STUDIES ON THE EFFECT OF CHEMICAL TREATMENT AND ADDITIVE ON PHYSICO-MECHANICAL PROPERTIES OF JUTE FIBRE AND FIBRE-PLASTIC COMPOSITE

Submitted By

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CANDIDATE'S DECLARATION

I hereby declare that the research work presented in this thesis entitled ***"STUDIES ON THE EFFECT OF CHEMICAL TREATMENT AND ADDITIVE ON PHYSICO-MECHANICAL PROPERTIES OF JUTE FIBRE AND FIBRE -PLASTIC COMPOSITE"*** has been carried out by me and that no part of this thesis has been submitted previously in any University or Institute for any degree or diploma.

Signature of the candidate

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Dedicated to

My

Parents

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Md. Ferdaus Nowaz

ABBREVIATIONS

ASTM	American Society for Testing Materials
BDC	Benzene Diazonium Chloride
FAAS	Flame Atomic Absorption Spectrophotometer
GPa	Giga Pascal
JRP	Jute Reinforced Plastic
Kgi	Kilogram inch
KPa	Kilo Pascal
m-HBDC	*m*-hydroxy benzene diazonium chloride
MMA	Metyl Methacrylate
MPa	Mega Pascal
o-HBDC	*o*-hydroxy benzene diazonium chloride
PAN	Polyaceto Nitrile
PE	Polyethylene
p-HBDC	*p*-hydroxy benzene diazonium chloride
PMMA	Polymethyl Methacrylate
p-nitroso *N,N*-DMA	*p*-nitroso *N, N* -dimethyl aniline
PP	Polypropylene
psi	per square inch
PVC	Polyvinyl Chloride

ABSTRACT

The physico-mechanical properties of alkali, oxidized, BDC, *p*-nitroso *N, N* -dimethyl aniline, *o*-, *m*- and *p*- hydroxy benzene diazonium chloride treated jute fibre and treated jute – polypropylene composites were studied. In manufacturing jute-PP composites carrot powder was used as additives for different properties.

The tensile strengths of differently treated jute fibre are found to increase except in the case of alkali treated one, where tensile strength was found to decrease. The highest tensile strength was obtained in the case of *p*-nitroso *N, N*-dimethyl aniline treated jute fibre. The tensile strengths of treated and raw jute fibres were found to change in the following order:

p-nitroso *N,N* -DMA treated > BDC treated >*o*- HBDC treated > *m*- HBDC treated >*p*-HBDC > raw jute> oxidized > alkali treated jute fibre.

The elongation at break of treated and raw jute fibre was found to change almost in the same order as it was in the case of tensile strength. The only difference is in the case of alkali treatment the decrease of tensile strength was found to be in large extent however, the decrease of elongation at break was found to be in limited extent.

The moisture regain properties of raw and differently treated jute fibre are found to be changed in opposite order. That is the alkali treated jute fibre has highest moisture regain property even higher than raw jute fibre. The *p*-nitroso *N, N*-dimethyl aniline, BDC, *o*-, *m*- and *p*-hydroxy benzene diazonium chloride treated jute have much lower values of moisture regain properties than those of oxidized, raw and alkali treated jute fibre.

The raw jute fibre and treated jute fibre were kept under the conditioned soil for observing biodegradation character. The biodegradation of raw jute fibre was found to be faster than that of treated jute fibre. For complete degradation, the treated jute fibre took around one year in comparison to three months for raw jute fibre under the identical conditions. It was also observed that the order of loss on tensile strength of differently treated fibre was raw jute fibre> alkali treated> oxidized> *p*-nitroso *N, N*-DMA > BDC > o-HBDC > *m*-HBDC >*p*-HBDC.

The treated jute fibre was used as reinforced materials to prepare composites with polypropylene (PP) used as polymer matrix. The treated jute fibre was mixed with PP in different weight fraction. The physico-mechanical properties (viz. tensile strength, tensile modulus, flexural strength, flexural modulus, Charpy impact strength and elongation at break) of these composites were studied.

The tensile strength, Charpy impact strength and elongation at break of raw jute fibre-PP composites were found to be lower than that of PP only. The raw jute fibre-PP composite showed higher tensile modulus, flexural strength and flexural modulus as compared to PP only. The tensile strength, tensile modulus, flexural strength, flexural modulus and Charpy impact strength of treated jute fibre-PP composites were found to be higher than those of raw jute fibre-PP composites. The tensile strength, tensile modulus, flexural strength, flexural modulus, Charpy impact strength and elongation at break of the raw jute fibre-PP and *p*-nitroso *N, N*- dimethyl aniline, benzene diazonium chloride treated jute fibre-PP composites were found to decrease with increasing fibre loading by weight fraction but in limited extent.

The tensile strength, tensile modulus, elongation at break, flexural strength, flexural modulus, Charpy impact strength of treated jute fibre-PP composite along with carrot powder were found to be highest than those of treated jute fibre-PP composite without carrot powder.

No systematic change is observed in the case of elongation at break of treated jute –PP composite along with carrot powder. However, treated jute fibre-PP composites containing 15% carrot have in general highest value than those of other composites.

The biodegradability test of different composites studied in this investigation showed that in general the chemical treatment of jute fibre decreases the biodegradability of the composite. However, incorporation of carrot powder increases the biodegradability.

Scanning Electron Microscope for observing surface morphology, particle size, particle distribution, porosity and pore size analysis was carried out of raw jute-PP, alkali bleached *p*-nitroso *N, N* -dimethyl aniline treated jute fibre without and with carrot powder-PP composites and alkali bleached *o*-HBDC treated jute fibre with carrot powder-PP composites in this work.

Thermo–gravimetric analysis (TGA) of composites was carried out. Thermo Gravimetric/Differential Thermal Analyzer (TG/DTA) has been designed to perform thermo gravimetric and differential thermal analytic measurement on raw jute-PP composites, alkali bleached oxidized *p*-nitroso *N, N*-dimethyl aniline treated jute fibre-PP composites, alkali bleached oxidized *p*-nitroso *N, N*-dimethyl aniline treated jute fibre along with carrot powder-PP composites and alkali bleached oxidized *o*-HBDC treated jute fibre along with carrot powder-PP composites.

INTRODUCTION

1.1 General remarks

Composites may be defined as the materials which are formed by the macroscopic combinations of two or more materials and whose properties are better than any of their individual component materials. Some plastics increase strength by reinforcing them with fibres which are considered as the fibre reinforced composite materials. Polymer composites consist of one or more discontinuous phases embedded in a continuous-phase of polymer matrix. The discontinuous phase is usually harder and stronger than continuous phase. This is called reinforcing material. Now a days fibreous materials are used as discontinuous phase which entangled with the polymeric continuous-phase thereby increase the strength mechanically. There are two types of polymer matrix namely (i) thermosetting (hardened on applying heat) and (ii) thermoplastic (softened and hardened by increase and decrease of temperature respectively) [1,2]

The fundamental aim manufacturing composites materials is to achieve high performance from the composite materials that is not available from the separate constituents or from other similar materials. In 1908, composites [3] were fast applied for the fabrication of biquantities of sheets, tubes and pipes in electro-technical usage (paper and cotton were used as reinforcement in sheets made of phenol and melamine-formaldehyde resins). During the long period of research it has been proved that plastic-composites of better mechanical properties can be produced by using either synthetic fibre or natural fibre as the reinforcement material. Although synthetic fibres such as glass, graphite (carbon), boron, metal and ceramic are the common reinforcing materials, however, there are some disadvantages of using synthetic fibres as reinforcing materials in the composites. The disadvantages are mainly -

1. Biodegradibility: synthetic fibres are not biodegradable particularly when disposal questions are arised. So these are harmful to the environment.
2. Cost: synthetic fibres are mostly high cost materials.
3. Weight: considering weight these are relatively heavier materials.
4. Renewability: synthetic fibres are mostly not renewable.

As a result many scientists have paid their attention to natural plant fibres of better mechanical and physico- chemical properties, which might be the better choice for producing reinforced materials of composites. Natural fibres or lignocellulosic fibres (contains both cellulose and lignin) have some advantages in their use as reinforcement material [4] for manufacturing of composite over synthetic fibres. These are:

1. These are highly biodegradable
2. These are of low cost.
3. These are easily available and renewable particularly in the context of Bangladesh, a highly fertile agricultural land.
4. These are relatively less abrasive.

As a result, now-a-days there is an increasing trend in using natural fibres or lignocellulosic fibres such as wood, agricultural crops like cotton, jute, flax, ramie, sisal, coir, knave etc, and agricultural residues like bagasse, corn stalks, rice husk etc. as reinforcement materials.

Among the various natural fibres, jute fibre is being considered as the best one [5]. This is because of the following advantages over other natural fibres.

1. Jute fibre is 100% biodegradable and recyclable
2. It is renewable
3. It has high tensile strength with low extensibility, These are suitable for making best quality of industrial yarn, fabrics and sacks.
4. Jute fibre does not contain any narcotic elements
5. Jute fibre does not have any unpleasant odour.
6. Jute fibre is abundantly available particularly in Bangladesh and India.
7. Jute is not abrasive in nature.
8. Jute is the cheapest among all natural fibre.
9. It does not irritate skin.
10. It does not produce any poisonous gas and residue when incinerated.

Hence natural fibre reinforced plastic composites are not cause harmful to health or environmen and these are partially biodegradable. Its biodegradability depends upon the percentage of jute fibre incorporated into the polymer matrix. Higher is the percentage of jute fibre (biodegradable material) higher will be the biodegradability of the composite. In addition to these the compatability of jute fibre with the polymer matrix may be enhanced by chemical treatment. Thus jute fibre was chosen as reinforcing material to prepare plastic composites in this investigation. To enhance the biodegradability, another fibreous natural product (carrot) was chosen as an additive of the composites studied in this work. Carrot was used by considering the presence of high percentage of carotene in carrot and the presence of large number of conjugated double bond in the long linear chain structure of carotene.

The lignocellulosic materials (jute fibre) and nonlignocellulose natural product (carrot powder) can be mixed either with thermosetting or thermoplastic polymer matrix to produce composite. The composite using thermosetting polymer shows some disadvantages. These are not flexible rather brittle and not repairable. To overcome these limitations thermoplastic matrices are generally used to prepare fibre reinforced composites. Many of the thermoplastic-based composites offer excellent resistance of impact loading and are thereby suitable for their use in high performance engineering work. Other interesting aspects of these composites include the possibility of thermoreforming and shaping at elevated temperature and also for thermal joining, repairing as well as recycling.

The high temperature required for manufacturing polymer plastic composites particularly high molecular weight polymer degrades the physico-mechanical properties of natural fibre. Experimentally it has found that processing temperature below 200^0C poly propylene composite lies retains the usual properties of jute fibre [6] . Thus among different thermoplastic polymer polypropylene (PP), is widely chosen for jute plastic composites. Polypropylyne has melting point in the range of $160\text{-}170^0$ C. Polypropylyne is found to be a most common plastic used to prepare natural fibre reinforced composites in some recent years. In addition, among the various thermoplastic polymers, polypropylene (PP) possesses some outstanding properties [7], Such as-

1. light weight
2. low price
3. good sterilizability.
4. good surface hardness.
5. high thermal stability
6. high hydrophobic character.
7. good abrasion resistance and finally high compatibility with natural fibre in presence of coupling agent.

Thus polypropylene would be the most suitable polymer matrix for the preparation of natural fibre reinforced composites. In this research polypropylene was used as the polymer matrix to prepare fibre-reinforced polypropylene composites.

Bangladesh has large amount of fertile and agricultural land. It produces huge amount of jute every year. Jute fibre is used to make yarn for manufacturing traditional products such as hessian cloth, sacks, carpet backing cloth (CBC), covering materials etc. In developing countries, jute is mainly used in manufacturing of hessian cloth and sacks for carrying cereals and sugar while carpet backing cloth (CBC) is the main jute product consumed in developed countries.

During the last few decades, world jute consumption has been dropped to a large extent due to intensive competition with synthetic fibres. Synthetic fibres in fact polymeric fibres contribute approximately 16 percent decrease in world jute consumption. The consumption of jute was 3.4 million tones in 1988-90, which is reduced to 2.9 million tones in 1998-2000. In developed countries the decline in consumption of jute products amounted to 40 percent from 668000 tones in 1988-90 to 395000 tones in 1990-2000. In developed countries, the jute market contracted by 10 percent from 2.8 million tones in 1988-90 to 2.5 million tones in 1998-2000.

Synthetic fibres gradually replace the jute fibre and traditional jute products because jute fibre has some limitations. These are:

1. Jute fibres are woody and coarse. So, it is not spinable to fine fabrics needed in garments industry.
2. Its elasticity and compressibility are quite low in comparison to synthetic fibre.
3. On exposure to sunlight the color of jute fibre changes from yellow to brown.
4. It has poor crease resistance.
5. The presence of residual oil in jute products causes harshness and coarseness of yarn and fabrics, loss of resiliency of jute carpet in usage.

The agri-scientists are trying their best to improve the above mentioned properties (draw backs) of jute fibre by applying gene technology. But till today there is no mentionable advancement in this line. Therefore in order to utilize jute fibre in a better way it is necessary to modify the jute fibre by treating it with various chemical substances. The modified jute fibre may be used in various ways. One of the latest applications of modified jute fibre (as a reinforcing material) is the manufacture of composite with plastic materials such as PE (Polyethylene), PP (Polypropylene), PVC (Polyvinyl chloride), PVA (Polyvinyl acetate), PMMA (Polymethyl methylacrylate) etc. These composites can be used-

1. in the packaging industry, i.e. the manufacturing of creates boxes or cases used for storage and transportation of agricultural products
2. in the automobile industry, i.e. in manufacturing body, door panels etc of auto vehicles.
3. as construction material mainly in partition wall..
4. in making house-hold furniture etc.

The natural fibre reinforced composites are mainly used in the area of automobile industry [8] . The use of composites to prepare automobile components is expected to increase by 54 percent per annum [9].

The scientists are trying to prepare composites of light weight having improved mechanical properties. In this study to do so, the jute fibre was modified by treating it with alkali(sodium hydroxide), *p*-nitroso *N, N*-dimethyl aniline, *o*-hydroxy benzene-diazonium chloride*, m*-hydroxybenzene diazonium chloride and *p*- hydroxybenzenediazonium choloride. The treated jute fibre were then used along with carrot powder to manufacture improved jute reinforced composites using PP as matrix. The physico-mechanical properties (such as tensile strength, tensile modulus, elongation at break, flexural strength, flexural modulus, and charpy impact strength) of raw and treated jute fibre and jute fibre-PP composite were studied. The biodegradability of the manufactured composites was also investigated. The composite contains nitrogenous substances. After decomposition of these composites the nitrogenous substances will go into the soil and can function as manure.

1.2 Composite materials and classification

The term composite material is used to describe macroscopic combinations of two or more materials. The fundamental goal in the production and application of composite materials is to achieve a better utility and performance from the composite that are not available from the indivisual constituents of the composite or from other similar materials. The concept of improved performance is broad and includes increased strength or reinforcement of one material by the addition of another material. The best example that can be cited in this regard is the development of Bakelite, or phenolic resin, which was synthesized by Backeland, a Belgium scientist, in 1906 [10]. Bakelite is a hard, and brittle material that has a very few mechanical applications of its own. However, the addition of a filler, yielded Bakelite molding compounds that were very strong and tough and found several applications in mass-produced automobile components. The saw dust additives improve Bakelite's processibility, physical, chemical, and mechanical properties, as well as reduce its cost. We are passing an era of polymer. Like other materials polymer composites are now an important class of engineering materials. The properties of composites are largely influenced by the properties of their constituents, the distribution and interactions among them. The constituents usually interact in a synergistic way, providing properties that are not accounted for by a simple volume-fraction or weight fraction sum of the components. Along with the volume or weight fraction and the distribution of discrete units in the continuous phase, the interfacial area plays an important role in determining the extent of interaction between the reinforcement and the matrix and in this way the final properties of the composite. The fabrication technology of composites, as well as some of their physical properties, is dominated by the chemistry and theology of the matrix resin and by the type and physical form of the reinforcement.

Reinforcing agents make it possible for any thermoset or thermoplastic-matrix property to be improved or changed to meet varying requirements. Thus most polymer composites have been developed or fabricated to improve mechanical properties such as flexibility, strength, stiffness, or toughness. The strengthening efficiency of the discontinuous phase plays the most important role in these properties of the products. The strengthening mechanism depends strongly on the geometry of the reinforcements. Therefore, polymer composites may be classified according to geometry of reinforcement materials. There are three major classes of polymer composites. These are fibrous, laminar and particulate. The commonly accepted classification scheme for polymer composites is presented in Fig. 1.1.

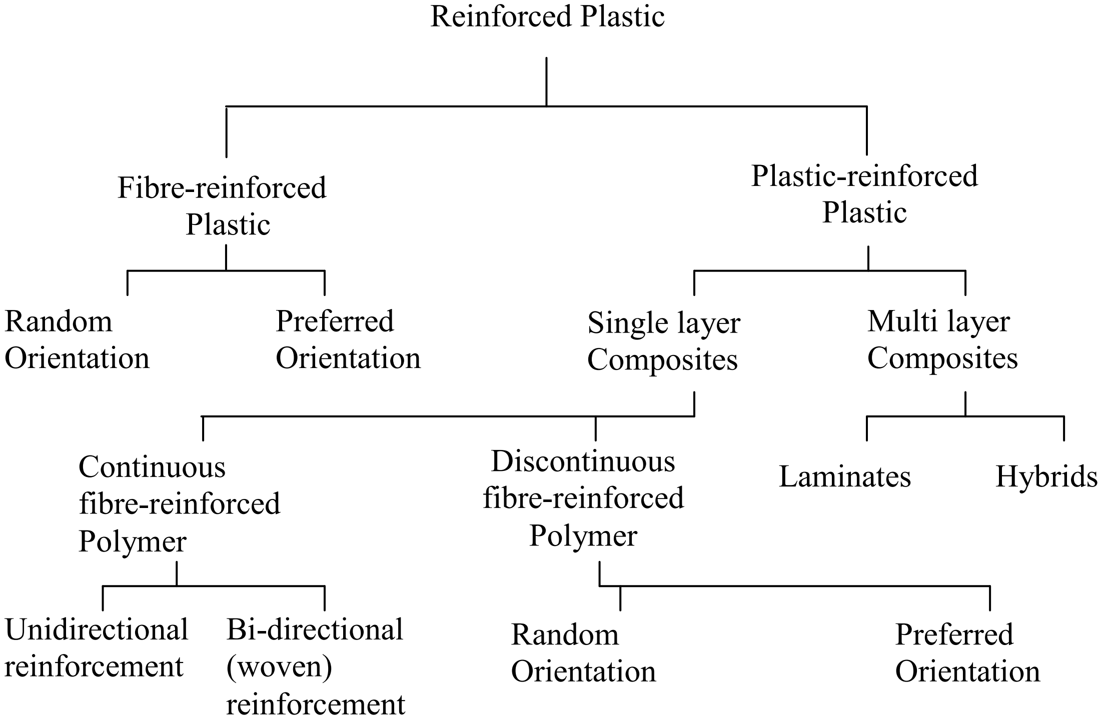


Fig. 1.1: Classification of polymer composites

1.3 Chemical composition of jute fibre and their structure

Jute is the complex lignocellulose based polymeric fibre. It may be considered as a composite material done by the nature. The major structural elements of jute fibre are cellulose, lignin and hemicellulose. Cellulose molecules are entirely held together within the cell units whereas lignin and hemicelluloses are distributed throughout the entire body of the fibre (just like the discontinuous phase) serving as cementing material. In addition to these major components, it also contains some minor constituents. These are fats and waxes, inorganic matters, pectinious materials and nitrogenous matter. The average composition of jute fibre is given below.

1.4 Composition (%) of olitorus jute fibre [11,12] %(wt/wt)

α-Cellulose	58.9-61.0
Lignin	13.2-13.5
Hemicellulose:(1) Pentosans	15.9-17.0
(2) Polyuronides	4.84-5.24
Fats and Waxes	0.09-1.4
Ash	0.50-0.52
Nitrogenous matter	1.56-1.87
Mineral Substances	0.50-0.79

1.5 Matrix materials

The physico-mechanical properties of composites based on the fibres depend not only on the characteristics of the fibres but also on the matrix itself as well as on the fibre-matrix interface. The matrix in a polymer composites maintains both the position and orientation of the fibres and protects them from potentially degrading environments. Polymer matrixes may be thermosets or thermoplastics. Thermosetting polymers are rigid, cross-linked materials that ruptured rather than melt at high temperatures. Thermoplastic polymers are linear or branched chained molecules that soften upon heating and become hard on cooling. Thermoset-based composites are somewhat less expensive than thermoplastic-based composites, but have lower heat distortion temperatures and poorer toughness when tested in an interlaminar mode. Thermosetting polymers, includes unsaturated polyesters, epoxies, and phenolic resins. Whereas thermoplastic polymers are polyamides, polyolefin's, polycarbonates and saturated polyesters.

Many of the thermoplastic-based composites offer excellent resistance to impact loading and are thereby suitable for use in high performance engineering applications. Other interesting aspects of thermoplastic composites include the possibility of thermoforming and shaping at elevated temperature and the potential for thermal joining and repair, as well as recycling."

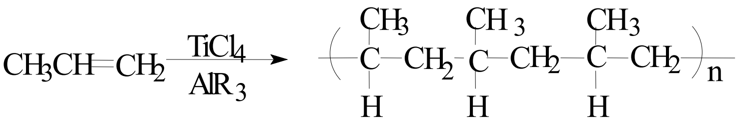
1.6 Thermoplastic polymer

Thermoplastic resins have received considerable attention in the past few years as the matrix material in organic resin-based composites. Whereas, thermosetting materials date back to 5000 years, when Egyptians used straw as reinforcing agent in a clay matrix to form bricks by heating. In Bangladesh particularly in rural area, similar composites were found to use as building materials. Here also straw is used as reinforcing material in clay matrix. These straw reinforced clay composite were extensively used in rural area for making low cost housing. The idea of reinforcedment using fibrous materials has come from these primitive facts. Thermoplastic composites are relatively new development. Although their use in advanced composites is not widespread. Thermoplastic composites are used extensively in commercial applications ranging from automobiles to durable goods.

Thermoplastic polymers are usually linear molecules with no cross linkage between the chain of the molecules. The molecules are held together by weak secondary forces, such as van der Waals forces or hydrogen bonding. These are readily deformed by the application of heat or pressure. Thermoplastic resins may be amorphous, that is, structureless, or semicrystalline, in which some of the molecules form an ordered array. A material is usually considered semicrystalline if it contains as little as 5% of the polymer in crystalline form. Semicrystalline resins exhibit high modulus, but amorphous materials are more tougher. Amorphous materials are usually more solvent sensitive and can be processed at lower temperature. One of the most important advantage of thermoplastic resins is their toughness, that is, high impact strength and fracture resistance, which, unfortunately, is not linearly transmitted into properties of the composite. Other advantages of thermoplastic polymers include long life at room temperature, post formability, that is thermal reforming, ease to repair by thermal welding or solvents and ease to handle. Thermoplastic polymer are not tacky. One of the principal advantages of true thermoplastic polymer is their ability to consolidate or flow at elevated temperature; however, this quality also limits their use at higher temperature. Amorphous materials begin to flow or creep above the glass-transition temperature, Tg, whereas crystalline resins must be heated above the melting point, Tm. As a of thumb rule Tg is approximately 2/3 Tm (Kelvin temperature). So crystalline polymers may begin to degrade at the temperatures required for processing. Even a relatively low temperature material such as polypropylene, which melts between 165 and 175^{0}C, must be heated to approximately 180-190^{0}C to process the composite. In many instances the processing window is quite narrow owing to a lower temperature limit set by the melting point and an upper temperature limit set the rate of thermal degradation.

