites" *Peer Reviewed Article Biosource*, 5 (2010) 2097-2111.
- [19] Andrzej K. Bledzki and Omar Faruk, "Wood Fiber Reinforced Polypropylene Composites: Compression and Injection Molding Process", *Polymer-Plastic Technology and Engineering*, 43 (2004) pp. 871-888.
- [20] H.M. Akil, M.F. Omar, A.A.M. Mazuki, S. Sallee, Z.A.M. Ishak, A. Abu Bakar, "Kenaf fiber reinforced composites: A review" *Materials and Design*, 32 (2011) 4107-4121.
- [21] Murtuza Ali Syed and Akheel Ahmed Syed, "Development of a new inexpensive green thermoplastic composite and evaluation of its physico-mechanical and wear properties" *Materials and Design*, 36 (2012) 421-427.
- [22] Farkhondeh Hemmati and Hamid Garmabi, "A study on fire retardancy and durability performance of Bagasse fiber/polypropylene composite for outdoor applications", *Journal of Thermoplastic Composite Materials*, 26 (2013) 1041.

- [23] Ochi S., "Mechanical properties of kenaf fibers and kenaf/PLA composites". *Journal of Mechanical Materials*, 40 (2008) 446-52.
- [24] Moyeenuddin A. Sawpan, Kim L. Pickering, Alan Fernyhough, "Flexural properties of hemp fibre reinforced polylactide and unsaturated Polyester composites", *Composites: Part A*, 43 (2012) 519-526.
- [25] Andrzej K. Bledzki, Omar Faruk, Klaus Specht, "Influence of Separation and Processing Systems on Morphology and Mechanical Properties of Hemp and Wood Fibre Reinforced Polypropylene Composites" *Journal of Natural Fibers*, 4(3) (2007) 37-56.
- [26] Samia Sultana Mir , Nazia Nafsin , Mahbub Hasan , Najib Hasan , Azman Hassan "Improvement of physico-mechanical properties of coir-polypropylene biocomposites by fiber chemical treatment" *Journal of Materials and Science*, 52 (2013) 251–257.
- [27] J. Aurrekoetxea, M.A. Sarrionandia, I. Urrutibeascoa, M.L. MasPOCH "Effects of injection moulding induced morphology on the fracture behaviour of virgin and recycled polypropylene" *Journal of Polymer*, 44 (2003) 6959–6964.
- [28] Han-Seung Yang, Hyun-Joong Kim, Hee-Jun Park, Bum-Jae Lee, Taek-Sung Hwang "Effect of compatibilizing agents on rice-husk flour reinforced polypropylene composites" *Journal of Composite Structures*, 77 (2007) 45–55.
- [29] J. Rout, M. Misra, S.S. Tripathy, S.K. Nayak, A.K. Mohanty "The influence of fibre treatment on the performance of coir-polyester composites" *Journal of Composites Science and Technology*, 61 (2001) 1303–1310.
- [30] Takeshi Moriwaki "Mechanical property enhancement of glass fibre-reinforced polyamide composite made by direct injection molding process" *Composites: Part A*, 21 (1996) 379-384.
- [31] J.L. Thomason, "The influence of fibre length and concentration on the properties of glass fibre reinforced polypropylene: Injection molded long and short fibre PP" *Composites: Part A*, 33 (2002) 1641-1652.
- [32] R. A. Sousa, R. L. Reis, A. M. Cunha and M. J. Bevis, "Integrated compounding and injection molding of short fibre reinforced composites" *Plastics, Rubbers and Composites*, 33 (2004) 746-760.
- [33] Victoria Chifor, Zafer Tekiner, Mehmet Turker, Radu Orban, experimental investigation of properties of polyethylene reinforced with Al powders" *J Zhejiang Univ-Sci A (Appl Phys and Eng)*, 12(8) (2011) 583-592.
- [34] Wang, C., Ying, S., "Thermal, tensile and dynamic mechanical properties of short carbon Fibre reinforced polypropylene composites" *Polymer and Polymer Composites*, 21 (2011) 65-72.
- [35] Noriyuki Hirano, Hidetaka Muramatsu, Takashi Inoue, "Study of fiber length and fiber-matrix adhesion in carbon fiber reinforced polypropylene" *Advanced Composite Materials*, 23 (2014) 151-161.

- [36] Nevin Gamze Karsli, Ayse Aytac, "Tensile and thermomechanical properties of short carbon fiber reinforced polyamide 6 composites" *Composites: Part B*, 51 (2013) 270-275.
- [37] D Saravana Bavan and GC Mohan Kumar, "Potential use of natural fiber composite materials in India" *Journal of Reinforced Plastics and Composite*, 29(24) 2010 3600-3613.
- [38] <http://www.custompartnet.com/wu/InjectionMolding>