1.7 Polypropylene (PP)

The most common polyolefin used to prepare composites is polypropylene, a commodity polymer that has been in commercial production for the last two decades following its controlled polymerization by Natta in 1954 [13]. Natta used a Ziegler catalyst consisting of titanium tetrachloride and an aluminum alkyl to produce isotactic polypropylene directly from propylene:



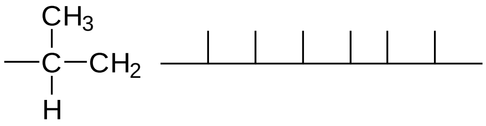
$$CH_3CH{=}CH_2 \xrightarrow[AlR_3]{TiCl_4} \left(\underset{H}{\overset{CH_3}{C}} - CH_2 - \underset{H}{\overset{CH_3}{C}} - CH_2 - \underset{H}{\overset{CH_3}{C}} - CH_2 \right)_n$$

Stereoregular (Isotactic)

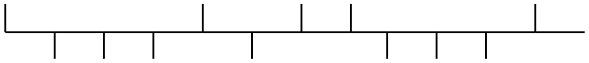
In manufacturing composites polypropylene may be used with many different reinforcing agents or fillers, such as talc, mica, or calcium carbonate; chopped or continuous stranded fibre. Glass is the most common reinforcing agent used for composites. Many additives have been developed to enhance the thermal stability of polypropylene and to minimize degradation during processing. One of the most important requirements of the polypropylene used in the manufacture of composites is that, it should be relatively pure and free of residual catalyst.

1.8 Molecular structure of PP

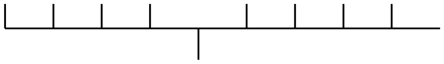
During mid fifties Natta [13] first determined the molecular structures of the various types of PP and introduced the descriptive nomenclature universally used today. Commercial interest lies primarily in highly crystalline PP, together with its further modifications through copolymerization. In isotactic PP, each monomer unit in the chain is arranged in a regular head-to-tail assembly without any branching. Furthermore, the configuration of each methyl group is the same (Fig. 1.2 A). This is caused by the template type constraints of the stereo specific catalytic site. Such a regular structure is the hallmark of a good catalyst. Occasionally, some imperfect monomer insertion gives the type of fault shown in Fig. 1.2 C, amounting to about 0.3-1.5 per hundred monomer units in the salable polymer. An extreme example of defects is atactic PP (Fig. 1.2 B), with complete loss of steric control. In syndiotactic configuration, methyl groups are alternatively arranged on either side of the carbon chain. Syndiotactic polymer is of theoretical, but not commercial importance.



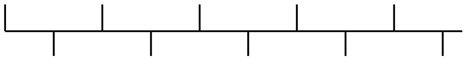
(A) Isotactic polypropylene; mp 176^0C



(B) Atactic polypropylene rubber



(C) Chain imperfection; mp< 176^0C



(D) Syndiotactic polypropylene; mp ca. 130^0C

Fig. 1.2: PP chain structure

1.9 Crystallization of PP

PP is a semi-crystalline polymer, which means it always has two phases, an amorphous and a crystalline phase. The useful properties of PP stem from its ability to crystallize and form rigid and tough articles. Highly isotactic polymer, with its regular structure, forms a helical coil having three monomer units per turn. These coils stack together into thin lamellar crystallites, which force the chains to fold several times as they emerge and reenter lamellae." Three crystalline forms are known (Table 1.1) of which the α-form is the most stable.

The most stable α-form of PP is favored at higher temperatures and slower cooling rates. Rapid quenching yields the β-form with lower density and melting point of 150^0C. Polymers of lower stereoregularity and random copolymers usually contain low melting γ-crystallites in addition to the α-form.

Formation of crystallites from a viscous melt is hindered by chain entanglements and by the need for helics to fold as they close pack into lamellae. This and the formation of nuclei might contribute to the low degree of crystallization even in highly steroregular polymers. Commercial articles vary from 30% crystallinity in rapidly quenched films to 50-60% in moldings. Even purified and annealed samples of very stereo regular polymer rarely achieve more than 70% crystallinity. It is to be pointed out that high helical contents are not synonymous with high crystallinities, which require three dementional long-range order. For these reasons PP is regarded as a semi crystalline polymer. The properties of crystalline PP are given in Table 1.1. The most predominant and stable crystalline form being the α-form, having a monoclinic structure. The more stable form is favored at higher temperatures and slower cooling rates.

Table 1.1: Crystalline properties of of PP

Crystal	System	Crystal density (20^0C), g/cm^3	Chains per unit cell	Mp, ^{0}C
Iso tactic α form	Monoclinic	0932-0.943	4	171
Iso tactic β form	pseudo hexagonal	0.922	9	150
Iso tactic γ form	triclinic	0.939	1	131
Amorphous	-	0.85	-	-
Syndiotactic	orthorhombic	0.93	2(4/1 helix)	138

1.10 Properties of PP

Polypropylene is a linear hydrocarbon polymer containing little or no unsaturation. It is therefore not surprising that polypropylene and polyethylene have many similarities in their properties [14]. Basic mechanical properties are largely influenced by molecular mass and molecular mass distribution (MMD), chain stereoregularity, and processing conditions, which introduce orientation, structural strain, etc. Various additive packages must be tailored to the application to achieve good and durable performance. Some typical properties of PP are given in Table 1.2. The final melting point of commercial PP lies in the range 160-170^{0}C, with purified polymer reaching 176^{0}C. Within the range of commercial polymers, the greater the amount of isotactic material the greater the crystallinity and hence, greater the softening point, stiffness, tensile strength, modulus and hardness. The crystalline and nonpolar structure of PP confers good resistance to a wide range of aqueous and polar media, including emulsifier solutions with their strong stress cracking abilities. Powerful oxidizing agents, highly aromatic and chlorinated solvents are too aggressive to safe storage in PP containers. One disadvantage of PP is the susceptibility of its methyl groups to thermooxidative degradation [15] .

Table 1.2: Properties of PP

Parameters	Standard Used	Values
Specific gravity	ASTM D792	0.90-0.91
Crystallinity, %	-	82
Melting temperature, ^{0}C	-	165-171
Tensile strength, MPa	ASTM D638	31-41
Tensile modulus, GPa	ASTM D638	1.10-1.55
Elongation at break, % -	ASTM D638	100-600
Impact strength, notched Izod, J	ASTM D256	21-53
Rockwell hardness (R-scale)	ASTM D785	90-95
Heat-deflection temperature,^{0}C, 455 kPa (66psi)	ASTM D648	225-250

1.11 Selection of PP as matrix

Polypropylene (PP) is one of the most common substances in modern society. PP is used in almost every sector of our life. But the only problem is that it is not biodegradable. It creats environmental problem. On the other hand it makes human life so easy that it is not possible to run human life without the use of PP. An intermediate strategy may be taken which will reduce the use of PP. If jute fibre can substitute PP partially in some cases the use of PP will be reduced to large extent. Jute fibre reinforced PP composite will serve not only the diversified application of jute fibre but also reduction of use of PP. The following factors are considered for selecting PP as matrix in making jute reinforced composites:

low cost
low melting point
non abrasive
environmental friendly
light weight

1.12 Lignocellulosic fibres

Lignocellulosic fibres refer to those agrobased substances which contain cellulose, hemicelluloses, and lignin as their structural molecules. Lignocellulosics include wood, agricultural residues, water plants, grasses, and other plant substances [16]. To better understand the properties of lignocellulosic fibre-reinforced composite materials, it is necessary to know the physical and chemical properties of lignocellulosic fibres. Fibres are classified as [17, 18]

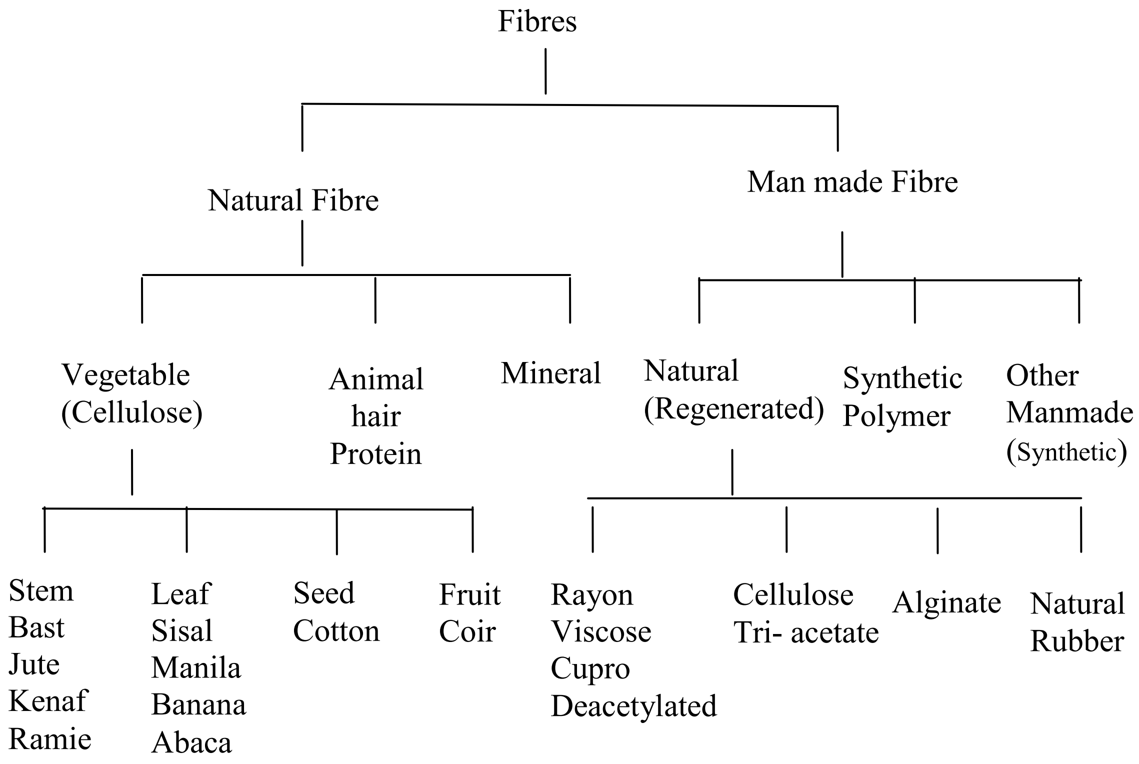


Fig. 1.3 Classification of fibre

Agro-based lignocellulosic fibres are also classified on the basis of parts of the plant where they are stored in [19]. Five different classes of fibre are foun.These are : (1) bark of the plant stem running the length of the stem; (2) leaf fibres, which rim the length of leaves; (3) seed-hair fibres; (4) core, pith or stick fibres, which form the low density, spongy inner part of the stem of certain plant and (5) all other plant fibres not included above [19]. Examples of bast or stem fibres include jute, flax, hemp, kenaf, ramie etc. Leaf fibres include banana, sisal, henequen, abaca, pineapple etc. Seed-hair fibres include coir, cotton, kapok, and milkweed floss. Core fibres represent the center or pith fibres of such plants as kenaf and jute and can represent over 85 percent of the dry weight of these plants. The remaining fibres include roots, leaf segments, flower heads, seed hulls and short stem fibre. While individual single fibres in all of these classes are quite short (except for flax, hemp, ramie, cotton, and kapok). However, the fibres obtained from inner bark of the plant are quite long. For example, hemp, jute, and kenaf can have fibre bundles as long as 400 cm and abaca, mauritius, and phormium are about half this length. Considering all types plant fibre, there is a vast array of potential long and short fibres for composite production. Table 1.3 shows a comparison of properties of natural lignocellulosic fibres and conventional man-made fibres. Jute, ramie, flax, and sisal are the most commonly used fibres for polymer composites.

Table 1.3: Properties of natural & synthetic fibres [20]

	Fibres	Density(g/cc)	Tensile strength(MPa)	Tensile modulus (GPa)	Elongation at break(%)	Decomposition, temperature(^{0}C)	Price in euro /Kg
Natural	Jute	1.3-1.5	187-540	3-55	1.4-3.1	270	0.7
	Ramic		585-900	33	2.0-3.5	260	
	Hemp fibres	1.4-1.5	580-1110	3-90	1.3-4.7	258	
	Bamboo			1.7-2.9	3.2		
	Flax	1.4	250-1000	12-100	1.3-40	280	0.15-0.76
	Sisal	1.4	5.7-855	24	2.9	270	0.7-1.02
	Cotton	1.5-1.6	350	11	2-10		0.35
	Banana fibre	1.3	791	30	2.10		0.7-0.9
	Kebnaf	1.4	930	53		270	
	Coconut		544	14			0.36-0.45
	Wood fibres	0.6		12	2.90		0.31-0.35
	Cellulose fibres	1.2		2.1			
	Wood flower	0.6		10			
Synthetic	E-glass fibre	2.5	1625-3400	72	2-5	756	1.6-2.0
	C-Glass fibre	2.5	2800	69		756	9.3-16
	S-Glass fibre	2.5	4600	87		946	8.3-20
	A-glass fibre	2.5	2400	68		696	2.5
	Aramid (Kelver	1.4	2380-3100	124		496	16-67
	Carbon fibre	1.8-1.9	2090-5200	525		3647	33-166
	Zirconium fibre	5.6	700	100		2497	41.7
	Alumina fibre	2.8	1000	100		1997	

1.13 Jute plant and fibre

Jute is a long, soft and shiny agro based fibre that can be spun into coarse and strong threads. It is produced from plants in the genus *Corchorus* that is classified with the family ***Sparrmanniaceae.*** Jute fibre obtained from the bark of two commonly grown species: *Corchorus Capsularies* (White jute) and *Corchorus Olitorius* (Tossa jute). The quality of tossa jute fibres is much better than other jute fibre. It is softer, silkier and stronger than white jute. The production is concentrated in Bangladesh and in some parts India, mainly in west Bengal. The jute fibre comes from the stem and ribbon (outer skin) of the jute plant. India, Pakistan, and China are the large buyers of local jute, while the United Kingdom, Spain, Germany and Brazil also import raw jute from Bangladesh.

A list of top ten producer of jute listed by `Food and Agricultural Organization of United Nations (Economic and Social Department) is shown below:

Table 1.4: Production of jute in different countries

Top ten jute producers in the year	
Country	Production (Tones)
Bangladesh	1,743,000
India	1,200,600
Peoples Republic of China	40,000
Myanmar	30,000
Uzbekistan	20,000
Nepal	16,988
Vietnam	8,800
Thailand	5,000
Sudan	3,300
Egypt	2,200
World(Total)	~2,833,041

Cultivation and retting: Farmers scatter the seeds on cultivated muddy soil. When the plants are about 15-20 cm tall, they are thinned out. About four months after planting, harvesting begins. The plants are usually harvested after they flower and before the flowers go to seed. The stalks are cut off close to the ground. The stalks are tied into bundles and retting to extract jute fibre.

Retting is the process of seperating fibre from the long lasting life stem or bast of the bast fibre plants. The available retting processes are: mechanical retting (hammering), chemical retting (boiling & applying chemicals), steam/vapor/dew retting and water or microbial retting. Water or microbial retting is most popular process in extracting jute fibres in Bangladesh..

Jute stalks bundles are submerged in water. The stalk stays submerged in water for near about 20 days. The retting process may require less time if the quality of the jute is better. The fibre extraction process is carried by the farmers while standing under water. The retted stalk is grabbed in bundles and hit with a long wooden hammer to make the fibre loose from jute core for extracting fibre. The extracted fibre is washed with water and squeezed for dehydration. The fibres is further washed with fresh water and allowed to dry in sun.

Jute fibre: Jute is a fibrous plant. The fibres are located in the phloem tissues. It has a woody core where fibres are cemented with that core by gummy and pectinous matters. These gummy and pectinous matters are decomposed and broken down at retting process and fibres are separated.

Fig. 1.4 Steps in harvesting jute fibre

1.14 Jute and allied fibres and their physical properties

Jute *(Corchorus capsularis & Corchorus olitorius)*, Kenaf *(Hibiscus cannabinus)* and Roselle *(H. sabdariffa var (Altissima)* are agri bast fibre plants next to cotton in importance. In the trade there are usually two names of jute, White and Tossa. *Corchorus capsularis* is called White Jute and Corchorus olitorius is called Tossa Jute. The genus of the jute is Corchorus and the family is Tiliaceae. In Bangladesh & India Roselle is usually called Mesta. Jute fibres are finer and stronger than Mesta and are, therefore, better in quality. The natural fibre color of white jute is white creamy and that of tossa jute is golden. Depending on demand, price and climate, the annual production of jute and allied fibres in the world remains around 3 million tonnes [21].

Structurally jute and allied fibre stems are composed of epidermis, cortex, large phloem, cambium, wide xylem or wood and central pith tissues. The tissue, phloem, is most important as it is connected with fibre development. Bast is another name of phloem tissue. Jute includes about 40 species mostly distributed in the tropical regions. The vegetative period of jute is about 3-5 months. At the harvest stage varieties of *C. capsularis* attain a height of about 5-12 feet and those of *C. olitorius* 5-15 feet or more. The stems of both are cylindrical. Leaves are glabrous. Flowers of both the species look yellow, are small in size and occur in condensed cymes [22] . The ribbons, fibres, leaves and stick contents of different jute and allied fibre plants vary considerably. The fibre content of *C. olitorius* jute plant is the highest and that of *H. sabdariffa* is the lowest. The green leaf content of *H. sabdariffa* plant is the highest. The dry ribbon contents of both *C. capsularis* and *C. olitorius* plants are higher than those of *H. cannabinus*. Physical compositions of different jute and allied fibre plants are given below:

Table 1.5: Physical compositions of different jute & allied fibre plants

Crop	Whole 100%	Ribbon %		Leaf		Sticks %		Fibres %
	Plant (t/ha)	Green	Dry	Green	Dry	Green	Dry	Dry
C. olitorius	46	38.7	11.7	11.0	2.7	50.3	16.6	6.8
C. capsularis	34	40.2	11.2	15.6	3.9	442	12.5	5.9
H. Sabdarifa	48	25.2	9.6	16.3	3.6	45.5	15.0	4.8
H. cannabinus	36	34.0	9.5	14.2	3.3	51.8	15.9	4.9
Approx. Avg.	40	37.0	10.3	14.2	3.3	48.8	15.2	5.5

Among jute, ramie, flax, hemp & cotton, jute has the shortest cell length (0.5-6.0 mm) and ramie has the longest fibre length (125-126 mm). In case of jute the average length of fibres from outer parts of the wedge is 0.3-2 mm and from the inner parts about 1-5 mm only. The values of different fibres table is given below:

Table 1.6: Cell lengths of jute & allied fibre plants

Properties	Jute	Mesta	Roselle	Ramic	Flax	Cotton
Ultimate cell Length (mm)	0.5-6.0	2-11	1.5-3.5	125-126	26-65	15-60
Length breadth ratio	110	140	100	3500	1700	1300

1.15 Chemical composition of jute fibres

The cell wall of a fibre is made up of a number of layers: the primary wall (the first layer deposited during cell development) and the secondary wall (S), which again is made up of three layers (S1, S2 and S3). In all lignocellulosic fibres, these layers contain cellulose, hemicellulose and lignin in varying amounts. The individual fibres are bonded together by a lignin-rich region known as the middle lamella. Cellulose attains its highest concentration in the S2 layer (about 50%) and lignin is most concentrated in the middle lamella (about 90%) which, in principle, is free from cellulose. The S2 layer is by far the thickest layer and dominates the properties of the fibres [23].

Main ingredients of jute fibres are about (59-61)% cellulose, (15-17)% pentosan or hemicellulose and (12.5-13.5)% lignin. There is a predominance of pentose sugars in hemicellulose and hence it is convenient to refer to it as pentosan. Chemical composition of the fibres depends on plant age, retting process etc. The details of chemical composition of jute fibre and other allied fibres are given below:

Table 1.7: Chemical composition of jute and other allied fibres

Constituent	Cellulose (%)	Pentosan (%)	Lignin (%)	Polyuronide (%)	Acetyl value	Fat & Wax (%)	Nitrogen matter (%)	Mineral substances (%)
Jute	59-61	15-17	12.5-13.5	4.8-5.2	2.8-3.5	0.9-1.4	1.56-1.87	0.5-0.79
Mesta	60	14.8	10.1	-	4.8	0.6	1.2	0.7
Roselle	59.7	15	9.9	-	4.8	0.6	0.8	0.5
Ramie	86.9	3.9	0.5	-	0.6	0.3	2.1	1.1

Cellulose is the basic structural component of all plant fibres. It is the most important organic compound produced by plants and the most abundant in the biosphere. The cellulose molecules consist of glucose units linked together in long chains, which in turn are linked together in bundles called microfibrils. The tensile strength of the cellulose microfibrils is very high. It is the strongest amongst the known material with a theoretically estimated tensile strength of 7.5 GPa or 1,087,500 pounds per square inch. In the S2 layer the microfibrils run almost parallel to the fibre axis. With S2 representing about 50% of the cell wall, this gives the fibres a very high tensile strength.

Hemicelluloses are also found in all plant fibres. Hemicelluloses are polysaccharides bonded together in relatively short, branching chains. They are intimately associated with the cellulose micro fibrils, embedding the cellulose in a matrix. Hemicelluloses are very hydrophilic (i.e., containing many sites to which water can readily forms bond).

Lignin is a Latin word for wood. Lignin is the compound which gives rigidity to the plant. Without lignin, plants could not attain long heights (e.g., trees) Lignin is a three-dimensional polymer with an amorphous structure and a high molecular weight. Of the three main constituents in fibres, it is expected that lignin would be the one with least affinity for water. Another important feature of lignin is that it is thermoplastic at temperatures around 90^0C it starts to soften and at temperatures around 170^0C it starts to flow). Lignin in jute makes the fibre resistant to ease microbial attacks, and provides better strength along with hardness and brittleness.

The polymers lignin and hemicellulose are responsible for most of the physical and chemical properties such as: biodegradability, flammability, sensitivity towards moisture, thermoplasticity, degradability by UV-light, etc.

1.16 Structure of jute fibre

Jute fibre has a multicellular structure made up of a number of unit cells of regular polygonal cross-section cemented together with non-cellulosic substances such as lignin and hemicelluloses. The multicellular structure is shown here.

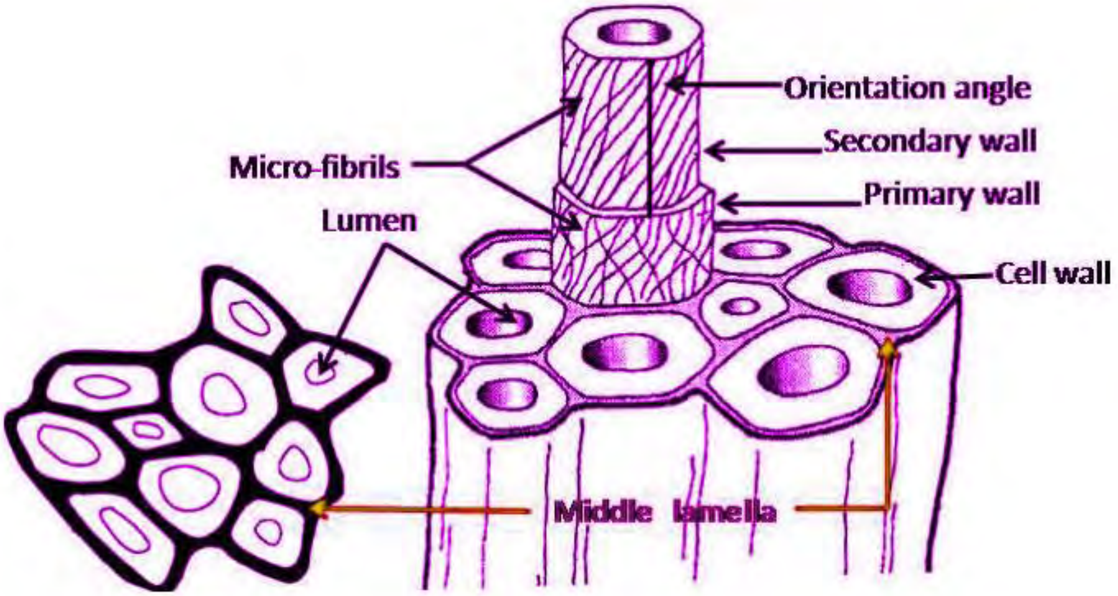


Fig. 1.5: Structure of jute fibre cell wall

The cell wall of a fibre is made of a number of layers. The so-called primary wall and secondary wall is made of the three layers. In all lignocellulosic fibres these are cellulose, hemicelluloses and lignin in varying amounts. The individual fibres are bonded together by a lignin rich region known as the middle lamella. Cellulose attains highest concentration in the second layer of secondary wall (about 50%) and lignin is mostly concentrated in the middle lamella (about 90%) which, in principle, is free of cellulose. Cellulose of the fibre, is a linear condensation polymer consisting of D-anhydroglucopyranose units joined together by glucosidic bonds. The long chains of cellulose are linked together in bundles called microfibrils.

1.17 Cellulose

Cellulose is a class of carbohydrates. It contains 44.4% carbon, 6.2% hydrogen and 49.4% of oxygen. Cellulose [12] is the principal constituent of all plant life. In cellulose the anhydro glucose units linked together through 1 and 4 positions by β-glycoside linkage [13]. The empirical formula of cellulose $(C_6H_{10}O_5)_n$ corresponds to a poly anhydride of glucose. The two terminal glucose residues of a cellulose molecule contain two different end groups; one contains a reducing hemiacetal group at C-1 position and is therefore known as the reducing end group, whereas the other contains an extra secondary hyroxyl group at C-4 position and is known as the non-reducing end group. The structure of cellulose molecule is given bellow:

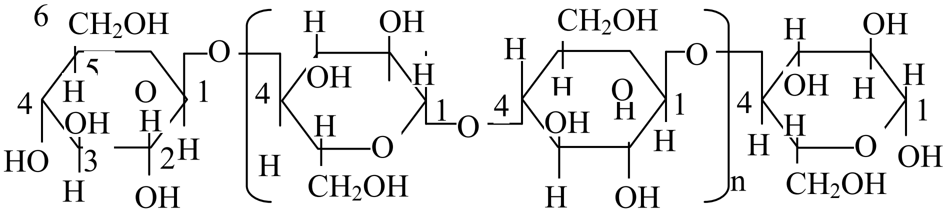


Fig.1.6: Structure of Cellulose.

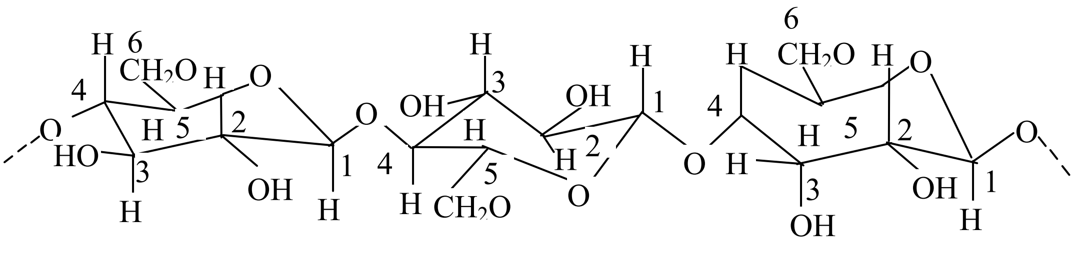


Fig.1.7: Rod like chain structure of cellulose.

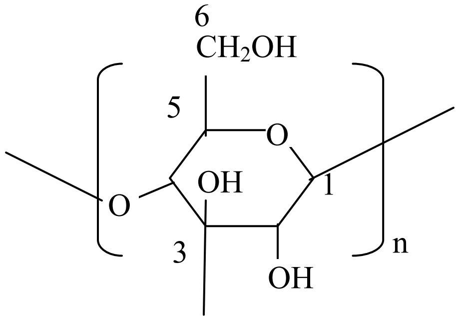


Fig.1.8: Cellulose unit

There are two secondary and one primary alcoholic hydroxyl groups in each basic anhydro-D-glucose unit $(C_6H_{10}O_5)_n$, which are attached to the carbon atoms at positions 2, 3 and 6 respectively of the basic unit. The reactivity of the hydroxyl groups varies from reaction to reaction. In many reactions (mainly estarification), the primary hydroxyl groups have higher reactivity. The two secondary hydroxyl groups at 2 – and 3- carbon atoms differ somewhat in their reactivity. The high hydroxyl content of cellulose might suggest high water solubility. This is because of interaction and formation of intra/intermolecular. /Intermolecular hydrogen bonding [23] between hydroxyl groups of adjacent chains as shown in the following figure and water molecules.

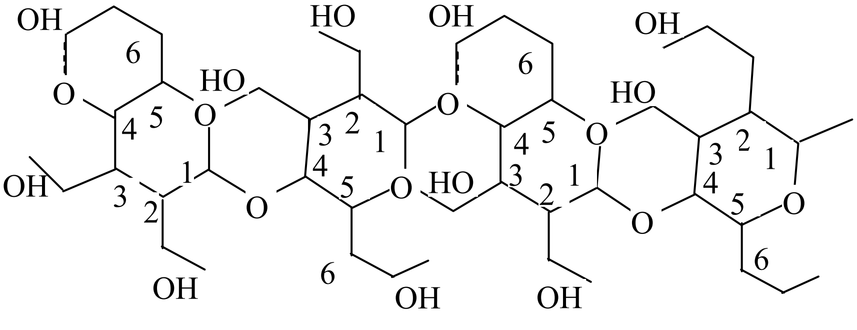


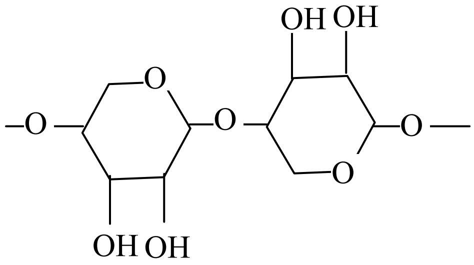
Fig.1.9: Hydrogen bonding in adjacent chains

From X-ray diffraction studies [24], it has been concluded that cellulose has two regions: (i) crystalline and (ii) amorphous. A chief portion of cellulose is arranged in crystalline areas. The crystalline regions are dispersed in the amorphous regions. The amorphous is the disordered region where most of the chemical reaction takes place. The crystalline areas are oriented parallel to the fibre axis and surrounded by amorphous areas.

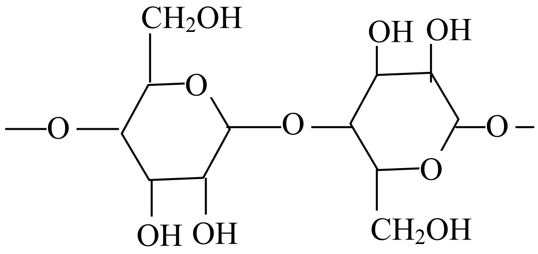
As early as 1920, Herzog and Jancke [25] recognized that cellulose from different sources such as cotton, ramie, wood, jute and flax gave indentical X-ray diagrams and concluded that all these fibres had indentical crystalline structure.

1.18 Hemicellulose

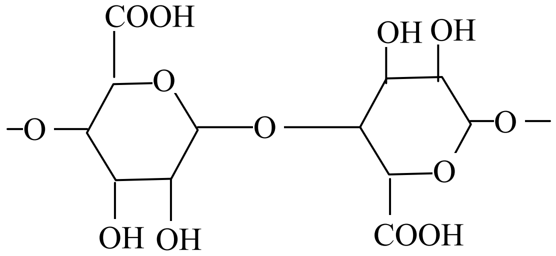
Hemicellulose also belongs to the group of cell wall polysaccharides. The hemicelluloses in isolated form are amorphous substances. Hemicellulose may be regarded as a mixture of polysaccharides which interpenetrates the cellulose and lignin of plant cell walls. It is a group of cell wall polysaccharides that unlike cellulose are soluble in dilute alkali solution and are readily hydrolysed to pentose and hexose with some uronic acid [26]. Structure of some of them are given below-



(a)



(b)



(c)

Fig.1.10: (a) Xylan (b) Galactan (c) Pectic acid

Chowdhury and Saha [27] identified a number of simple sugars and galacturonic acid from the hydrolysate of jute hemi cellulose. Norman [28] found about 15-18% xylan type hemicellulose in jute fibre. He also classified hemicellulose into "polyuronides" and cellulosan". The xylan is a cellulosan type hemicellulose and is free from uronic acid, while polyuronides invariably contain uronic acid. High xylan content fibre usually means high lignin content and is a characteristic of a fibre of poor quality and vice versa.

Sarkar [29] and others showed xylose linked with methyluronic acid formed the basic building units of hemicellulose in jute fibre. It appeared that six xylose units were linked with one methl glucouronic acid unit.

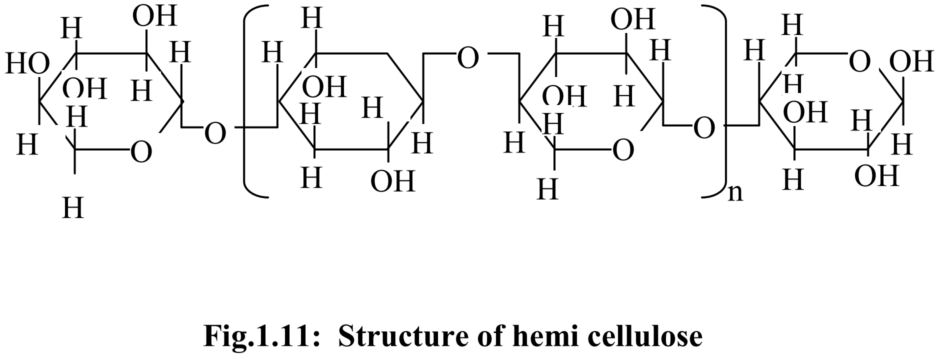


Fig.1.11: Structure of hemi cellulose

The acetyl content of the jute fibre is associated with the hemicellulose components. Sarker [29] and co-workers determined the acetyl content of delignified jute hemicellulose and found practically all the acetyl groups of original jute in it. The hemicellulose is relatively short chain compounds. The short chain poly saccharides contribute would, therefore, rigidly into the largely (ordered)oriented cellulose structure between which some cross bridging or looping may occur. Removal of hemicellulose from fibre decreases its tensile strength appreciably though there is some improvement in the texture and dyeability [30] of the fibre. The removal of hemicellulose from jute causes disturbance in physico-chemical balance of the molecule which decreases its length.

1.19 Lignin

The principal substances embedded in cellulose is lignin.. Although it is not a polysaccharide but it remain along with the polysaccharide and cellulose constitutes of the cell wall of wood and plants. Actually, lignin acts as the binding material i. e. cementing the cellulose and other polysaccharide (cellulose and hemicellulose) in fibres to form the wood structure.

It is reported that lignin consists largely, if not entirely, of phenylpropane building stones [31].

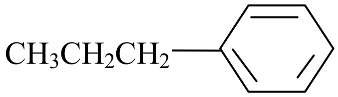


Fig.1.12: Building block of lignin

The lignin of coniferouse wood consist of phenyl ring which carries a hydroxyl group at the para position and methoxy group at the meta position to the side chain, thus forming a guaiacyl group

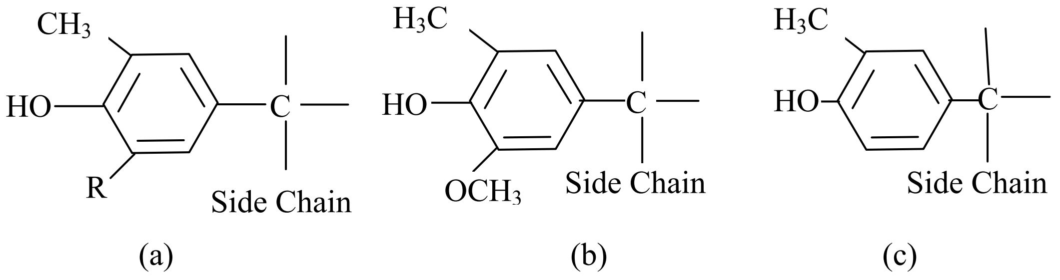


Fig.1.13: (a) Guaiacyl group (b) Syringyl group (c) Vantlly group

In lignins of deciduous wood, phenyl rings (in which of the building units have an additional methoxy group at the 5- carbon atom, thus forming a 4- hydroxy-3, 5-dimethoxyphenyl group) form syringyl group ($R=OCH_3$) and a little amount of vanillyl group($R=H$). Thus lignin is therefore, composed of vanillyl and syringyl group containing building blocks.

The lignin of monocotyledonous plant consists of some building blocks in which the phenyl ring contains only a hydroxyl group at the para position and no methoxy groups at all, thus froming a *p*-hydroxyphenyl group to the side chain.

According to Brauns [32], lignin contains one free phenolic hydroxyl group per lignin building unit consisting of 4-5 building stones. This means that about four of the other phenolic hydroxyl groups in the lignin building unit must be blocked, either by ether formation within the lignin molecule or by cross linkages with other lignin molecules. There is also a possibility that in protolignin (lignin *in situ*) some phenolic hyroxyl groups are combined with carbohydrates by a glucosidic bond. The isolated lignin and lignin in situ contain free phenolic hydroxyl groups. This is shown by the fact that after being methylated with diazomethane, they yield veratric aldehyde. The relative amount of phenyl group has been analysed. In soluble native spruce lignin, there is one phenyl group for every 7 building stones and in milled sprucewood lignin, there is one phenyl group for every 14 building stones. These free guaiacyl propane-building stones must be present either as end group, in a straight chain of 7 and 14 building stones, respectively, or at the end of a shorter chain with some side (branched) chains.

Klason originally ascribed the color reaction given by lignin with chloroglucinol and hydrochloric acid. This indictes the presence of a coniferyl aldehyde group (shown in building block A of Fig. 1.13) in the lignin molecule. Adler and co-workers [33, 34] Kratzl and Rettenbacher [35] and Pew [36, 37] have confirmed this fact.

Swedish lignin chemists have estimated the number of free phenolic hydroxyl groups to be one for every 5 building stones and coniferyl aldehyde groups (shown in building block A of fig. 1.13) to be one for every 35 building blocks in milled sprucewood lignin. Hence the ratio of free phenolic hydroxyl group to the coniferyl aldehyde group is 7:1.

The presence of aliphatic hydroxyl groups in lignin has been established. Some of these groups are present as α- hydroxyl groups in a benzyl alcohol grouping. Apart from these hydroxyl groups in terminal building blocks, some secondary hydroxyl groups are present at the α- carbon atom of other building blocks. The number of aliphatic hydroxyl groups varies between 4 and 5 per lignin building unit.

The presence of carbonyl groups has been shown by Brauns [38], Nord [39] and also by Bjorkman [40], who established the presence of one carbonyl group per lignin building unit. The presence of a carbonyl group in the from of a keto-enol group,-COCH(OH)- (shown in building block F of Fig. 1.13), in lignin was postulated by Merewether [41].

Kratzl [42] established that the keto-enol group -COCH(OH)- is attached to the remainders of the lignin molecule through an acetal or hemiacetal bond at the γ-carbon atom of the side chain.

Figure.1.13 is constructed by combining the building units at random and assumed to be the present structure of lignin molecule.

Building block A carries a coniferyl aldehyde group. It may be partially substituted by a coniferyl alcoholic group. A is combined with building block B through an ether bond between the phenolic hydroxyl group of A and a hydroxyl group at the β-carbon atom of B. A and B form the structure of α-guaiacylglycerol B-coniferl ether. B is connected with building stone C through a linkage between the carbon atom 5 of B and the β-carbon atom of C and an ether linkage between the phenolic hydroxyl group of B and the hydroxy group at the α-carbon atom of C, thus forming a phenylcoumaran ring. C is connected with D through a linkage between the 2 carbon atoms at the 5-positions of the benzene rings, thus forming a biphenyl group. E is attached to F in the same way as A to B. At the α-carbon atom, F has a carbonyl group. F and G are linked by a β- aryl bond in the same way as A and B. Building blocks H and I form a side chain in the lignin molecule connected through an ether linkage formed by the phenolic hydroxyl group of C and the hydroxy group of the β-carbon atom of H. H and I are connected through an α, β-carbon-to-carbon linkage. Building stone I is connected with building block J through an ether linkage between the phenolic hydroxyl group of I and the hydroxyl group at the α-carbon atom of J. the side chain of J contains a carbonyl group at α-, and a methylene group at the β- carbon atom. Building blocks A-B form a straight chain in which they are put together at random.

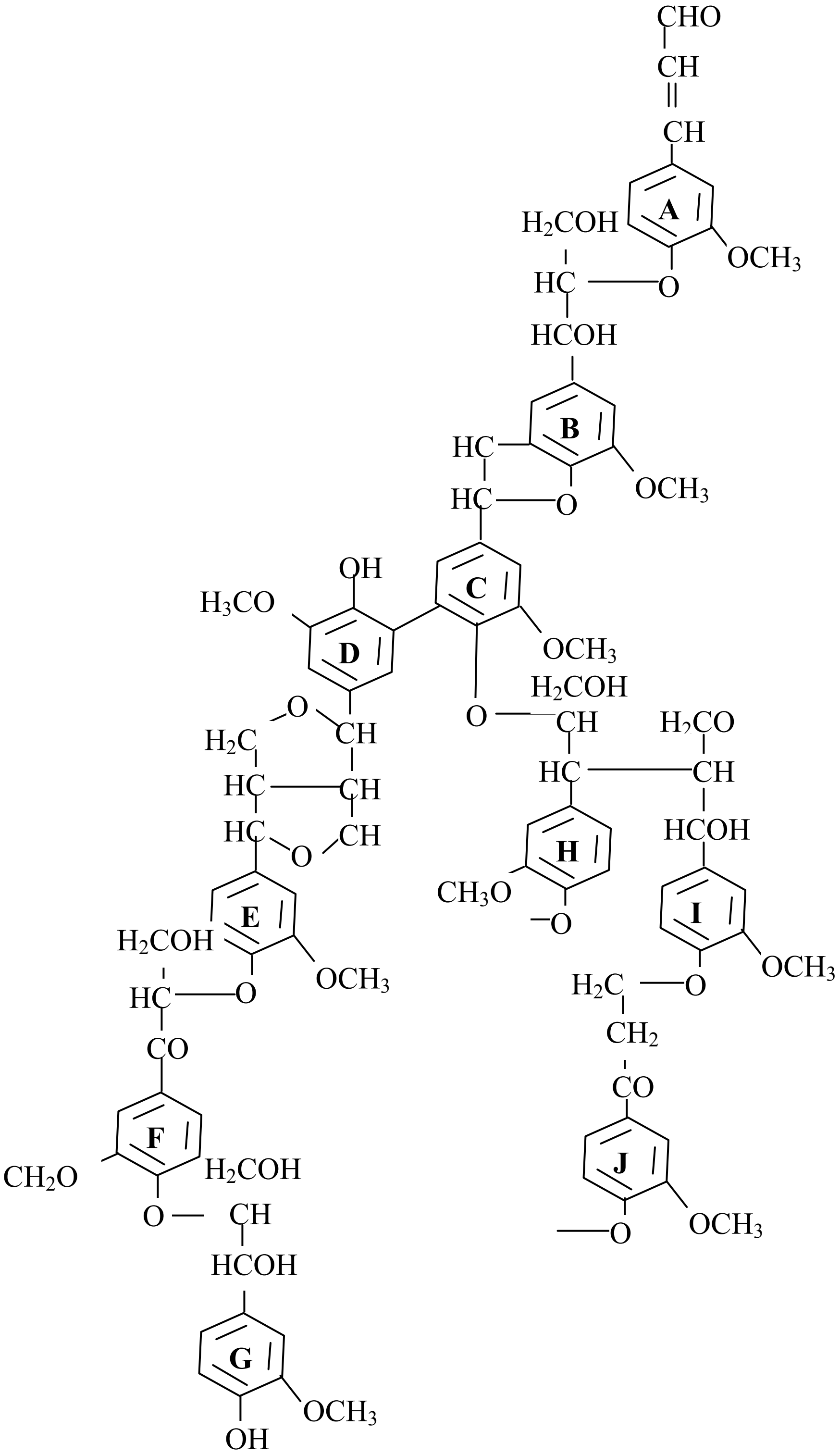


Fig.1.14: Structure of lignin

1.20 Advantages and disadvantages of using jute fibre in plastic composites

Advantages: Jute fibre has many advantages over other fibres as reinforcing agent in plastic composites. These are summerised below:

- ✓ Jute fibre is completely bio-degradable and recyclable and hence environment friendly.
- ✓ It does not require pesticide and chemical fertilizer.
- ✓ It is the cheapest natural fibre obtained from the bast or skin of the plant's stem.
- ✓ It has high tensile strength, low extensibility and ensures better quality of coarse fabrics.
- ✓ It helps to make best quality industrial yarn, fabric, net and sacks.
- ✓ It has good thermal and acoustic insulating properties.
- ✓ It has good electrical insulating properties,
- ✓ It's low specific weight result in a higher specific strength and stiffness than glass.
- ✓ It is considered to be a non-hazardous fabric material.

Disadvantages: In comparison to the advantages listed above the disadvantages of jute fibre are low. These are listed below:

- ✓ Variable quality, depending on unpredictable influences such as weather.
- ✓ Moisture absorption, which eases swelling of the fibres.
- ✓ Low durability (treatment can improve this considerably).
- ✓ Poor fire resistance.
- ✓ Price of fibre fluctuates by depending on production.

1.21 Lignocellulogic fibre- reinforced thermoplastic composites

There is a long history of the use of lignocellulosic materials with thermosetting polymeric materials, like phenol or urea-formaldehyde resin in the production of composites. The use of lignocellulosic fibres with thermoplastic polymer, however, is a more recent innovation. Lignocellulosic fibres have been incorporated in a wide variety of thermoplastic materials such as polypropylene, polyethylene, polystyrene, poly-vinyl chlordide, polyamides etc. Thermoplastic materials selected for use with lignocellulosic materials must melt at low temperature or below the degradation point of the lignocellulosic fibre, normally less than 220^{0}C [43].

Incorporation of lignocellulosic fibres with thermoplastic materials can be done in several ways [44]. In one case, thermoplastic materials are simply mixed with biobased powder or fibre (nut shell powder or wood fibre are presently used) and the mixtures are heated. The plastic melts, but the wood fibre and plastic components remain as distinct separate phases. One example of this technology is reinforced thermoplastic composites, which are light in weight, have improved acoustical, and heat reformability properties, and the cost is less than comparable products made from plastic alone. These advantages make possible exploration of new processing techniques, new applications, and new markets in such areas as packaging, furniture, housing, automobiles etc.

A second way to incorporate wood fibre in plastics is to use a compatibilizer to make the hydrophobic (plastic) material mix better with the hydrophillic (wood) material. The two components remain as separate phases, but if delamination and/ or void formation can be avoided, properties can be improved over those of either separate phase. These types of materials are usually referred to as wood fibre/plastic blends [45].

A third way of incorporation of wood fibre in thermoplastics is in products that can best be described as wood-plastic alloys. In this case the wood and plastic become one material and it is not possible to separate them. The formation of wood-plastic alloys is possible through fibre modification and grafting research. This can be done if it is considered that biobased fibres consist of a thermoset polymer (cellulose) in a thermoplastic matrix (lignin and the hemicelluloses). The glass transition temperature (GTT), however, of the thermoplastic matrix is higher than the decomposition temperature of the fibre. If the GTT is lowered through chemical modification, it should be possible to thermoplasticize the lignin and the hemicelluloses at temperatures below decomposition. If a reactive thermoplastic is used, it is then reacted with the modified biobased fibre and it would be possible to form biobased fibre/ thermoplastic alloys. Rowell et al [46] reported that only the hemicelluloses and lignin have been modified in thermoplasticization using maleic and succinic anhydriedes. Matsuda et al [47] also extensively investigated the esterification of wood in order to make a totally thermoplastic material. They esterified wood without a solvent by simply heating wood powder with succinic anhydride in a mixer for 3 h at temperatures higher than 60^{o}C.

1.22 Properties of lignocellulosic fibre- thermoplastic composites

Three to three and half decades before, the concept of blends and alloys were essentially unknown in plastics industry. Blends and alloys have revolutionized the plastics industry, as they offer new materials with properties that were not achieved before. These materials can be tailored for specific end uses. The jute and kenaf industries have the same opportunity to follow this trend and greatly expand markets for new materials based on blends and alloys with other resources. Newer materials and composites that have both economic and environmental benefits are being considered for applications in the automotive, building, furniture, and packaging industries. Mineral fillers and fibres are used frequently in the plastics industry to achieve desired properties or to reduce the cost of the finished article. For example, glass fibre is used to improve the stiffness and strength of plastics, although there are several disadvantages associated with its use. Glass-fibre production requires a great deal of energy-processing temperatures that can exceed 1200^{0}C. They tend to abrade processing equipment and increase the density of the plastic system. The use of lignocellulosic fibres in thermoplastics has received a lot of interest due to their low densities, low cost, and low abrasive nature. The inherent polar and hydrophilic nature of the jute and kenaf fibres and the nonpolar characteristics of the polyolefins lead to the difficulties in compounding and result in inefficient composites [48]. The high moisture absorption of the linocellulosic fibres and their low microbial resistance are disvantages that need to be considered, particularly during shipment and long-term storage as well as during processing of the composites [49]. Proper selection of additives is necessary to improve the interaction and adhesion between the fibre and matrix phases. Recent research on the use of jute and kenaf fibre suggests that these fibres have the potential for being used as reinforcing fillers in thermoplastics. The low cost and low densities and the nonabrasive nature of the fibres allow high filling levels and thereby result in significant cost savings. The primary advantages of using these fibres as additives in plastics are: low densities, low cost, nonabrasive, high filling levels, low energy consumption, high specific properties, renewability, wide distribution, biodegradability, and improvement of the rural/agricultural-based economy.

Jute and other lignocellulosic materials change dimensions with changing moisture content because the cell wall polymers contain hydroxyl and other oxygen-containing groups that attract moisture through hydrogen bonding [50]. This hydrophilic behavior affects the properties of the fibres themselves as well as the properties of their composites. The hydrophilic character of fibres is usually incompatible with hydrophobic matrix material unless a compatibilizer or coupling agent is used. This leads to poor interfacial adhesion between: the fibre -and matrix as well as poor fibre dispersion.

In general, cellulosic fillers or fibres have a higher Young's modulus as compared to thermoplastics materials, thereby contributing higher stiffness to the composites. The increase in the Youhg's modulus with the addition of cellulosic materials depends on many factors such as amount of fibres used, orientation of the fibres, interaction and adhesion between the fibre and matrix [51]. In general, dispersing agents and/or coupling agents, are necessary for the property enhancement, when fibres are incorporated into thermoplastics. Dispersing agent facilitates the fibre dispersion and improves the interfacial adhesion between the fibres and the polymer matrix. Grafting of chemical species onto the fibre surface has also been reported to improve the interaction between the fibres and matrix. Although grafting can improve the properties of the composite to a significant extent, this process increases the material cost of system. The use of dispersing agents and/or coupling agents is a cheaper route to improve properties and makes more practical sense for high volume, low cost composite systems.

In a natural fibre-thermoplastic composite the lignocellulosic phase is present in a wide range of diameters and lengths, some in the form of short filaments and others in the form that seems closer to the individual fibre. The high shearing energy of blending the fibres and the polymer in a mixer results in fibre attrition but can also axially separate the filaments into discrete individual fibres. Cellulosic fillers/fibres can be classified under three categories depending on their performance when incorporated into a plastic matrix. Wood flour and other low cost agriculture based flour can be considered as particulate fillers that enhance the tensile and flexural moduli of the composite with little effect on the composite strength. Wood fibres and recycled newspaper fibres have higher aspect ratios and contribute to an increase in the moduli of the composite and can also improve the strength of the composite when suitable additives are used to improve stress transfer between the matrix and the fibres. The improvement in modulus is not significantly different than the cellulosic particulate fillers. The most efficient cellulosic additives are some natural fibres such as kenaf, jute, flax, etc. The specific Young's modulus, specific flexural modulus, the ratio of the composite modulus to the composite specific gravity of composites with natural fibres such as kenaf are significantly higher than those with wood fibres. The specific moduli (the ratio of the composite modulus to the composite specific gravity) of high fibre volume fraction of bast fibres-PP composites are high and in the range of glass fibres-PP composites. The most efficient natural fibres are those that have a high cellulose content coupled with a low micro fibril angle resulting in high filament mechanical properties. A list of mechanical properties of PP composites reinforced by different natural fibre and inorganic substances is given in Table no. 1.8 [52-54] .

Table 1.8: Comparison of filled reinforced PP composites

Filled/Rain-forcement of PP	ASTM Standard	None	Kenuf	Jute	Talc	Ca_2CO_3	Glass	Mica
% filler by weight	-	0	50	50	40	40	40	40
% filler by volume (estimated)	-	0	39	39	18	18	19	18
Tensile modulus, GPa	D 638	1.7	8.3	7.8	4	3.5	9	7.6
Specific Tensile modulus, GPa	-	1.9	7.8	7.2	3.1	2.8	7.3	6.0
Tensile strength, MPa	D 638	33	68	72	35	25	110	39
Specific Tensile strength, MPa		37	58	67	28	20	89	31
Elongation at break, %	D 638	10	2.2	2.3	-	-	2.5	2.3
Flexural strength, MPa	D 790	41	91	99	63	48	131	62
Specific flexural strength, MPa	-	46	85	92	50	38	107	49
Flexural modulus, GPa	D 790	1.4	7.8	7.7	4.3	3.1	6.2	6.9
Specific flexural modulus, GPa	-	1.6	7.3	7.1	3.4	2.5	5.0	5.5
Notched Izod imjpact, j/m	D256A	24	32	31	32	32	107	27
Specific gravity	-	0.9	1.07	1.08	1.27	1.25	1.23	1.26
Water absorption ,% (24 hrs)	D 570	0.02	1.05	-	0.02	0.02	0.06	0.03
Mold (liner) shrinkage, cm	-	0.028	0.002	-	0.01	0.01	.004	-

1.23 Effect of coupling agents on the composite properties

Coupling agents improve the compativility between hydrophilic reinforcing agent and hydrophobic polymer preferably via chemical bonds. Their use confers reinforcing properties of inexpensive extenders as well as improves the performance of reinforcements, and allows the filler content to be increased. The reinforcing effect of fillers depends on their chemical nature , shape (fibres, flakes, spheres), and size (fibre length, particle size). The most important reinforcement effects are[55]:

1. Increase strength, ultimate elongation, rigidity (modulus of elasticity), and in some cases impact strength.
2. Improve heat distortion temperature and dimensional stability, reduce shrinkage, and improved mechanical stability at high temperatures and over extended times (fatigue)
3. Modify of density (usually increase)
4. Improve chemical resistance and lower water absorption
5. Better surface quality and surface hardness

Special fillers are used to obtain composites with the following properties:

1. Low flammability
3. Electrical conductivity and electromagnetic shielding
4. Radiation and UV shielding
5. Biodegradability
6. Noise suppression

1.24 Composite manufacturing processes

There are a number of processes by which composite are manufactured. Among the various methods the following are very widely used.

(1) Compression moulding

(2) Extrusion moulding

(3) Injection moulding

(4) Hand moulding

As the ingredient of composite materials as a whole, there are many options to be chosen from the areas of resins, fibres and coires, all have their own unique set of properties such as strength, stiffness, toughness, heat resistance, cost, production rate etc. However, the end properties of a composite produced from these different materials is not only a function of the individual properties of the resin matrix and fibre (and in sandwich structure the core as well), but is also a function of the way in which the materials themselves are designed to be the part of the composite and also the way in which they are processed.

1.25 Application of lignocellulosic fibre reinforced thermoplastic composites

Natural fibres are now widely used in practical applications, mostly in the packaging and automobile industries [56-64]. In the latter area, the low density fibre's can be fully employed, resulting in important weight savings and thus reduced fuel consumption. Also the good thermal and acoustic insulation properties, due to the presence of hollow space inside the fibres, are an asset for interior parts. Some other advantages of natural fibres that promote their use in automotive components are the low abrasion on tools and favourable accident protection (less splintering during impact). Also recyclability of the parts is a major concern now a days in automotive industry, favouring natural fibre composites over glass fibre reinforced polymers. In this regard, mainly thermal recycling or incineration with energy recovering benefits by natural fibre composites, because of the considerable residue obtained after burning of glass fibre reinforced composites. Some researchers hold the view that natural fibre composites can be reprocessed into parts with a superior performance compared to their recycled glass fibre counterparts, because the higher flexibility of the natural fibres in comparison with glass fibres would result in less fibre shortening during the recycling processes. However, bearing in mind the fibres vulnerability towards thermal degradation, this statement becomes rather questionable since a reforming process at elevated temperature would eventually harm the natural fibres to a significant extent. Anyway , a thorough research regarding the quality of recycled natural fibre reinforced polymer composites is still lacking and would be necessary to give a well founded opinion on this matter.

In spite of all the benefits mentioned above, the applications of natural fibre composites are still limited to semi-structural parts, bearing no high mechanical loads. This is because of the mediocre interface properties between the fibres and a polymer matrix, resulting in low composite performance. Other applications of flax material are particleboards, where flax chives compete with wood particles and paper production [65]. These applications utilize the inferior substances of the flax stem and fibre for a functional purpose, but are examples of cheap filler materials, rather than composite reinforcements. To date, no full load bearing applications for natural fibre composites are known because of the above mentioned problem of poor interaction between fibres and matrix. Therefore, pre-treatments of fibre and/or matrix are a prerequisite to obtain qualitative composite parts. This will raise of course the cost of the final product, excluding hereby applications where cost is a key issue.

1.26 Carrot

Carrot is a herbaceous root vegetable, Daucus carota subsp. sativus, in the-parsley family (Apiaceae or Umbelliferae), which also includes the similar parsnip. The domesticated carrot is a cultivar of the wild carrot (Daucus carota), also known as "Queen Anne's lace," which is native to temperate parts of Europe and southwest Asia. The term carrot also applies to the long, edible, usually tapering taproot of the domesticated form. These taproots commonly are orange in color, but may be a variety of colors depending on the cultivar, including white, pink, yellow or purple. They have a crisp texture when fresh.

Carrot growing wild play a valuable role in the ecosystem: the leaves and roots are a source of food for animals, such as larvae of Lepidoptera species, and carat flowers provide nectar for bees, who in turn pollinate the plants. The domesticated carrot provides a nutritious food for humans/and its distinctive flavor, texture, and color is a source of joy. Humans have learned how to cultivate this root vegetable, produce diverse cultivars of it, and prepare it in many ways, including eating it raw, cooking it in a soup or stew, making carrot cake, and so forth.

Description

Daucus carota is a member of the Apiaceae or Umbelliferae family (both names are allowed by the International Code of Botanical Nomenclature). This family comprises unusually aromatic plants with hollow stems, including the cumin, parsley, carrot, parsnip, dill, caraway, fennel, and other relatives. The family also includes some highly toxic plants, such as hemlock.

Apiaceae is a large family with about 300 genera and more than 3,000 species. The earlier name Umbelliferae derives from the inflorescence (arrangement of flowers on a stem) being in the form of a compound "umbel." Each umbel comprises many small radially symmetrical flowers with five small sepals, five petals, and five stamens.

The wild carrot, Daucus carota, known also as bishop's lace or Queen Anne's lace, is a flowering plant in the family Apiaceae that is native to temperate regions of Europe and southwest Asia. Daucus carota subsp. sativus is the domesticated form of the wild carrot Daucus carota. It has been bred for its greatly enlarged and more palatable, less woody-textured edible taproot, but is still the same species.

Wild carrot or Queen Anne's Lace

Wild carrot is a variable biennial plant, usually growing up to one meter (39 inches) tall and flowering from June to August. The umbels are claret-colored or pale pink before they open, then bright white and rounded when their hundreds of tiny blossoms are in full flower. The umbels measure 3-7 centimeters (1.2 - 2.75 inches) wide with a whorl of narrow bracts beneath. Finally, as the flowers turn to seed, the umbels contract and become concave like a bird's nest. This has given the plant its British common or vernacular name, bird's nest. Very similar in appearance to the deadly poison hemlock, it is distinguished by a mix of bi-pinnate and tri-pinnate leaves, fine hairs on its stems and leaves, a root that smells like the cultivated carrots, and occasionally a single dark red flower in its center.

Wild carrot was introduced and naturalized in North America, where it is often known as "Queen Anne's lace." It is so called because the flower resembles lace, the red flower at the center represents a blood droplet where Queen Anne pricked herself with a needle when she was making the lace. The function of the tiny red flower, colored by anthocyanin, is to attract insects. Because Queen Anne's lace was introduced into North America as a foreign species, the United States Department of Agriculture has listed it as a noxious weed.

The edible part of a domesticated carrot, *Daucus carota* subsp. *sativus* is a taproot. It grows a rosette of leaves in the spring and summer, while building up the stout taproot, which stores large amounts of sugars for the plant to flower in the second year. The flowering stem grows to about one meter (39 inches) tall.

History

The wild ancestors of the carrot are likely to have come from Afghanistan which remains the center of diversity of *D. carota,* the wild carrot. Selective breeding over the centuries of a naturally-occurring subspecies of the wild carrot, *Daucus carota* subsp. *sativus* has produced the familiar garden vegetable (Rose and O'Reilly 2006; Mabey 1997).

In early use, carrots were grown for their aromatic leaves and seeds, not their roots. Some relatives of the carrot are still grown for these, such as parsley, fennel, dill, and cumin. The first mention of the root in classical sources is in the first century C.E. The modern carrot appears to have been introduced to Europe in the eighth to tenth centuries; Ibn al-Awam, in Andalusia, describes both red and yellow carrots. Simeon Seth also mentions both colors in the eleventh century. Orange-colored carrots appeared in the Netherlands in the seventeenth century (Dalby 1997).

In addition to wild carrot, these alternative (mostly historical) names are recorded for *Daucus carota:* bee's-nest, bee's-nest plant, bird's-nest, bird's-nest plant, bird's-nest root, carota, carotte (French), carrot, common carrot, crow's-nest, daucon, dawke, devil's-plague, fiddle, gallicam, garden carrot, gelbe rube (German), gingidium, hill-trot, laceflower, mirrot, mo'hre (German), parsnip (misapplied), Queen Anne's lace, rantipole, staphylinos, and zanahoria (Spanish) (Nowick 2007).

Cultivars

Carrots come in a wide variety of shapes and sizes.Carrot cultivars can be grouped into two broad classes, **eastern carrots** and **western carrots.** More recently, a number of novelty cultivars have been bred for particular characteristics.

Eastern carrots

Eastern carrots were domesticated in Central Asia, probably in modern-day Afghanistan in the tenth century, or possibly earlier. Specimens of the eastern carrot that survive to the present day are commonly purple or yellow, and often have branched roots. The purple color common in these carrots comes from anthocyanin pigments.

Western carrots

Carrots with multiple taproots (forks) are not specific cultivars, but are a byproduct of damage to earlier forks, often associated with rocky soil.

The western carrot emerged in the Netherlands in the fifteenth or sixteenth century, its orange color making it popular in those countries as an emblem of the House of Orange and the struggle for Dutch independence. The orange color results from abundant carotenes in these cultivars. While orange carrots are the norm in the West, other colors do exist, including white, yellow, red, and purple. These other colors of carrot are raised primarily as novelty crops.

The Vegetable Improvement Center at Texas A&M University has developed a purple-skinned, orange-fleshed carrot, the *Beta Sweet* (also known as the maroon carrot), with substances to prevent cancer, which has entered commercial distribution.Western carrot cultivars are commonly classified by their root shape:

- ✓ *Chantenay* carrots are shorter than other cultivars, but have greater girth, sometimes growing up to eight centimeters (three inches) in diameter. They have broad shoulders and taper towards a blunt, rounded tip. They are most commonly diced for use in canned or prepared foods.
- ✓ *Imperator* carrots are the carrots most commonly sold whole in U.S. supermarkets; their roots are longer than other cultivars of carrot, and taper to a point at the tip.
- ✓ *Danvers* carrots have a conical shape, having well-defined shoulders and tapering to a point at the tip. They are somewhat shorter than imperator cultivars, but more tolerant of heavy soil. Danvers cultivars are often pureed as baby food.
- ✓ *Nantes* carrots are nearly cylindrical in shape, and are blunt and rounded at both the top and tip. Nantes cultivars are often sweeter than other carrots.

Carrots selectively bred to produce different colors

While any carrot can be harvested before reaching its fail size as a more tender "baby" carrot, some fast-maturing cultivars have been bred to produce smaller roots. The most extreme examples produce round roots about 2.5 cm (one inch) in diameter. These small cultivars are also more tolerant of heavy or stony soil than long-rooted cultivars such as *nantes* or *imperator*. The "baby carrots" sold ready-to-eat in supermarkets are, however, often not from a smaller cultivar of carrot, but are simply fall-sized carrots that have been sliced and peeled to make carrot sticks of a uniform shape and size.

Carrot flowers are pollinated primarily by bees. Seed growers use honeybees or mason bees for their pollination needs.
Carrots are used as food plants by the larvae of some Lepidoptera species, including common swift, garden dart, ghost moth, and large yellow underwing.

Food enthusiasts and researchers have developed other varieties of carrots through traditional breeding methods.

One particular variety lacks the usual orange pigment from carotenes, owing its white color to a recessive gene for tocopherol (Vitamin E). Derived from *Daucus carota* L. and patented (US patent #6,437,222) at the University of Wisconsin-Madison, the variety is intended to supplement the dietary intake of Vitamin E.

Production trends

In 2005, China was the largest producer of carrots and turnips, according to the Food and Agricultural Organization, although figures obtained from China sometimes are considered suspect. According to these figures, China accounted for at least one third of the global output, followed by Russia and the United States.

1.26.1 Composition of carrot

Moisture	from 86 to 89%
Protein	0.7%
Crude fibre	2.4%
Ca	34 mg/100 g
P	25 mg/100 g
Na	40 mg/100 g
K	240 mg/100 g
Mg	9 mg/100 g
Ca	80 mg/100 g
Fe	2.2 mg/100 g
Cu	0.02 mg/100 g
Zn	0.2 mg/100 g
Carotene	5.33 mg/100 g
Thiamine	0.04 mg/100 g
Riboflavin	0.02 mg/100 g
Vitamin C	4 mg/100 g
Energy value	126 kJ/100 g
Reducing sugar	1.67–3.35%
Non-reducing sugar	1.02–1.18%
Total sugar	2.71–4.53%
Fat	0.5%

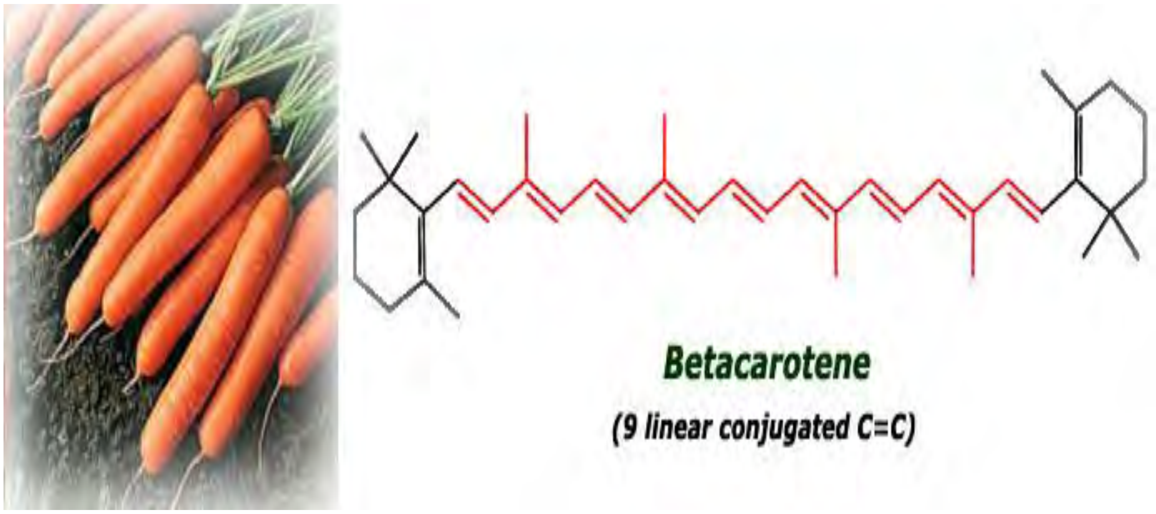


Fig. 1.15: structure of carotene

1.26.2 Uses of carrot

Carrot can be eaten raw as a whole, chopped, grated, or added to salads for color or texture. They are also often chopped and boiled, fried or steamed, and cooked in soups and stews, as well as fine baby foods and select pet foods. A well known dish is *carrots julienne.* Grated carrots are used in carrot cakes, as well as carrot puddings, an old English dish thought to have originated in the early 1 800s. Together with onion and celery, carrots are one of the primary vegetables used in a *mirepoix* to make various broths.

The greens are edible as a leaf vegetable, but are rarely eaten by humans. In late 1980s, baby carrots or mini-carrots (carrots that have been peeled and cut into uniform cylinders) have been a popular ready-to-eat snack food available in many supermarkets. Carrot juice is also widely marketed. Baby carrots tend to be very tender, but not as flavorful as full grown carrots (Herbst 2001).

Carrot gets its characteristic orange color from β-carotene, which on consumption by humans is metabolized into vitamin A. Carrots are the rich source of vitamin A, with a 100 gram portion having about five to ten milligrams of carotene (Bender and Bender 2005). Massive overconsumption of carrots can cause hypercarotinemia, a condition in which a person's skin appears orange (although this is superior to overdose effects of vitamin A, which can cause liver damage).

Carrots are also rich in dietary fibre, antioxidants, and minerals. For best nutrition, the carrot greenery should be removed as soon as possible as it takes moisture and vitamins from the roots (Herbst 2001).

Lack of vitamin A can cause poor vision, and better vision can be restored by adding vitamin A back into the diet. A common urban legend in part based on this is that carrots aid a human being's night vision. It is believed that this myth partly stemmed from disinformation introduced in 1940 by the British Royal Air Force to cover up the discovery and use of radar technologies that was allowing pilots to be successful at night (Kruszelnicki 2005). It reinforced existing German folklore and helped to encourage children to eat the vegetable.

Ethnomedically, carrot are used to treat digestive problems, intestinal parasites, and tonsilitis.

Falcarinol, a seventeen-carbon diyne fatty alcohol was isolated from carrot. It was shown to have potent anticancer properties on primary mammary epithelial cells (breast cancer) (CLC 2007).

Carrot contains a considerable amount of β-carotene as well as crude fibre. It is expected that carrot will interact with jute reinforced composite both chemically (becase it contains carotene) and mechanically(becase it contains fibrous material) thereby will enhance the physico mechanical properties of the composite.

Although lot of information are obtained about the use of carrot in our every day life, however no information is found in the litereture about its use as filter or reinforcing agent in composite materials.

1.27 Physico-mechanical properties of jute fibre

Physico-mechanical properties of jute fibre, such as tensile strength, elongation at break, flexibility moisture absorption [66] etc. depend of three factors. These are: (i) the length of the fibre molecules, (ii) the mode of alignment amongst them and (iii) the nature of inter chain cohesive forces. In pure cellulosic fibre the lateral cohesive forces include hydrogen bonds, have maximum intensity in the crystalline regions, where the chain molecules are arranged in a more organized manner. The crystalline portions, (which allow a better freedom of movement of the chain molecule) account for elongation, flexibility and moisture affinity [67]. In jute fibre, crystalloid is exhibited only by a limited portion of the celluloid fraction amounting to about 40% of the fibre mass, while in cotton, the corresponding value is about 70%. The low crystalloid in jute fibre as compared to cotton fibre arises due to the presence of non-celluloid constituents in jute fibre [68].

Like tensile strength, the other properties of jute fibres, such as- elongation and flexibility are also influenced largely by the cross-linkages in the amorphous regions. The low interchain cohesion in the amorphous regions permits better freedom of movement to the chain molecules. In jute fibre, however, due to the presence of cross-linkages the relative movement of the carbohydrate chains is much restricted, which ultimately affects both flexibility and elongation.

Jute fibre has high affinity for moisture. High hygroscopic nature of the fibre compared to other pure cellulosic fibres is attributable to its low crystalline / non crystalline ratio[69].

Inspite of these, jute is the second most widely used natural fibre next to cotton. The yield of jute fibre is only about 4.5% of the green weight of stem.

The bast cells of the jute fibre are from 12.7 to 4.80 mm in ultimate length and from 0.508 to 0.635 µm thickness.Though the ultimate fibres are so short, jute fibre appears to be much longer than the ultimate fibres and joined in a matrix by gummy materials. The ultimate fibres overlap one another to produce a compact structure. The elements (ultimate fibres) of the jute fibre are relatively short. In cross-section, the jute fibre shows a bundle of several elements bound together; these are more or less polygonal in outline, with sharply defined angles. Between the separate elements a narrow medium layer is present. The lumen or central canal is wide round or oval in cross section [70]. Longitudinally, the lumen shows remarkable constrictions or irregular thickness in the cell wall but externally the fibre is smooth and lustrous. Each ultimate fibre is composed of a large number of smaller units known as fibrils and these are arranged in right-handed spirals. The fibrils are again made up of molecular chains, closely held together. These are known as micells.

1.28 Colors of jute

The color of jute fibre may vary from pale cream through golden yellow, reddish brown and grey to almost black. The cream and golden brown or reddish brown color is the characteristics of white and tossa variety of fibres respectively. The grey tinge of black color is imparted to the fibres by iron salts when these are present in high amounts in the retting water as well as in soil. Although the factors contributing to the natural color of jute fibre are not yet definitely known, but it is believed that lignin plays an important role in the exhibition of colors. The variation in color arises from some structural difference in the lignin molecule of different fibres [71] particularly, with respect to the phenolic or enolic hydroxyl groups. This occurs when fibres are exposed to light [72]. The grey or black color was originally believed to be derived from a reaction product of tannin components of the fibre with iron salts during retting. However, later on it has been confirmed that it is not tannin but a portion of the lignin, having tannin like properties produces the dark color with iron salts [73].

1.29 Chemical properties of jute fibre

Unlike pure cellulose, jute fibre is highly reactive towards various chemical reagents such as acids, alkalis and oxidizing reagents. The higher reactivity arises mainly from the non-cellulosic constituents of the fibre, namely, hemicellulose and lignin [74]. Lignin is not hydrolysable by acids. It is readily oxidisable and soluble in hot alkali, while carbohydrates are easily hydrolyzed by strong mineral acids to water-soluble sugar [75]. Jute fibre is highly susceptible to the action of light. The main features of the photochemical changes are the loss in tensile strength and development of yellow or brown colors [76]. The degradation of jute fibre caused by light has been found to be the highest amongst all natural cellulosic fibres. The reactions involved in photochemical degradation of textiles are mainly oxidative in nature. On prolonged exposure to light, the constituent chain molecules are gradually oxidized in all possible manners and ultmately broken down to smaller fragments. As a result, the tensile strength of the fibre is adversely affected. It has been reported that all the main fibre components including cellulose suffer degradation and components like lignin and hemicellulose are much more reactive to light. Due to the influence of light, ligneous residues (phenolic group) are converted into colored quinoid derivatives resulting in yellow or brown color. It is established that lignin is responsible for yellowing of jute fibre. It is also reported that in absence of moisture or atmospheric oxygen, this photochemical action of light on jute fibre is minimum [77,78].

1.30 Structural analysis of jute fibre

1.30.1 Fourier Transform Infrared Spectroscopy

The most important source of infra-red light for scanning the spectrum of an organic compound is Nast glower which consists of a rod like sintered mixture of the oxides of Zirconium, Ytterium and Erbium. The rod is electrically heated to 1500^0C to produce infra-red radiations.

A rod of silicon carbide can also be electrically heated to produce infra-red radiations. To obtain monochromatic light, optical prisms or gratings can be used. For prism material, like glass or quartz can not be used since they absorb strongly through most of the infra-red region. Sodium chloride or certain alkali metal halides are commonly used as cell containers or for prism materials as these are transparent to most of the infra-red region under consideration, Sodium chloride is not hygroscopic and is, therefore, protected from the condensation of moisture by working at suitable temperature. Grating gives better resolution than do prisms at high temperatures.

Light from the source is split into two beams. One of the beams is passed through the sample under examination and is called the sample beam. The other beam is called the reference beam. When the beam passed through the sample, it becomes less intense due to the absorption of certain frequencies. Now, there will be a difference in the intensities of the two beams. Let I_0 be the intensity of the reference beam and I be the intensity of the beam after interaction with the sample, respectively.Then

$$A = \log (I_0/I)$$

Also transmittance $T=I/I_0$

or $A= \log (1 /T)$

When the infra-red spectrum of an unknown compound is scanned, a large number of information are obtained.These are-

(1) Functional groups present in the compound
(2) The environment that influence the group frequency
(3) Type of carbon skeleton
(4) Type of a compound (aromatic/aliphatic)

1.30.2 Scanning Electron Microscopy (SEM)

The optical microscope is used for small scale material characterization. As the sophistication of investigations increased, either the Transmission Electron Microscope (TEM) or the Scanning Electron Microscope (SEM) often replaces the other traditional microscopes. Both the instruments have superior resolution and depth of surface. Because of its reasonable cost and wide range of application, the SEM is the preferred instrument used in material studies. The SEM provides the investigator a highly magnified image of the surface of a material that is very similar to that one would expect if one could actually see the surface visually. The resolution of the SEM can approach a few nm (nano-metre) and it can operate at magnifications from about 10X to 300000X. There are various applications of the SEM, such as [79]:

(1) Examinations of metallographically prepared samples at magnifications well above the useful magnification of the optical microscope
(2) Examination of fractured surfaces and deeply etched surfaces requiring depth of field well beyond that possible by the optical microscope

(3) Evaluation of crystallographic orientation of features on a metallographically prepared surface

(4) Evaluation of chemical composition gradients on the surface of bulk samples over distances approaching 1 μm

Schematic diagram of a SEM is shown in Figure 1.15. In a scanning electron microscope, a source of electron is focused in a vacuum into a fine probe that is passed over the surface of a specimen. A diffusion or turbomolecular pump creates the vacuum while an electron gun provides the source of electrons. A series of lenses are used to demagnify the spot of electrons on to the specimen surface. As the electrons penetrate the surface a number of interactions occur that result in the emission of electrons or photons from the surface. Detectors collect the emitted (output) electrons that are used to modulate the brightness of a cathode ray tube (CRT). Every point that the electron beam strikes on the sample is mapped directly onto a corresponding point on the screen. The collective points that are displayed onto a monitor or else transmitted to a photographic plate provide an image of the sample. Samples used in a scanning electron microscope can be of any form as in any solid or liquid having a low vapour pressure. Electrically conductive materials can be prepared using standard metallographic polishing and etching. Non conducting materials are generally coated with a thin layer of carbon gold or gold alloy. Samples must be free from water, organic cleaning solutions and remnant oil based films and must be electrically grounded to the holder. Fine samples such as powder are dispersed on an electrically conducting film.

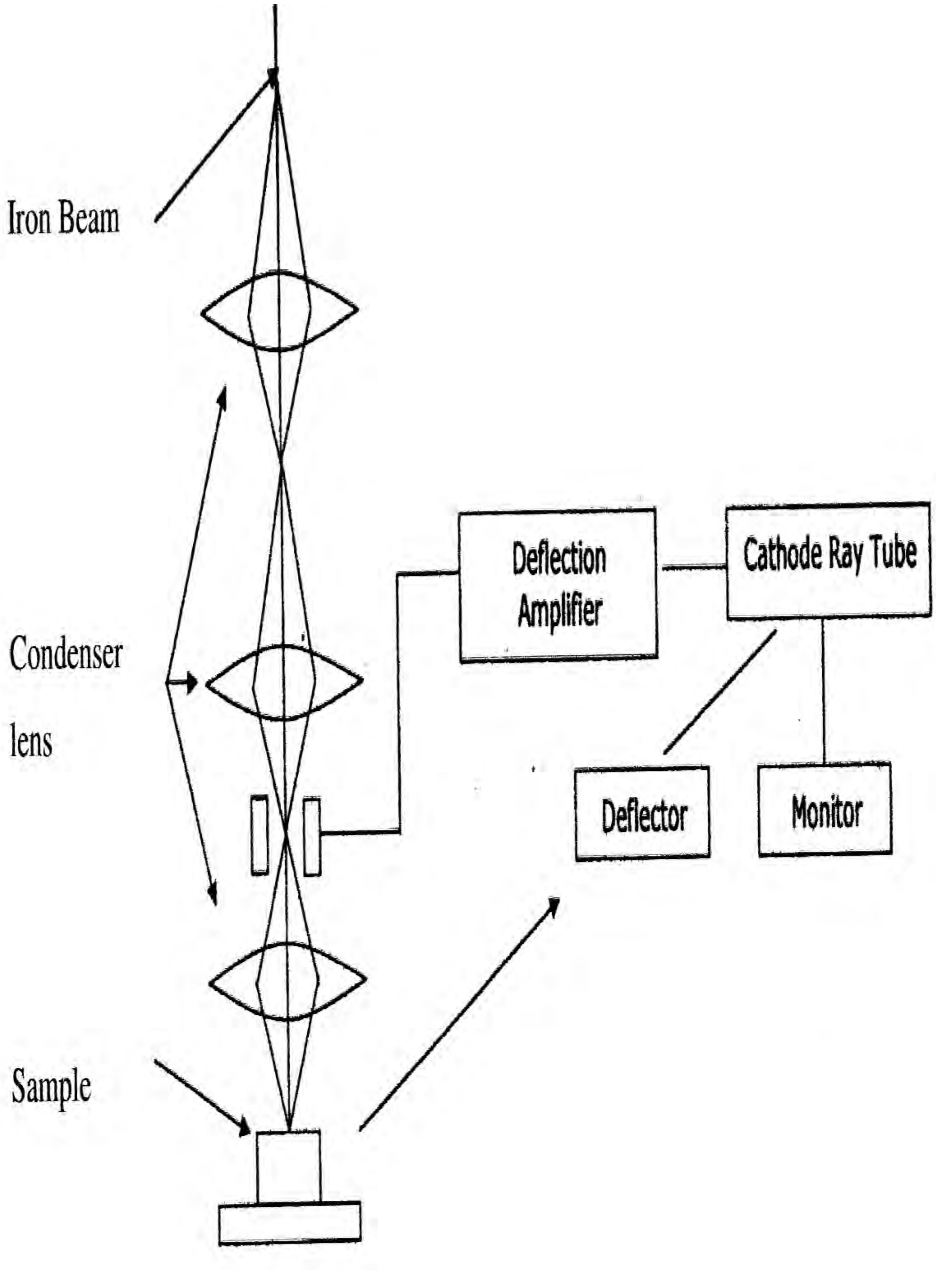


Fig. 1.16: Schematic diagram of a Scanning Electron Microscope (SEM)

1.31 Thermal analysis

Thermal analysis includes a group of techniques where some physical property of the sample is monitored under controlled conditions with variation of temperature at a programmed rate. With change of temperature the mass change is monitored which indicates the chemical or physical changes of the ematerials studied. This is called Thermogravimetry (TG). When heat application monitored, the result indicate crystallization, phase change etc. as well as reactions. This is called Differential Thermal Analysis (DTA). Together, both are a powerful method of analysis particularly of solids/solid composites..

1.31.1 Thermo Gravimetric Analysis (TGA)

Thermogravimetric analysis or thermal gravimetric analysis (TGA) is a method of thermal analysis in which changes in physical and chemical properties of materials are measured as a function of increasing temperature (with constant heating rate), or as a function of time (with constant temperature and/or constant mass loss). TGA can provide information about physical phenomena, such as second-order phase transitions, including vaporization, sublimation, absorption and desorption. Likewise, TGA can provide information about chemical phenomena including chemisorptions, desolvation (especially dehydration), decomposition, and solid-gas reactions (e.g., oxidation or reduction).

TGA is commonly used to determine selective characteristics of materials that exhibit either mass loss or gain due to decomposition, oxidation, or loss of volatile (such as moisture) matter. Common applications of TGA are (1) material characterization through analysis of characteristic decomposition patterns, (2) studies of degradation mechanisms and reaction kinetics, (3) determination of organic content in a sample, and (4) determination of inorganic (e.g. ash) content in a sample, which may be useful for colaborating predicted material structures or simply used as a chemical analysis. It is an especially useful technique for the study of polymeric materials, including thermoplastics, thermosets, elastomers, composites, plastic films, fibres, coatings and paints.

In research and testing TGA is commonly employed to determine characteristics of materials such as polymers, to determine degradation temperature, absorbed moisture content of materials, the level of inorganic and organic components in materials.

1.31.2 Differential Thermal Analysis (DTA)

The technique of DTA is an important tool to study the structural and phase changes occuring both in solid and in liquid materials during heat treatment. These changes may be due to dehydration, transition from one crystalline form to another, destruction of crystalline structure, melting, oxidation, decomposition, degradation etc. DTA is a process of accurately measuring the differences in the temperature between a thermocouple embedded to a sample and a thermocouple in a standard inert material such as aluminum oxide while both are being heated at a uniform rate.

The principle of DTA consists of measuring heat changes associated with the physical or chemical changes occuring when a sample substance is gradually heated. The thermocouple made up of platinum-platinum rhodium (13%) for DTA is incorporated at the end of each of the balance beam ceramic tubes and the temperature difference between the holder on the sample side and the holder on the reference side is detected. This signal is amplified and becomes the temperature difference signal used to measure the thermal change of the sample. These differences of temperatures appear because of the phase transitions or chemicall reactions in the sample involving the evolution of heat and are known as exothermic reaction or absorption of heat known as endothermic reaction. The exothermic and endothermic reactions are generally shown in the DTA curves traces as positive and negative deviations respectively from base line. So DTA offers a continuous thermal record of reactions in a sample. The areas under the bands or peaks of DTA spectra are proportional to the amount of heat absorbed or heat evolved from the sample under investigation, where temperature and sample dependent thermal resistance are the proportionality factor.

1.31.3 Differential Thermo Gravimetric (DTG) Analysis

DTG stands for Differential Thermo Gravimetric analysis.In DTG it is not the weight itself rather the first derivative of the sample weight with respect to time at constant temperature or with respect to temperature at constant rate of heating is determined.

1.32 Aim of the present investigation and possible with outcome

It appears from foregoing presentation and also from internet searching that no attempt has so far been made to study the physico-mechanical properties of benzenediazonium salts treated jute fibre-pp composite using carrot as filling materials or additives. However, some works have been carried out on the physico-mechanical properties such as tensile strength, tenacity, elongation at break, moisture regain and shrinkage in length of benzenediazonium salts treated jute fibre reinforced-PP composites in our laboratory. Although a remarkable improvement of physico-mechanical properties have been achieved in these studies but in these work no attempt has been made to increase the biodegradability of chemically treated jute-PP composites. Biodegredability is an important factor in the use of plastic-composites, when environmental pollution is being considered. Thus the main aim of this study is to investigate the effect of substituted benzenediazonium salts on jute fibre and to study the use of these treated jute fibres along with carrote powder in manufacturing jute fibre-PP composites.

The specific aims of this study are:

(i) to prepare improved composite materials using chemically treated jute fibre along with carrot powder

(ii) to investigate the physico-mechanical properties of the jute fibre-PP composites

(iii) to investigate the effect of treatment of jute fibre using benzene diazonium salt derivatives(such as *o*-, *m*- and *p*-hydroxy derivatives) on the physico-mechanical properties (such as tensile strength, tensile modulus, flexural strength, flexural modulus, Charpy impact strength and elongation at break) of chemically treated jute fibre-PP composites

(iv) to study the effect of using carrot powder on bio-degradation and mechanical properties of chemically treated jute-PP composites.

Application of chemically jute fibre and jute fibre (chemically treated) reinforced polypropylene composites

jute fibre is physically hard coarse and stiff, chemically it contain high percentage of lignin and relatively less percentage opf cellulose than those of other natural fibre (which are used in manufacturing good quality of fabrics).For those reasons jute fibre is not spinable and can not be used as fabrics materials. By chemical treatments the above mentioned physical properties can be reduced and percentage of cellulose may be increased to a satisfactory level, sothat it may become spinable and suitable for manufacturing fabrics.

Plastic materials are not biodegradable.That is why it is not ecofriendly.At the same time it is not machinable and it is relatively heavier than wood, bamboo etc. which are traditionally used as engineering materials in Bangladesh. By incorporating jute and chemically treated jute fibre in plastic materials like polythene, polypropylene etc. the physico-mechanical properties of plastic materials can be improved to a satisfactory level. In addition to these plastic material could be converted to a composite materials which would be biodegradable(so that it would be ecofriendly) and would also be lighter than traditionally used as engineering materials such as iron,steel, etc. Therefore, jute-reinforced plastic composite could be used as engineering materials for making auto-veicle body, household furnitures etc.

It is to be mentioned here that in Bangladesh wood and bamboo are traditionally are used as the materils for making furniture and other household goods. As a result de-forestation take place.Deforestation is abig threat to the environment. Therefore by using jute-PP composites for manufacturing furnitures and household article it bay be substantially reduce deforestation.

LITERATURE REVIEW

Quite a good number of published articles in the field of fibres and its composites with polymer matrix have been reviewed. These are reported below in brief.

1. H. Kumar and Siddaramaiah [80] carried out research work on bamboo fibres. The untreated and alkali-treated bamboo (Bambusa) fibres were coated with polyethlene glycol-based polystyrene (PE) and its semi-interpenetrating polymer network (SIPN) with polystyrene (PS). Tensile strength and chemical resistance were measured on alkali-treated and untreated fibres with or without polymer coatiing. The PE and PE/PS (50/50) IPN-coated bamboo fibres showed improvement in tensile behaviour and chemical resistance.

2. D. K. Raval, B. N. Narola and A. J. Patel [81] synthesized a mdified urea-formaldehyde resin by the comdensation of urea and formaldehyde in the presence of varying proportions of casein up to 25% (w/w) of urea under alkaline conditions. The resin samples were employed for the fabrication of jute fibre reinforced composites. The prepared composites were tested for their mechanical properties and resistance toward various chemicals.

3.C. Datta, D. Basu, A. Banerjee [82] studied the mechanical and dynamic mechanical properties of jute fibre-Novolac-epoxy composite laminates. Jute fibre composite was prepared using a polymer matrix of epoxidized novolac resin (ENR) with different weight percentages of the resins. It was found that the storage modules at room temperature was enhanced by about 100% or more in the case of 30 and 40% ENR-containing matrixes, whereas the enhancement in the case of 20 and 12% ENR-containing matrixes is only 50% of the pure matrix. It was also observed that it is possible to manufacture jute fibre composites with increased stiffness without sacrificing their ductility.

4. B. N. Dash, M. Sorkar, A. K. Rana, M. Mishra, A.K. Mohanty and S. S. Tripathy [83] prepared biodegradable composite specimens having 45, 50, 55, 60 and 65% of jute by

mass were prepared following film stacking method by compression moulding technique. It was found that with increase in jute fibre content, the flexural strength and modulus increased from 25.89 and 4709 MPa (45% jute fibre) to 41.75 and 8613 MPa (60% jute fibre) respectively and thereafter decreased with higher loading of jute fibre. For tensile strength and modulus, the same trend was observed. At 45% jute fibre content, the values were 33.61 and 2599 MPa respectively, whereas at 60% jute fibre content the values were 41.23 and 3346 MPa respectively.

5. Debasis De, Debapria. De and B. Adhikari [84] carried out research work on curing characteristics and mechanical properties of alkali-treated grass-fibre-filled natural rubber composites and effects of binding agent. To improve adhesion between fibre and matrix, natural rubber was reinforced with a special type of alkali-treated grass fibre. The cure characteristics and mechanical properties of grass-fibre-filled natural rubber composites of different mesh sizes were studied with various fibres loading. Increasing the amount of fibres resulted in the composite having reduced tensile strength but increased modulus. The better mechanical properties of the 400-mesh grass-fibre-filled natural composite showed that the rubber/fibre interface was improved by the addition of resorcinol formaldehyde latex (RFL) as binding agent for this particular formulation. The optimum cure time decreased with increase in fibre loading.

6. M. N. Islam, M. A. Khan, M. A. Zaman [85] studied the water absorption behavior of jute fibre-reinforced polymer composites using the thermal neutron radio graphy facility of 3MW TRIGA MARK-II. The composite was prepared with jute fabrics and a formulated solution composed of urethane triacrylate oligomer and additive urea under Co-60 radiation. The water absorption of the composite with time was reported to be negligible.

7. The composites prepared from unsaturated polyester resin and jute sliver with 60% jute fibre loading by weight by B. N. Dash, A. K. Rana, S. C. Mishra, H. K. Mishra, S.K. Nayak, and S. S. Tripathy [86]. The composite specimens were prepared using both untreated (control) and chemically modified (bleached) jute fibres by solution

impregnation and hot curing methods and were designated as JPH-60(C) and JPH-60(B), respectively. The specimens were subjected to tensile and flexural tests and the fractured surfaces were observed under SEM analysis.

8. A. K. Rana, A. Mandal, B. C. Mitra, R. Jacobson, R. Rowell, and A. N. Banerjee [87] prepared jute fibre-reinforced polypropylene composites in the presence of compatibilizer. Jute fibres were chopped to approximately 100 mm in length and then processed through a granulator having an 8-mm screen. Final fibre lengths were up to 10 mm in size. These fibres, compatibilizer and the polypropylene granules were mixed. The jute fibre loading were 30,40,50 and 60 wt%, and at each fibre loading, compatibilizer dose were 0,1,2,3 and 4 wt% by weight of fibre loading, the use of the compatibilizer improved the flexural strength as high as 100%, tensile strength to 120% and impact strength by 175%. Remarkable improvements were obtained even with 1% compatibilizer.

9. H. Cabrl, M. Cisneros, J. M. kenny, A. Vazquez and /C. R. Bernal [88] studied the mechanical properties, water uptake properties and di-electric properties of jute fibre-reinforced plypropylene composites. It was found that the tensile Young's modulus and tensile strength monotonically increased with increasing the jute fibre volume fraction, whereas the impact resistance increased up to a critical value of the jute fibre volume fraction and then declined. A change in the dependence of the water uptake and dielectric properties with jute fibre loading at critical fibre content was also found.

10. D. K. Raval, B.N. Narola and A. J. Patel [89] synthesized the resorcinol-urea-formaldehyde-casein (DSUFC) resin by poly-condensation reaction of urea, casein and formaldehyde in the presence of varying proportion of resorcinol under alkaline condition. The resin samples were cured isothermally at 120^0C using two different curing agents, p-toluic acid and hexamine. The resin samples were employed for the fabrication of glass fibre and jute fibre reinforced composites, respectively by maintaining 2:3 and 3:2 proportion of resin. Thus prepared composites were tested for their mechanical properties and resistance towards various chemicals. As resorcinol content was increased,

the flexural strength and flexural modulus of composites were found to decrease. The impact strength of composites was found to increase with the increase in resorcinol content. This strength showed the enhancement in the toughness of the composite with increasing the resorcinol content. The composites showed excellent resistance towards common organic solvents (acetone, carbon tetrachloride, toluene, methanol and ethanol) and somewhat poor resistance towards mineral acid and alkali.

11. Improvement of jute yarn through in situ graft copolymerization using UV radiation was studied [90] by K. M. Iddris Ali and M. A. Khan. In this study radiation time was varied from 15 min to 180min and concentration of methyl methylacrylate (MMA) was varied from 10% to 90% . The highest grafting of 11% is obtained with 50% MMA concentration at 60 minutes irradiation time. Different types of additives such as urea, $LiNO_3$, maleic anhydride (MA) were incorporated into MMA+MeOH solution. By using additives tensile strength and elongation at break increased by 65% and 109% respectively.

12. Graft copolymer of acrylamide (AM) onto jute pulp initiated by $CuSO_4$/glycine/ $KHSO_3$/ H_2O system was studied by S. K. Swain, N. L. Debsarkar, P. K. Sahoo [91], Jute pulp was prepared from jute fibre by digestion with NaOH. The optimum conditions for grafting have been determined by studying the effects of concentration of monomer and initiator, reaction time, temperature and reaction medium. The grafted samples after purification were subjected to the determination of rate of grafting and grafting percentage. It is observed that Cu (II)-glycine complex coupled with $KHSO_3$ forms a suitable system for graft copolymerization onto pure jute pulp.

13. A study was reported by M. Ali, M. N. Islam, A. J. Mian, and A. M. S. Chowdhury [92] on the modification of textile properties of jute fibre by the treatment with neutral sodium sulfite liquor at varying temperature. It was reported that jute fibre undergoes a sulfonation reaction and is partially dissolved out from the fibre along with some hemicellulose depending of the degree of sulfonation. The treatment brings some changes

in the physico-mechanical properties of the jute fibre. The modified jute fibre utilized in fine yarn spinning for diversified textile uses.

14. Sodium hypochlorite bleaching of jute fibre was done by N. C. Pan, A. Day and K. Kumar [93]. They studied the physico-mechanical properties of bleaching raw jute fabric. Raw jute fabric was bleached with different concentration of NaOCl. The bleached jute fabric was found to achieve a level of whiteness that is suitable for deep shape dyeing. Loss of strength was noticed after bleaching as a certain amount of the hemicellulose and lignin components were removed during bleaching. Sodium hypochlorite still finds favorable bleaching agent in view of its low cost and easy of availability as compared to other bleaching agents.

15. N. Matins, M. Ahmed, M. M. Mallick and S. Rahman [94] studied the electrical resistance and effective parallel capacitance of bleached jute fibre. The electrical resistance and parallel capacitance of bleached jute fibre were measured at 20^0C, 26^0C and 100^0C. The result showed that the electrical resistance (R) decreased with increase in temperature. The capacitance (Cp) showed higher values at lowest temperature of 20^0C and became lower at 26^0C. It again increased at the highest temperature like 100^0C. But capacitance (Cp) decreased with the increase in a. c. frequency up to a value 100 KHz at 20^oC and gave a higher peak at 300 KHz. and then again found to be decreased over frequency higher than 300 KHz. At a temperature of 100^0C. the capacitance was found to be decreased with the increase of a. c. frequency and no peak was found at 300 KHz.

16. Modification of jute fibre grafting for use in composites was reported by D. S. Varma and Maralis [95]. Moisture absorption of jute fibres could be reduced significantly by graft copolymerization with metyl methyl acrylate (MMA). The tensile strength and elongation at break of jute fibre decreased on grafting whereas the initial modulus increased with increasing percentage of graft add on. Glass fibre-grafted jute fibre with unsaturated polystyrine composites should give better tensile, flexural and laminar shear strength than composites fabricated using untreated jute fibre.

17. A urethane acrylate (UA) polymer with an aliphatic chain was used to prepare a number of formulations in the presence of plasticizer and monomer of different characteristic was studied by M. K. Uddin, M. A. Khan and K.M. Iddris Ali [96] Using Hessian cloth jute plastic composites were found to increase. The composites were buried in soil, semi mud, mud and water in order to study the degradable character of the composite. The composites were found degradable in mud but not decomposable in water and soil.

18. Graft coplymerization of methyl methacrylate (MMA) onto jute fibre has been reported by M. M. Haque, M. M. Habibuddoula, A. J. Mahmood and A. J. Mian [97], by using ceric ion initiator. Effect of temperature, time of reaction, lignin content of jute fibre, monomer concentration and initiator concentration has been studied. After studied the maximum percentages of grafting and grafting efficiency have been found to be 132% and 71% respectively.

19. A. A. Shaikh, and S. A. Channiwala [98] prepared jute-polyester composite with variation in volume fraction from 4 to 36%. It was found that with the increase in jute fibre content, the flexural strength and modulus increased. Jute-polyester amide composite specimens having 45, 50, 55, 60 and 65% of jute fibre by mass were prepared following film stacking method by compression moulding technique. It was found that with increase in jute fibre content, the flexural strength and modulus increased from 25.89 and 2739 MPa respectively (for 15% jute fibre) to 41.75 and 4623 MPa respectively (for 30% jute fibre) respectively and thereafter decreased with higher loading of jute fibre . At 15% jute fibre content the values of tensile strength and modulus were 23.65 and 1556 MPa respectively, whereas at 30% jute fibre content the values of tensile strength and modulus were 31.23 and 2336 MPa respectively.

20. D. Ray, B. K. Sorkar, A. K. Rana and N. R. Bose [99] studied the effect of alkali treated jute fibres on composite properties. Jute fibres were subjected to a 5% alkali (NaOH) solution treatment for 2, 4, 6 and 8h at 30^0C. An improvement in the crystallinity in the jute fibres increased its modulus by 12%, 68% and 79% after 4, 6 and

8h of treatment respectively. The tenacity of the fibres improved by 46% after 6 and 8h treatment and the % of breaking strain of composites was reduced by 23% with 4h treated fibres, the flexural strength improved from 199.1 Mpa by 20%, flexural moudulus improved from 11.89 GP a to 14.69 GPa by 23% and laminar shear strength increased from 0.238 Mpa to 0.2834 MPa by 19%.

21. Grafting of methyl methacrylate (MMA) onto jute fibres has been reported by M. Misra, A. K. Monhanty, B.E. Singh [100] using $S_2O_3^{2-}$ thiourea redox initiator system. The effects of monomer concentration, $S_2O_3^{2-}$ and graft yield were studied. Besides these the effect of temperature, time and amount of jute fibres and the effects of some inorganic salts and organic solvents and graft yields were also investigated.

22. H. Matsuda and M. Udea [101] extensively investigated the esterification of wood in order to make a totally thermoplastic material. They esterified wood without any solvent by simply heating with succinic anhydride in a mixer for 3h at a temperature greater than 60^0C. The uses of maleic anhydride (MA) or maleic anhydride polypropylene (MAPP) as coupling agent to prepare composites were investigated by various methods. Significantly, improved mechanical properties have been obtained using MAPP as a coupling agent.

23. S. Gupta, P. K. Ganguly and G. K. Bhattacharya [102] studied mechanical behaviour of jute ply yarns. Two, Three and four ply jute yarns were prepared with fine (163 tex) and coarse (344 tex) component single yarns and low (15.92) and high (25.75) ply twist multiplier. It was observed that as the number of ply increased, the tenacity, breaking elongation, specific work of rupture and packing factor increased but specific flexural rigidity decreased except for coarse component yarn and high twist level. Wetting of ply yarn decreased tenacity and specific flexural rigidity when improved breaking elongation and specific work of rupture. The effect of wetting on ply yarns having coarse component yarns were more pronounced compared to those of finer components yarns.

24. M. A. Kabir, M. R. Islam and M. M. Huque [103] studied the effect of hydroxy-benzenediazoium salts on physico-mechanical properties of jute fibre. They observed that the tensile strength, tenacity and moisture regain properties of the treated jute fibre were found to be lower in comparison to those of raw jute fibre. The tensile strength and tenacity of the fibre treated with *o*-, *m*- and *p*-hydroxybenzenediaxonium salts were found in the following order: *o*-hydroxybenzenediaxonium salts > *m*-hydroxybenzenediaxonium salts > *p*- hydroxybenzenediaxonium salts. It was also found that the jute fibre treated in basic media showed higher tensile strength than that treated in acidic media.

25. M. A. Kabir, M. R. Islam and M. M. Huque [104] studied the effect of disubstituted benzenediazonium salts on physico - mechanicla properties of jute fibre. The tensile strength of treated jute fibre with benxenediazonium salt was found in the following order-

benzene-1, 4-diazonium chloride> benzene-1, 3-diazonium chloride> benzene-1, 2-diazonium chloride. The jute fibre treated in basic media showed higher tensile strength than that treated in acidic media.

26. S.S. Tripathy, L.D. Landro, D. Fontanelli, A. Marchetti, G. Levita [105] studied the mechanical properties of jute fibres and interface strength with an epoxy resin. Four different forms of jute fibres, namely untreated jute filament (UJF), sliver jute filament (SJF), bleached jute filament (BJF), and mercerized jute filament (MJF) have been subjected to tensile strength analysis. Fibres of each type, at three different gauge lengths, i.e. 15, 30, and 50 mm, were used to study the effect of guage length strength distribution. The mean jute fibre strength was found to be the maximum for UJF. The BJF has strength values very close to UJF. The MJF exhibited very low strength, close to the SJF. The SJF exhibited the least strength at each gauge length. This appreciable strength reduction is likely due to the damage the fibres undergo during the production of sliver from UJF. The strength was also found to decease with an increase in gauge length. The BJF was found to have the maximum and minimum for MJF with epoxy matrix. The interfacial adhesion of SJF is in between of BJF and MJF.

27. K.H. M. Mannan and S. Munir [106] studied the characterization of jute fibres treated with soap glycerol micelles. A tossa variety of jute fibre (Corchorus olitorious) treated with soap glycerol micelles are characterizes by infrared (IR) spectroscopy, X-ray diffraction method, and densitometry. The Percentage crystallinity was measured by the X-ray diffraction method and are found to increase from 45 to 53% on treated jute fibres. The tensile strength and strain percent at maximum load and Young's modulus of treated jute fibres were increased. Under natural weathering at 12 -30^{0}C and 30-80% relative humidity over a prolonged period of 8 weeks, all the tensile properties for micelle-treated jute fibres increased during the first 2 week of exposure and then decease exponentially to the starting values.

28. P. Ghosh and D. Das [107] studied the modification of jute fibre by acrylic acid (AA) in presence of H_3PO_4 and $K_2S_2O_8$ as catalysts under thermal treatment. Jute fabric was modified using acrylic acid (AA) as the finishing agent in the presence of $K_2S_2O_8$ and Na_3PO_4 catalysts separately. Treatment with 10% acrylic acid at 30^{0}C and at pH 7 produced optimum effects: a batching time of 45-60 min at 30^{0}C, followed by drying of the batched fabric at 95^{0}C for five min and curing of the dried fabric at 140^{0}C for 5 min produced most balanced improvements in the textile related properties. Na_3PO_4 catalyst allowed etherification of AA with cellulose, hemicellulose and lignin constituents of jute fibre and $K_2S_2O_8$ catalyst allowed radical polymerization of free acrylic acid on jute-bound acrylic acid moieties. The said processes ultimately lead to same degree of cross linking of the chain polymers of jute fibre.

29. A. K. Saha, S. Das, R. K. Bhatta and B. C. Mitra [108] carried out research work on the improvement of functional properties of jute fibre-based composite by acrylonitrile pretreatment. Cyanoethylation of jute fibre in the from of nonwoven fabric was successfully achieved using an acrylonitrile monomer which is said to react with the hydroxyl groups of jute fibre constituents. The degrees of cyanoethylation to different extents were undertaken by varying the reaction time. The extent of cyanoethylation increased with increase of the reaction time. Cyanoethlated fibres thus obtained were

further treated with unsaturated polyester resin to obtain modified fibre composites. These composites have been found to be tolerant against cold and boiling water where water absorption and thickness swelling are much reduced compared to those of unmodified jute fibre composites was remarkably reduced.

30. M. H. Ali Mian, M. A. Samad, N. N. Sarker, G. M. Talukder and T. Baksh [109] carried out research work on the physico-mechanical characteristics of Mesta (Hibiscus SabDariffa L) and Keneaf (Hibiscus Cannabinus L.) fibre. The physico-mechanical characteristics of the fibres of the new varieties viz. Mesta HS-24 (Hibiscus sabdariffa L.) and kenaf HC-2 (Hibiscus cannabinus L.) developed by BJRI have been studied and compared. The bundle srength, bursting energy and breaking tenacity of Kenaf HC-2 were comparatively greater than those of Mesta HS-24. The breaking elongation was similar. But the fibre of both of kenaf HC-2 was slightly finer than that of Mesta HS-24.

31. T. V. Dieu, L. T. Phai, P. M. Ngoc, N. H. Tung, L. P. Thao And L. H. Quang[110] carried out research work on preparation of polymer composites based on polypropylene reinforced by jute fibres. The use of graft coplymer of maleic anhydride polypropylene (MAPP) as a coupling agent in jute fibre polypropylene composites improved the mechanical properties of the composites. The scanning electron microscope (SEM) observation for fractured surfaces of unmodified and modified jute fibre-polypropylene composites confirmed that the increase in performance was due to an increase of jute fibre-matrix adhesion. Jute fibre and glass fibres were hybridized by ply-by-ply and skin-core structures. In this study glass and jute fibres were used as the skin and core layers, respectively. The test results showed that the hybrid composites have superior mechanical properties. Especially, the impact strength increases significantly from 13.2 kJ, which was 190% higher than that of a jute fibre reinforced composite.

32. E Laranjeira, L. H. Carvalho, S. M. L. Silva, J. R. M. Almedia [111] prepared the jute fibre composites and mechanical properties of composites were determined. Higher values for all mechanical properties were obtained when long-fibre oriented composites were tested, even at low jute fibre content 9-10% (w/w). The tensile behaviour of the

unidirectional composites qualitatively followed the theoretical isostrain and isostress behaviours, when the tests were conducted along and perpendicular to the jute fibre axis, respectively. The tensile properties of the composites tested perpendicular to the jute fibre were dominated by the strain at the jute fibre-matrix interface.

33. Graft polymerization of acrylonitrile (AN) onto jute fibre was studied using Ce (IV) ion, lippuric acid redox initiator system by S. Patnaik, A. K. Mohanty and B.E. Shingh [112]. The effect of time, temperature, monomer concentration, metal ion (Ce^{4+}) was observed. The effects of some organic solvents and inorganic salts of graft yield were also studied. IR spectra of chemically modified bleached jute fibre and grafted jute fibre were taken and their characteristics bands were indentified. It is reported in this work that more than 90% graft was achieved.

34. S. Das, A. K. Saa, P. K. Choudury, R. K. Basak, B. C. Mitra, T. Todd, S. Lang and R. M. Rowell [113] studied the dimensionl stability of jute fibre composite by treating high pressure stream. Steam stabilization of jute fibre imparts the dimensional stability to the jute fibre composite. The dimensional stability has been marginally increased with an increase in treatment time after 4 min. But the jute fibre losses its mechanical strength with an increase in process time. Thermal stability of steam-sabilized jute fibre is almost the same as that of untreated jute fibre.

35. M. A. Salam [114] carried out research work on the effect of hydrogen peroxide bleaching onto sulfonated jute fibre. Bleaching of raw and sulfonated jute fibre with hydrogen peroxide were carried out in an aqueous medium. The raw and sulfonated jute fibres were bleached with hydrogen peroxide under different conditions such as varying pH, treatment time, temperature, hydrogen peroxide concentration and fibre-liquor ratio. The optimum whiteness index tenacity were 76 and 13.7 for bleached sulfonated jute and 42 and 12.9 for bleached raw jute fibre with 2.1% hydrogen peroxide at pH 11, temperature 95^0C, treatment time 110 min and jute fibre-liquor ratio 1:7. The photo-oxidative degradation of bleached sulfonated jute fibre was characterized by UB light exposure and compared with that of bleached raw jute fibre. It has been observed that the

photo-oxidative degradation as well as loss in tenacity and yellowness of the bleached slfonated jute fibre was 63 and 40% lower than that of bleached raw jute fibre had excellent impact on color fastness with reactive dyes.

36. Imrovement of jute fibre through UV cured film urethane acrylate (UA) studied by K. M. Iddris Ali, M. I. U. Bhuiyan, M. K. Uddin and M. A. Khan [115] Physical and mechanical properties of the UV cured film, role of plasticizers and water uptake were investigated. Through plasticizers the tensile strength of the UV cured films is decreased, they substantially enhance both tensile strengths by 300% . Water and moisture take up at different relative humidity conditions significantly.

37. Jute yarns were grafted with a single impregnating monomer 1, 6-hexanediol diacrylate (HDDA) by M. A. Khan, S. Shehrzade, M. Sarwar, U. Chowdhury, and M. M. Rahman [116]. They observed that the concentration of monomer, soaking time and intensity of UV radiation were optimized with extent of mechanical properties such as tensile strength, elongation at break, and modulus. Enhanced tensile strength (67%) modulus (108%), and polymer loading (11%) were achieved with 5% HDDA concentration, 5-minute soaking time and fourth pass of UV radiation. To further improve the mechanical properties the jute yarns were pretreated with UV radiation (5,10,15,30, and 50 passes) and treated with optimized monomer concentration (5%) . UV-pretreated samples showed the enhanced properties. The tensile strength and modulus increased up to 84% and 132% , respectively, than that of virgin jute yarn, An experiment involving water absorption capacity showed that water uptake by treated samples was much lower than that of the untreated samples.

38. H. Lilholt and A. B. Bjerre [117] carried out research work on the effect of polypropylene matrix, for producing composite, on the porosity of jute fibre. They observed that with the increase in PP the prosity decreased and hence good stiffness and strength were noticed. So good stiffness and strength of jute fibres were exploited to give load bearing composites of good performance.

39. H. S. Sabharwal, M. Akhtar, R. A. Balanchette, and R. A. Young [118] carried out research work on producing pulp for paper making from jute fibre. Jute is a viable fibrous soure for paper making by mechanical pullping processes in developing countries. Mechanical pulping of jute fibre consumed less energy as compared to other conventional wood and non-wood fibrous materials. Considerable energy savings and enhancement in strength properties can be realized by bio-treatment of jute bast with CZ-3 strain of Ceriporiopsis subvermispora, using a white rot fungus, prior to refining was recommonded. Bio- mechanical pulping of jute bast would result in energy saving of 115,000 kWh per 100 tons of oven dry pulp if wood was replaced by jute bast with an added advatage of obtaining stronger pulps.

40. Graft polymerization of methyl methacrylate (MMA) on different modified jute fibres using V^{5+} cyclohexanol redox initiator in aqueous solution was studied by A. K. Mohanty and V.E Singh[119] . High lignin content of jute fibres was responsible for the low grafting yield. The softening of jute fibres after removal of certain impurities enhanced considerably.

41. M. N. Islam, M. Ali, A. J. Mian and A. M. S. Chowdhury [120] studied the fine spinning of jute fine yarns. The modified jute fibre obtained in this study showed better quality in respect of physico-mechanical properties comparing with raw jute fibre. The modified fibre processed into the fine counts of yarn than those obtained in conventional spinning of jute fibre. The modified jute fibre was processed using cotton spinning system in order to develop fine spinning of jute fibre with or without blending of cotton.

42. The textile properties of jute fibre were improved chemically by adopting the principle of neutral sulphite cooking process by M. N. Islam, M. Ali, A. J. Mian and A. M. S. Chowdhury [121]. It was found that lignin and hemicellulose of the jute fibre were partially removed and that the residual lignin in the jute fibre remained insoluble forming condensation products of lignin sulphonates. The brightness and rigidity of the jute fibre were much improved without impairing the tensile properties, Bleachability and mechanical properties of the modified jute fibre were comparatively better.

43. Gassan, A. K. Bledzki [122] carried out research work for improving the mechanical properties of jute fibre/epoxy composites by alkali treatment of jute fibres. The mechanical properties of tossa jute fibres were optimized by using a NaOH- treatment process with defferent alkali concentrations and shrinkages. Shrinkage of the jute fibres during treatment had the most significant effect on the fibre structure and in term, on the jute fibre mechanical properties such as tensile strength, modulus and toughness. An alkali treatment under isometric conditions (20 min at 20^0C in NaOH solution) lead, with respect to yarn axis to an increase in jute yarn tensile strength and modulus of about 120% and 150%, respectively.

44. A. N. Shah and S. C. Lakkad [123] studied the mechanical properties of epoxy and polyester resins reinforced unidirectional composites by jute and glass fibres singly and in combination as a hybrid. the results showed that the jute reinforced laminates had much better properties than the resins alone.

45. S. Sultana M. M. Huque and M. M. Helali [124] studied the physico-mechanical properties of sodium periodate oxidized jute reinforced polypropylene (PP) composites. Their reults showed that the mechanical properties of the oxidized jute fibre-PP composites were significantly higher than those of raw jute fibre-PP composites. Morphological studies of these composites showed better interfacial bonding between jute fibre and matrix for oxidized jute fibre PP composites than raw jute fibre-PP composites. Water absorption properties of the composites also showed better result for oxidized jute fibre-PP composites than raw fibre-PP composites.

46. A. C. Karmaker and J. A. Youngquist [125] prepared composites with polypropylene (PP) and jute fibre by injection moulding technique. Maleic anhydride was added as coupling agent to improve the adhesion between jute fibre and PP. The coupling agent improved the tensile and bending strength, however, the elastic and bending moduli were found not to be influenced by the coupling agent.

47. A study of the graft polymer of MMA on to chemically modified jute fibres using Ce (IV) ion and toluene was carried out by H. K. Ras, N. C. Nayak and B. E. Shingh [126] . The optimum conditions for grafting were obtained and time was also studied. It was shown that MMA grafted jute fibre was thermally more stable than the original jute fibres.

48. Studies on Two-phase morphology of chemically modified jute fibres using wide angle X-ray diffraction technique were made by S. Moharana, P. K. Misra, S. S. Tripathy [127] . The morphology of jute fibres modified by grafting with MMA was studied. Grafting with yield > 20% caused a decrease in crystallinity.

49. Processing and characterization of jute fibre reinforced thermoplastic polymers was studied by A. C. Karmaker and G. Hinrichsen [128]. jute fibres were investigated to verify their possible application on reinforcement of thermoplastics. A laboratory process was modified and laminates were produced using polymer films of low density polyethylene (LDPE), high density polyethylene (HDPE), polyethylene (PE) copolymer and polypropylene (PP) as inter layers. Variation of the processing parameters was carried out in order to find optimal adjustment. High moulding temperature led to a decrease of mechanical properties and water absorption ability of the composites. The effect of water treatment on mechanical properties was also studied.

50. Radiation induced jute fibre plastic composite; preparation and IR studies were reported by K. M. Iddris Ali and M. A. Khan [129]. Jute fibre plastic composite was prepared with tossa jute yarns and metyl methacrylate (MMA) mixed with methanol at different properties using Co-60 gamma sources irradiation. Incorporation of minute amount of (1%) additive like N-vinyl pyridine, tripropylene glycol diacrylate and trimethylol propane triacrylate or urea substantially increases the grafting of MMA onto jute yarn. Tensile strength, water absorption and moisture absorption at different relative humidities had been detected. Both tensile strength and elongation at break decreased with increasing grafting. IR study revealed that MMA has been grafted onto jute cellulose at the sites of - OH groups of the jute cellulose backbone.

51. Improvement of properties of natural polymers with organometallic complexes under ultraviolet radiation were studied by M. Hashiruzzaman, M. A. Khan and K. M. Idriss Ali [130]. Thin polymer films were prepared under UV radiation with a triacrylated aliphatic urethane oligomer, which was diluted with reactve monomers such as N-vinylpyrrolidone and tripropylene glycol diacrylate. The effect of incorporation of a minute amount (0.15%) of a pyridine complex and its ligands on the characterization of these polymers was investigated. Jute yarns were treated with the solutions containing these materials under the UV radiation. It was found that pyridine based complex substantially enhanced the tensile strength of jute yarns.

52. Preparation of jute-plastic composite by the preirradiation method was studied by M. Azam Ali, M. A. Khan, K. M. Idriss Ali, F. Khan and S. R. Ahmad [131] The jute fibre-plastic was prepared by shaking the preirradiated jute fibres (by gamma rays) in a deoxygenated aqueous methyl methacrylate (MMA) solution that contained a surfactant and a homopolymer inhibitor ($FeSO_4$). The composite was characterized by IR and differential scanning calorimetric analysis. It was observed that the jute fibres were found to be grafted with MMA in the experimental conditions. The undrafted jute samples lost both tenacity and strechability. The moisture content sharply decreased with increasing in grafting up to the 15% grafting level.

53. Improvement of physico-mechanical properties of hessian cloth (jute) by graft copolymerization of urethane acrylate applying UV-radiation [132] was studied by M. A. Khan, M. N. Islam and K. M. Idriss Ali. Enhancement of tensile strength of both treated and untreated jute fibre was observed.

54. Green composites was fabricated from biofibrs (Hemp and henequen) and polyhydroxybutyrate (PHB) by A. K. Mohanty, L. T. Drzal, P. Mulukutla, S. M. Desai and M. Misra [133]. The incorporation of natural fibre into the composite structure improved the modulus and impact strength. There was a 100% increase in tensile modulus of PHB with 30-wt% hemp fibre reinforcement and no significant change in the tensile strength is observed. However, addition of 5-% maleated PHB improved the strength as well as the modulus by almost 55% and 165% respectively.

55. S. Wong, R. Shanks and A. Hdzic [134] prepared composites of poly-3-hydroxybutyric acid with modified flax fibres. The flax fibres modified by plasticizer absorption to reduce the moisture, so that the flax fibres were not brittle. The morphology, thermal and dynamic mechenical properties of these composites was investigated, Migration of plasticiser from the fibres to PHB modified the crystallization, crystalinity and glass transition temperature of PHB. Due to good adhesion between the flax fibres and the matrix, transcrystallinity was observed in all of the PHB-flax-plasticizer combinations.

56. M. Ali, M. N. Islam, A. J. Mian and A. M. S chowdhruy [135] reported on the modification of textile properties of jute fibre by treatment with neutral sodium sulphite liquor at varying temperature under pressure. The lignin of the jute fibre underwent a sulphonation reaction and was partially dissolved out from the fibre along with some hemicelluloses depending on the degree of sulphonation. The treatment brought some changes in the physicochemical properties of the fibre. It was concluded that the modified jute fibre may be utilized in fibre yarn spinning for diversified textile uses.

57. M. Avella, E. Martuscelli, B. Pascucci, M. Raimo, B Focher and A. Marzetti [136] prepared a new class of biodegradable straw composites. In this study it was observed that the addition of 10-20% steam exploded straw to poly-3-hydroxy butyrate (PHB) markedly increased the physico-chemical characteristics because of intermolecular interactions that occured mainly in the amorphous regions of the two polymers.

58. A study on degradable property of UV-cured Hessian cloth (jute) was made by M. A. Khan, M.K. Uddin, M. N. Islam and K. M. Idriss Ali [137]. Tensile strength and elongation at break was determined. Loss of these properties due to simulating weathering was also measured and degradability was also studied.

59. Moisture absorption characterization of jute fibre cross-linked with diethyl dihydroxy ethylene urea (DMDHEU) was studied by N. C. Mukherjee and A.K. Das [138] . Cross-linking treatment of jute fibre with DMDHEU makes it less hygroscoic. Hygroscopicity decreased with the increase in cross-linking content, curing time and curing temperature.

Alkali-swollen jute fibre retains it moisture than non-swelled jute fibre possibly due to the removal of hemicellulose which is non-crystalline.

60. Effect of ethylenediamine treatment onto jute fibre was studied by A. C. Mukherjee, S. K. Bandopadhyaya and A. Mukhopadhyaya [139] . The physico-mechanical properties of jute fibre such as weight loss, swelling, moisture absorption and tensile properties were studied. Changes in fine structure of jute fibre were assessed from X-ray and IR studies.

61. S. Das, A. K. Saha, P. K. Choudhury, R. K. Basak, B. C. Mitra, T. Todd, S. Lang and R. M. Rowel [140] reported on a new process development to improve the dimensinal stability of jute fibre composite. They said that steam pretreatment process can minimize the irreversible swelling of jute fibres without any chemical modification of jute fibres.

62. C. M. Clemons, D. f. Caulfield and A. J. Giacomin [141] investigated the microstructure of injection moulded polypropylene reinforced with jute fibre and reported that there was little fibre orientation at low jute fibre contents and a layered structure arised at high jute fibre contents. They also reported that dynamic fracture toughness (Charpy impact test) increased with jute fibre content and with orientation of jute fibres perpendicular to the crack direction.

63. X. Li, Y. Z. Meng, S. J. Wang, A. V. Rajulu and S. C. Tjon [142] reported on biodegradable composites prepared by poly (propylene carbonate) (PPC) reinforced with short hildegaradia populifolia natural fibres, They observed the effect of alkali treated fibres compared with untreated fibres on the composites have better bonding. Approximately similar mechanical properties were obtained for both alkali-treated and untreated holdegardia populifolia fibre reinforced PPC composites. They also reported that tensile strength and tensile modulus of the composites increased dramatically with increasing fibre content but elongation at break decreased sharply with increasing fibre content.

64. M. J. Saad, Z. A. M. Ishak and H. D. Rozman [143] reported on the empty fruit bunch (EFD) fibre reinforced Polypropylene (PP) composites. They modified the EFD fibres

with maleic anhydride (MA) before preparing the composites. They observed that MAH-treated fibre reinforced PP composites produce higher tensile strength and better dimensional stability properties.

65. G. S. Tay, A. Abusamah and H. D. Rozman [144] investigated the effect of epichlorohydrin loading on the modified oil palm empty fruit bunch (EFB) fibre reinforced polyurethane composites (PU). They reported that composites made with EFB modified with epichlorohydrin to 8% weight Percent gain (WPG) produced higher tensile properties than others. They expressed that higher degree of modification could cause disruption of crystalline region to the EFB.

66. K. Oksman and C. Clemons [145] studied and reported the mechanical properties and morpholgy of polypropylene (PP)-wood flour (WF) composites with different impact modifiers and maleated polypropylene (MPP) as a compatibilizer. They used three types of elastomers as impact modifiers and observed improved impact strength for PP-WF composites. Addition of maleated elastomers gave the greatest improvement in impact strength of the composites. MPP did not affect the impact properties of the composites but showed better tensile strength.

67. M. A. Kabir and M. U. Ali [146] studied the physico-mechanical properties of 2,4-DNPH treated jute fibre. They observed that as the reaction period was increased to 1 h to 2.5 h the tensile strength was found to increase gradually and then decreased with the passage of time. The percent moisture regain property was observed to decrease as the reaction period increased.

68. P.K. Ganguly, A. K. Samanta, B Nandi, F. K. Dutta, N.C. Shome [147] studied the crosslinking in jute fibre with different preparatory routes. They dyed jute fibre with fibre-reactive dyes and cross linked with dimethyl ethylene urea in order to evaluate the effect of chemical treatments on fabric properties, i.e. tensile strength, crease recovery, light fastness and color fastness.

69. The influence of N-acetylglycerine on the kinetics of the ceric ion initiated graft copolymerization of acrylonitrile and methyl methacrylate onto jute fibres studied by C.

M. Patra and B. C. Singh [148] . IR spectra of chemical modified jute and grafted jute, temperature were presented and discussed. A graft yield >185% could be achieved and grafting improved the thermal stability of the jute fibres.

70. M. Ali, A. J. Mian, M. N. Islam [149] prepared the plain woven fabrics from the blends of sulphonated jute fibre with natural and synthetic fibres, and studied their physico-mechanical and dripping properties. They observed that the blended fibre fabrics show improved textile properties, almost similar to those of the cotton fabrics.

71. The physico-mechanical properties of jute fibre reinforced epoxy composites by chemical treatment were studied by J. Gassan and A. K. Bledzki [150]. Composite strength and stiffness are increased in comparison to the untreated jute fibre. The Young's moduli of composites with treated and untreated jute fibres were approximately 30% and 50%, respectively, lower than glass-fibre/epoxy composites.

72. Physico-mechanical properties of 3-(trimethoxysilan) proyl-methacrylate monomer grafted and 2-hydroxy ethyl methacrylate (HEMA) grafted jute fibres were investigated by M. M. Hassan, M. R. Islam and M. A. Khan [151] and M. B. Ahmad, M. A. Khan, W. M. Z. W. Yunus and M. Z. A. Rahman [152].

73. The effect of silane treated wood and jute fibre reinforced composites were studied by B. V. Kokta, R. G. Raj and C. Daneault [153] and M. A. Khan, F. Mina and L. T. Drzal [154]. Grafting of vinyl silanes to polyalkene substrates in the presence of peroxide leads to significant improvements in the materials properties. Compared with the untreated material, crosslinked polyethylene shows enhanced impact strength, better thermal performance and higher chemical resistance.

74. Maleic anhydride grafted polypropylene (MAPP) has been widely used as coupling agent to improve the interfacial adhesion between fibre and thermoplastic matrix. Improvement of physico-mechanical properties of cellulose fibre polypropylene composite by grafting maleic anhydride was studied by A. K. Bledzki, O. Faruk and M. M. Huque [155]. Improved physico-mechanical properties of jute and hemp fibre

reinforced polypropylene composites were obtained by the addition of MAPP as coupling agent.

75. M. Kazayawoko, J. J. Balainecz and L. M. Matuana [156] elucidated the ineraction between anhydride groups of maleated polypropylene and hydroxyl groups of wood fibre and explained the mechanisms of the interfacial adhesion between wood fibre and polypropylene matrix.

[76. R. Karnani, M. Krishnan and R. Narayan[157] reported the improved adhesion and enhanced polar interaction at the fibre/matrix interface by the modification of PP matrx with anydride and modification of fibre surface with silane.

77. L. M. Matuana, J. J. Balatinez, R. N. S. Sodhi and C. B. Park [158] reported on esterification of cellulosic fibres with phthalic anhydride and maleated polypropylene. FTIR spectroscopy results showed that anhydride moieties of both phthalic anhydride and maleated polypropylene entered into the esterification reaction with the hydroxyl groups of the cellulosic fibres. The treatment procedures were followed using solvent system.

78. M.L. Hassan, R. M. Rowell, N. A. Fadi. S. F. Yacoub and W. Christiansen [159] reported on esterification of bagasse fibres in absence of solvent to modify mainly the thermoplastic matrix of bagasse, modify mainly the thermoplastic marix of bagasse, they esterified mainly hemicelluloses and lignin, and keep cellulose as a reinforcing element. They proved the occurrence of thermo plasticization of the esterified bagasse fibres using SEM and supported by the absence of reversible swelling of some esteified bagasse composites.

EXPERIMENTAL

&

METHODOLOGY

3.1.1 Type of polypropylene used

A commercial grade polypropylene (PP) was used in this study. It was manufactured by The Polyolefin Company Pte., Ltd., Singapore; and its commercial name is Cosmoplene. Melting point of this PP was measured and found to be ~160°C. Melting point and FT-IR spectroscopic observations indicate that the used PP was an isotactic commercial grade polypropylene. In the literature it is mentioned that the melting point of commercial grade PP lies in the range 160-170°C but pure PP melts at 176°C [160].

3.1.2 Sizing of jute fibre

The jute fibre (Tossa variety) was collected from Bangladesh Jute Research Institute, Dhaka. The middle part of the jute fibre was taken by removing the lower hard woody and upper soft parts of jute fibre. For the present investigation it was cut into pieces of 25 cm length and was divided into bundles of 0.5g.

3.1.3 Chemicals

The oxidizing agent sodium periodate (reagent grade) was used. The coupling agents used in this study were benzene diazonium chloride and para nitroso *N, N*-dimethyl phenyl amine. Acidic medium was maintained by adding sulfuric acid. Alkali treatment was done by using sodium hydroxide and sodium bicarbonate. The list of chemicals used in this study and their supplier name are given below:

Chemicals/Reagent used	**Name of the suppliers**
Sodium hydroxide (NaOH)	Merck, India
Sodium bicarbonate.($NaHCO_3$)	Merck, Germany
Sulphuric acid(H_2SO_4)	Merck, India
Hydrochloric acid(HCl)	Merck, Germany
Sodium periodate($NaIO_4$)	Merck, Germany
Aniline (C_6H_7N)	Merck, India
p-nitroso *N,N*-dimethyl aniline ($C_8H_{10}N_2O$)	Merck, India
Sodium nitrite ($NaNO_2$)	Merck, Germany
o-amino phenol (C_6H_7NO)	Merck, Germany
m-amino phenol (C_6H_7NO)	Merck, Germany
p-amino phenol (C_6H_7NO)	Merck, Germany

3.2 Treatment of jute fibre

The raw jute fibres were first cleaned manually and chopped into approximately 3mm length. The fibres were then washed with distilled water and dried in open air. The air-dried fibres were then oven dried at 105°C for 6 hours. Then the fibre was bleached with alkali solutions (sodium hydroxide/sodium bicarbonate, 10g/L) for 30 minutes at 70 ± 2^0C. The fibre to liquor ratio was 1:20 (w/v).

3.2.1 Treatment of jute fibre with alkali

Jute fibre treated with alkali was prepared by immersing ten bundles of raw jute fibre separately in solution of 10% sodium hydroxide (w/v) and allowed to ripe for 0.5, 1, 2, 3 and 4 hours. Excess of alkali was removed by squeezing. The treated jute fibre was then separated out, washed by water and finally dried with a hot air blower. The physico-mechanical properties of alkali jute fibre were determined.

3.2.2 Oxidation of jute fibre with sodium periodate

Sodium periodate solution (0.08 M) was prepared in distilled water. Dried jute fibres were immersed in 0.08M sodium periodate solution. The fibre to liquor ratio was 1:20 (w/v). The pH of the aqueous solutions was adjusted to 3 by adding sulfuric acid. The oxidation reaction was carried out for 5 hours at 70±2^{0}C. The reaction mixture was stirred by glass rod occasionally. After completion of the reaction, the mixture was cooled and filtered to isolate the oxidized jute fibres. The oxidized jute fibres were thoroughly washed in tap water and finally washed with distilled water. The pH of the washed fibres was found neutral. The washed oxidized fibres were first air-dried and then dried in oven at 105°C for 6 hours.

3.2.3 Treatment of jute fibre with benzene diazonium chloride

Benzene diazonium chloride was synthesized in the laboratory with aniline and sodium nitrite in presence of mineral acid at 0-5^{0}C using the standard diazotization method [70]. The solution of aniline (phenyl amine) in hydrochloric acid (phenyl ammonium chloride solution) was stored in a beaker of ice bath. The sodium nitrite solution is also cooled in the ice bath. The nitrite solution was then added to the phenyl ammonium chloride solution very slowly, so that the temperature never goes above 5°C. The reaction scheme for synthesis of benzene diazonium chloride is shown in figure 3.1. The solution containing diazonium chloride was used immediately in the coupling reaction with the jute fibre.

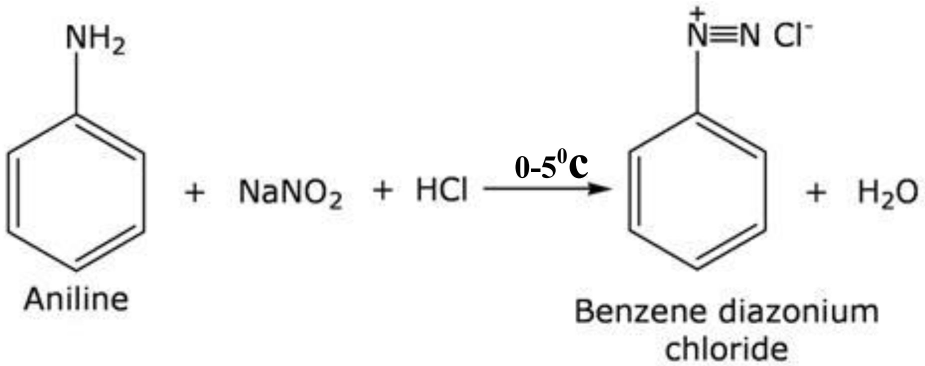


Fig. 3.1: The reaction scheme for synthesis of benzene diazonium chloride

Jute fibre was dried at l05°C for 24 hours and then kept in a sealed container. Dried jute fibre was submerged into the freshly prepared cooled solution of diazonium chloride for 10 minutes at about 5°C in an ice bath with constant stirring. Jute fibre was then taken out, washed with tap water followed by distilled water and finally dried in open air.

3.2.4 Treatment of jute fibre with *p*-nitroso *N, N* -dimethyl aniline

p-nitroso *N, N*-dimethyl phenyl amine was synthesized in the laboratory with *N, N*-dimethyl aniline and sodium nitrite in presence of mineral acid (HCl) at 0-5^{0}C using the standard diazotization method [161]. The solution of *N, N*-dimethyl aniline in hydrochloric acid was stored in a beaker of ice bath. The sodium nitrite solution is also cooled in the ice bath. The nitrite solution was then added very slowly to the acid solution, so that the temperature never goes above 5°C. The reaction scheme for synthesis of *p*-nitroso *N, N*-dimethyl aniline is shown in figure 3.2. The solution containing *p*-nitroso *N, N*-dimethyl aniline was used immediately in the coupling reaction with jute fibre.

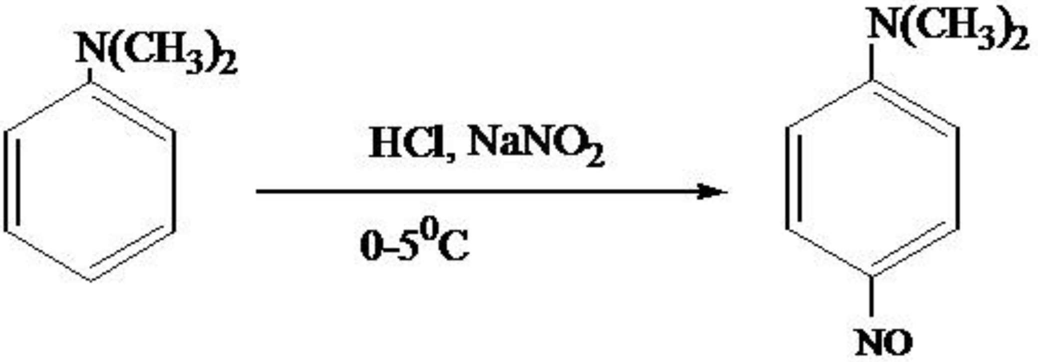
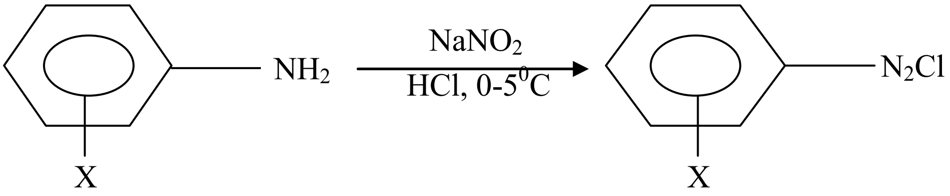


Fig. 3.2: The reaction scheme for synthesis of *p*-nitroso *N,N*-dimethyl aniline

Jute fibre was dried at 105°C for 24 hours and then kept in a sealed container. Dried jute fibre was submerged into the freshly prepared cooled solution of *p*-nitroso *N, N*-dimethyl aniline for 10 minutes at about 5°C in an ice bath with constant stirring. Jute fibre was then taken out, washed with tap water followed by distilled water and finally dried in open air.

3.2.5 Preparation of *o*-, *m*--and *p*-hydroxy benzene diazonium chloride

Ortho-, meta- and para-amino phenol (0.001 mole, 0.152g) were mixed with conc. hydrochloric acid (10cm^3) with constant stirring and the mixture was cooled to 0^{0}C in an ice bath. An aqueous (20%) solution of sodium nitrite (10cm^3) was also cooled in an ice bath and was added slowly through a dropping funnel to the above mixture with constant stirring so that the temperature of the mixture would not rise above 5^{0}C throughout the addition. The addition of sodium nitrite was stopped as soon as the reaction mixture just produced a blue coloration on starch iodine paper. The resulting solutions of the diazonium chloride were used immediately after their preparation.



Where, X= (a) *o*-hydroxy- (b) *m*- hydroxy- (c) *p*-hydroxy-

Fig.3.3: Preparation of various hydroxy benzene diazonium chloride.

3.2.6 Treatment of jute fibre with various substituted *o*-, *m*- and *p*-hydroxy benzene diazonium chlorides

Ten bundles (5g) of raw jute fibre were washed with water to remove dirt particles. A 5% sodium hydroxide solution was added drop wise into the freshly prepared *o*-hydroxy benzene diazonium chloride (section 3.2.5) to maintain pH range 8-9. Then the freshly prepared cooled solution of *o*-hydroxy benzene diazonium chloride was then added slowly to the bundles of raw jute fibre with constant stirring for about ten minutes. During treatment the jute fibre becomes colored. The bundle of jute was then separated out, washed with soap solution followed by distilled water and finally dried using a hot air blower. Similar operations were carried out also by using other substituted benzene diazonium chlorides (*o*-, *m*-hydroxy benzene diazonium chloride and *p*-hydroxy benzene diazonium chloride). The physico-mechanical properties of these treated jute fibres were determined.

3.2.7 Determination of physico-mechanical properties of raw jute and treated jute fibre

Physic-mechanical properties such as tensile strength, tenacity, percent elongation at break, moisture regain, weight loss, shrinkage in length, biodegradability of raw and treated jute fibre have been studied in their research work. The method's, applied for the measurement of these properties are described in the following sections:

3.2.8 Determination of tensile strength

When an external force is applied axially on the specimen, an internal force is developed in order to resist the external force. The internal force per unit area at any section is called stress, σ :

$$\sigma = F/A \text{ (MPa)}$$

Where,

F= the force applied on the specimen (in Newton, N)

A=area of cross section (in mm^2)

The minimum stress at which the specimen breaks away is called the tensile strength and its unit is Mega Pascal (MPa).

A jute fibre of length 25 cm and weight 0.5 gm considered as a yarn in the related experiments. Tensile strength of jute fibre was measured by "Universal Testing Machine" in the Laboratory of Mechanical Engineering, BUET, Dhaka.

The sample (0.5g fibre, 25 cm in length), was fixed in between the two jaw's of the instrument that were placed at a distance of 10 cm apart from each other. One twist per 2 cm was given along the length of fibre between the jaws. Different loads were then applied successively. At a certain load the sample yarn was ruptured. This load was breaking load (in Newton) of the yarn.

Tensile strength in lbf/in^2 of sample yarn could also be calculated by using the following formula [162]

$$\text{Tensile strength} = \frac{b}{M} \times 0.04733 \text{lbf/in}^2$$

Where,

b=bundle breaking load, lbf and

M= bundle mass, g

3.2.9 Determination of tenacity

Tenacity of a yarn is defined [163] as the strength per unit yarn number and another term of yarn number is denier. The denier of a yarn is the weight in gram of a length of 9000 meters of that yarn. Tenacity is expressed in gf/Denier.

So, Denier (D) = $\frac{W(g)}{L(m)}$ ×9000 meters (m) and tenacity = $\frac{Breakinglaad}{Deniar}$

Tenacity can also be determined by using the following formula [164].

$$\text{Tenacity}= \frac{b}{M} \times 2.766\times10^{-5}\text{gf/Denier}$$

Where,

b=bundle breaking load, lbf and

M= bundle mass, g

3.2.10 Determination of percent elongation at break

Elongation [165] is deformation of strain caused by a tensile force. The deformation strain may be measured at a specified load or at rupture. It is expressed as percent of the original length.

$$\text{So, percent elongation} = \frac{L_f - L_i}{L_i} \times 100$$

Where,

L_f= length of fibre in cm between two jaws just at rupture

L_i= initial length in cm between two jaws

3.2.11 Determination of moisture regain

To determine the moisture regain an accurately weighed amount of jute fibre was dried at 105^0C and exposed to a standard atmosphere (Relative humidity is 65±2 % and temperature is 20 ± 2^0C) for 48 hours and again weighed carefully in the some condition of atmosphere. The percent moisture regain [166] was calculated using the following relation:

$$\text{R}= \frac{b-a}{a} \times 100$$

Where,

R= moisture regain percent

a= weight of the dried sample

b=weight of the moist sample

3.2.12 Determination of weight change

The weight loss of the treated jute fibre was determined [167] on the basis of oven dry weight. The weight of the jute fibre was measured before and after treatment. The weight change percentage was expressed as follows:

$$W_C = \frac{W_i - W_f}{w_i} \times 100$$

Where,

W_C = change in weight in percent

W_f = final weight of chemically treated (in gram) dried jute fibre (dried with hot air blower).

W_i = initial weight of dried jute fibre (in gram).

3.2.13 Determination of shrinkage

To determine the percent shrinkage, jute fibre was cut out to a size of 25 cm length. It was then treated with various chemical reagents. The treated fibre was then washed thoroughly with water, dried and finally the length was measured again. The percent shrinkage [168] was calculated using the following relation.

$$L_{sh} = \frac{L_f - L_i}{L_i} \times 100$$

Where,

L_{sh}= Length shrinkage in percent

L_f= Final length after chemical treatment

L_i= Initial length of dried jute fibre (25 cm) before treatment

3.3 Biodegradation test

The samples prepared (as described in sections 4.2.2 and 4.2.4) were taken for biodegradation test. The procedure of biodegradation the place where manure is deposited is described below in brief.

Soil containing about 75% moisture was collected from the place where manure is deposited. Seventy bundles of treated jute fibre, raw jute fibre and their composites were kept under the soil in different pots separately but in identical condition. The soil was put in an earthen and then subjected to the action of micro-organisms i.e. both fungi and bacteria that are normally present in the soil. After a certain regular interval of period ten bundles of treated jute fibre and their composites were taken out, washed with distilled water and dried. Tensile strength of these was measured. The results of tensile strength are presented in tables 4.9.-32. The results of biodegradation test are shown in table 4.33(a) and 4.33(b).

3.4 Preparation of composite materials

3.4.1 Polypropylene and jute

A commercial grade polypropylene (PP) was used in this study. The polypropylene manufactured by Polyolefin Company, Pvt. Lt., Singapore. Its commercial name is Cosmoplene. Melting point of this PP was measured and found to be ~160^{0}C. Melting point and spectroscopic observations indicated that the used PP was an isotactic polypropylene (soft, elastic and non-crystalline) and commercial grade.

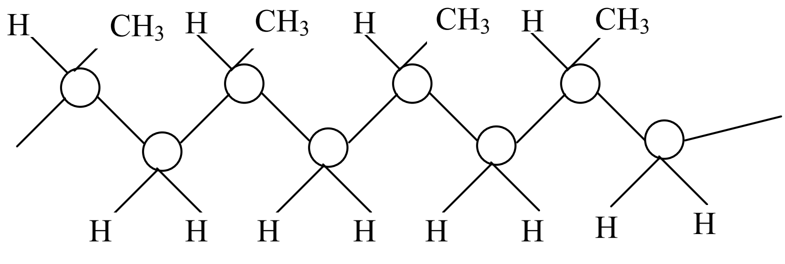


Fig. 3.4: Structure of isotactic polypropylene

The jute fibres were collected from Bangladesh Jute Research Institute (BJRI), Dhaka, Bangladesh. The collected raw jute fibres were mixed grade of Tossa variety (Corchorus and Olitorius). The middle parts of the raw jute fibres were used in this study and were chopped into lengths of approximately 3 mm.

3.4.2 Composite fabrication

Jute-polypropylene composites were prepared using raw jute and chemically modified jute fibre along with carrot powder (described in section 3.2.3-3.2.5 and 3.2.8) following the procedure described below-

The raw and treated jute fibres were dried in an oven at 105^0C for 6 hours. PP polymers were also dried in oven for 3 hours at room temperature. Raw and treated jute fibres were mixed thoroughly with polypropylene to prepare composites. PP matrix and jute fibres were taken in different weight fraction as listed in the following table 3.1.

Table 3.1: Relative amounts of jute fibre (reinforcing materials) and polymer matrix by weight by weight fraction

Polymer matrix (%)	**Reinforcing material (wt %)**	**Additive (wt %)**
PP : 80	Raw jute fibre: 20	--
PP : 75	Raw jute fibre: 25	--
PP : 70	Raw jute fibre: 30	--
PP : 65	Raw jute fibre: 35	--
PP : 80	Alkali treated jute fibre: 20	--
PP : 75	Alkali treated jute fibre: 25	--
PP : 70	Alkali treated jute fibre: 30	--
PP : 65	Alkali treated jute fibre: 35	--
PP:80	*p*-nitroso *N,N*-DMA treated jute fibre: 20	--
PP:75	*p*-nitroso *N,N*-DMA treated jute fibre: 25	--
PP:70	*p*-nitroso *N,N*-DMA treated jute fibre: 30	--
PP:65	*p*-nitroso *N,N*-DMA treated jute fibre: 35	--
PP : 80	*o*-HBDC treated jute fibre: 20	--
PP : 75	*o*-HBDC treated jute fibre: 25	--
PP : 70	*o*-HBDC treated jute fibre: 30	--
PP : 65	*o*-HBDC treated jute fibre: 35	--
PP : 80	*m*-HBDC treated jute fibre: 20	--
PP : 75	*m*-HBDC treated jute fibre: 25	--
PP : 70	*m*-HBDC treated jute fibre: 30	--
PP : 65	*m*-HBDC treated jute fibre: 35	--
PP : 80	*p*-HBDC treated jute fibre: 20	--
PP : 75	*p*-HBDC treated jute fibre: 25	--
PP : 70	*p*-HBDC treated jute fibre: 30	--
PP : 65	*p*-HBDC treated jute fibre: 35	--

Contd

PP : 75	Raw jute fibre: 20	Carrot powder :5
PP : 75	Alkali treated jute fibre: 20	Carrot powder :5
PP : 75	*p*-nitroso *N,N* - DMA treated jute fibre: 20	Carrot powder :5
PP : 75	*o*-HBDC treated jute fibre: 20	Carrot powder :5
PP : 75	*m*-HBDC treated jute fibre: 20	Carrot powder :5
PP : 75	*p*-HBDC treated jute fibre: 20	Carrot powder :5
PP : 70	Raw jute fibre: 20	Carrot powder :10
PP : 70	Alkali treated jute fibre: 20	Carrot powder :10
PP : 70	*p*-nitroso *N,N* - DMA treated jute fibre: 20	Carrot powder :10
PP : 70	*o*-HBDC treated jute fibre: 20	Carrot powder :10
PP : 70	*m*-HBDC treated jute fibre: 20	Carrot powder :10
PP : 70	*p*-HBDC treated jute fibre: 20	Carrot powder :10
PP : 65	Raw jute fibre: 20	Carrot powder :15
PP : 65	Alkali treated jute fibre: 20	Carrot powder :15
PP : 65	*p*-nitroso *N,N* - DMA treated jute fibre: 20	Carrot powder :15
PP : 65	*o*-HBDC treated jute fibre: 20	Carrot powder :15
PP : 65	*m*-HBDC treated jute fibre: 20	Carrot powder :15
PP : 65	*p*-HBDC treated jute fibre: 20	Carrot powder :15
PP : 60	Raw jute fibre: 20	Carrot powder :20
PP : 60	Alkali treated jute fibre: 20	Carrot powder :20
PP : 60	*p*-nitroso *N,N* - DMA treated jute fibre: 20	Carrot powder :20
PP : 60	*o*-HBDC treated jute fibre: 20	Carrot powder :20
PP : 60	*m*-HBDC treated jute fibre: 20	Carrot powder :20
PP : 60	*p*-HBDC treated jute fibre: 20	Carrot powder :20
PP : 70	Raw jute fibre: 25	Carrot powder :5
PP : 70	Alkali treated jute fibre: 25	Carrot powder :5
PP : 70	*p*-nitroso *N,N* - DMA treated jute fibre: 25	Carrot powder :5
PP : 70	*o*-HBDC treated jute fibre: 25	Carrot powder :5
PP : 70	*m*-HBDC treated jute fibre: 25	Carrot powder :5
PP : 70	*p*-HBDC treated jute fibre: 25	Carrot powder :5
PP : 65	Raw jute fibre: 25	Carrot powder :10
PP : 65	Alkali treated jute fibre: 25	Carrot powder :10
PP : 65	*p*-nitroso *N,N* - DMA treated jute fibre: 25	Carrot powder :10
PP : 65	*o*-HBDC treated jute fibre: 25	Carrot powder :10
PP : 65	*m*-HBDC treated jute fibre: 25	Carrot powder :10
PP : 65	*p*-HBDC treated jute fibre: 25	Carrot powder :10
PP : 60	Raw jute fibre: 25	Carrot powder :15
PP : 60	Alkali treated jute fibre: 25	Carrot powder :15

Contd

PP : 60	*p*-nitroso *N,N* - DMA treated jute fibre: 25	Carrot powder :15
PP : 60	*o*-HBDC treated jute fibre: 25	Carrot powder :15
PP : 60	*m*-HBDC treated jute fibre: 25	Carrot powder :15
PP : 60	*p*-HBDC treated jute fibre: 25	Carrot powder :15
PP : 55	Raw jute fibre: 25	Carrot powder :20
PP : 55	Alkali treated jute fibre: 25	Carrot powder :20
PP : 55	*p*-nitroso *N,N* - DMA treated jute fibre: 25	Carrot powder :20
PP : 55	*o*-HBDC treated jute fibre: 25	Carrot powder :20
PP : 55	*m*-HBDC treated jute fibre: 25	Carrot powder :20
PP : 55	*p*-HBDC treated jute fibre: 25	Carrot powder :20
PP : 65	Raw jute fibre: 30	Carrot powder :5
PP : 65	Alkali treated jute fibre: 30	Carrot powder :5
PP : 65	*p*-nitroso *N,N* - DMA treated jute fibre: 30	Carrot powder :5
PP : 65	*o*-HBDC treated jute fibre: 30	Carrot powder :5
PP : 65	*m*-HBDC treated jute fibre: 30	Carrot powder :5
PP : 65	*p*-HBDC treated jute fibre: 30	Carrot powder :5
PP : 60	Raw jute fibre: 30	Carrot powder :10
PP : 60	Alkali treated jute fibre: 30	Carrot powder :10
PP : 60	*p*-nitroso *N,N* - DMA treated jute fibre: 30	Carrot powder :10
PP : 60	*o*-HBDC treated jute fibre: 30	Carrot powder :10
PP : 60	*m*-HBDC treated jute fibre: 30	Carrot powder :10
PP : 60	*p*-HBDC treated jute fibre: 30	Carrot powder :10
PP : 55	Raw jute fibre: 30	Carrot powder :15
PP : 55	Alkali treated jute fibre: 30	Carrot powder :15
PP : 55	*p*-nitroso *N,N* - DMA treated jute fibre: 30	Carrot powder :15
PP : 55	*o*-HBDC treated jute fibre: 30	Carrot powder :15
PP : 55	*m*-HBDC treated jute fibre: 30	Carrot powder :15
PP : 55	*p*-HBDC treated jute fibre: 30	Carrot powder :15
PP : 50	Raw jute fibre: 30	Carrot powder :20
PP : 50	Alkali treated jute fibre: 30	Carrot powder :20
PP : 50	*p*-nitroso *N,N* - DMA treated jute fibre: 30	Carrot powder :20
PP : 50	*o*-HBDC treated jute fibre: 30	Carrot powder :20
PP : 50	*m*-HBDC treated jute fibre: 30	Carrot powder :20
PP : 50	*p*-HBDC treated jute fibre: 30	Carrot powder :20
PP : 60	Raw jute fibre: 35	Carrot powder :5
PP : 60	Alkali treated jute fibre: 35	Carrot powder :5
PP : 60	*p*-nitroso *N,N* - DMA treated jute fibre: 35	Carrot powder :5
PP : 60	*o*-HBDC treated jute fibre: 35	Carrot powder :5

Contd.

PP : 60	*m*-HBDC treated jute fibre: 35	Carrot powder :5
PP : 60	*p*-HBDC treated jute fibre: 35	Carrot powder :5
PP : 55	Raw jute fibre: 35	Carrot powder :10
PP : 55	Alkali treated jute fibre: 35	Carrot powder :10
PP : 55	*p*-nitroso *N,N* - DMA treated jute fibre: 35	Carrot powder :10
PP : 55	*o*-HBDC treated jute fibre: 35	Carrot powder :10
PP : 55	*m*-HBDC treated jute fibre: 35	Carrot powder :10
PP : 55	*p*-HBDC treated jute fibre: 35	Carrot powder :10
PP : 50	Raw jute fibre: 35	Carrot powder :15
PP : 50	Alkali treated jute fibre: 35	Carrot powder :15
PP : 50	*p*-nitroso *N,N* - DMA treated jute fibre: 35	Carrot powder :15
PP : 50	*o*-HBDC treated jute fibre: 35	Carrot powder :15
PP : 50	*m*-HBDC treated jute fibre: 35	Carrot powder :15
PP : 50	*p*-HBDC treated jute fibre: 35	Carrot powder :15
PP : 45	Raw jute fibre: 35	Carrot powder :20
PP : 45	Alkali treated jute fibre: 35	Carrot powder :20
PP : 45	*p*-nitroso *N,N* - DMA treated jute fibre: 35	Carrot powder :20
PP : 45	*o*-HBDC treated jute fibre: 35	Carrot powder :20
PP : 45	*m*-HBDC treated jute fibre: 35	Carrot powder :20
PP : 45	*p*-HBDC treated jute fibre: 35	Carrot powder :20

Composites were prepared by thoroughly mixing the required amount of polypropylene, jute fibre and carrot powder as listed in table-3.1. The mixture was then passed through a single screw extruder machine. The processing temperature of extrusion was controlled at $160^0C \pm 2^0C$. The jute fibre-PP mixtures were continuously fed into the extruder. The composites were delivered through a dice of rod shape at uniform rate. The composites were cut into small pieces of 15-20 cm in length by stainless steel scissors. The small pieces were dried in an oven at 105^0C for 6 hours. The extruder used for manufacturing composites was designed and made in our laboratory taking the help of local experts. The photograph of extruder machine is shown in figure 3.5

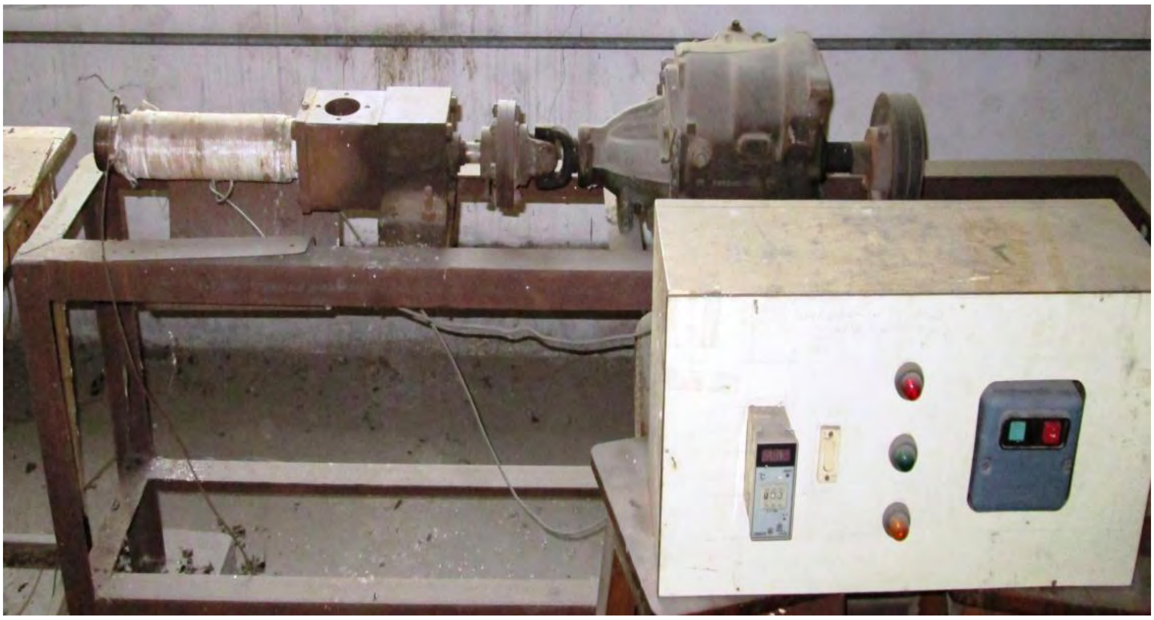


Fig. 3.5 :Photograph of extruder machine

3.4.3 Preparation of test specimens by injection moulding

The dried chopped granulated products were moulded as per ASTM specimens (tensile and flexural test bars) by an injection- moulded machine at a moulding temperature of $170^0C \pm 2^0C$. The pressure, temperature and heating time of the samples were controlled at the same rate to prepare all sample specimens. The used injection moulding machine is vertical and operated manually. The sample was heated to melt in the heating chamber, then pumped into closed mould die. This was done by the use of a plunger or ram into the heated cylinder load (approx. $900N/mm^2$). The mould was kept for few minutes to cool down and then opened to remove the test sample. By this way, all the tensile and flexural test specimens were prepared by injection moulding technique. Single moulds were used to prepare tensile and flexural test bars. The photograph of injection moulding machine is shown in figure 3.6. Injection moulded tensile and flexural test specimens are shown in figure 3.7.

Fig. 3.6: Photograph of injection moulding machine

.

Fig. 3. 7: Photograph of (a) tensile strength test specimen

Fig. 3. 7: Photograph of (b) flexural strength test specimen

3.5 Structural characterization

The composite materials were characterized by FT-IR Spectroscopy and Scanning Electron Microscopy as stated below:

3.5.1 FT-IR spectroscopy

The infrared spectra of the PP polymer, raw jute fibre, oxidized jute fibre and 30 wt% fibre reinforced composites were recorded on a Shimadzu FTIR-8400 spectrophotometer (figure 3.8). The sample pellets for FT -IR spectroscopy were prepared as follows:

Approximately 0.5 mg of powdered samples was mixed thoroughly with approximately 100 mg of dried powdered potassium bromide in a small agate mortar pestle. The mixture was taken in a die of specific dimensions. Pellets were made by applying vacuum pressure. IR spectra with all information about absorbance were obtained in the printed form. IR spectra obtained in this study are presented in the result and discussion section.

Fig. 3.8: Photograph of FT-IR instrument (Shimadzu FTIR-8400)

3.5.2 Scanning Electron Microscopy (SEM)

Image analysis was carried out using a Scanning Electron Microscope (model: S-3400N, Hitachi, Japan) for observing surface morphology, particle size, particle distribution, porosity and pore size. The SEM analysis was carried out at the Glass and Ceramics Engineering Department of BUET, Dhaka

Fig. 3.9: Photograph of the SEM instrument (model: S-3400N, Hitachi, Japan)

3.6 Mechanical properties of the composites

In order to investigate the mechanical properties of the prepared composites the following tests were carried out; (a) tensile (b) three point flexural and (c) Charpy impact test. For these tests the appropriate ASTM methods were followed. Specification and picture of the used machines, set-up of the tests, operating conditions and dimension of the test specimens are described below.

3.6.1 Tensile test

To test the tensile strength the load must be applied in axial direction of the specimen. The tensile test of the composites was carried out in an universal testing machine, model-5/500, capacity: 5KN, Ogawa Seiki C. Ltd. Japan. The photograph of universal testing machine is shown in figure 3.11. Tensile tests were conducted following ASTM D 638-0186 [169]. The dimensions of dumb bell-shaped injection moulded test specimen (i.e., its length, width, thickness) were 148.4 mm 10 mm and 4 mm respectively (shown in Fig 3.10). Eight to ten specimens of each sample were tested and the average values were reported by taking closely matched five values. The maximum load values were also recorded by the instrument, which can be recalled after the completion of the test. The tensile strength (σ) is calculated by using the following equation.

$$\text{Tensile strength, } \sigma = F/A$$

Where,

F= breaking load and

A= area of cross section

When load is applied on the specimen it is deformed. In case of determination of tensile strength due to the application of load (force) the specimen is elongated. The elongation per unit length is called strain

strain, $C = \Delta L/L$

Where,

ΔL= the deformation over the length L (mm)

L= gauge length (mm)

Tensile modulus= σ / C N/mm^2

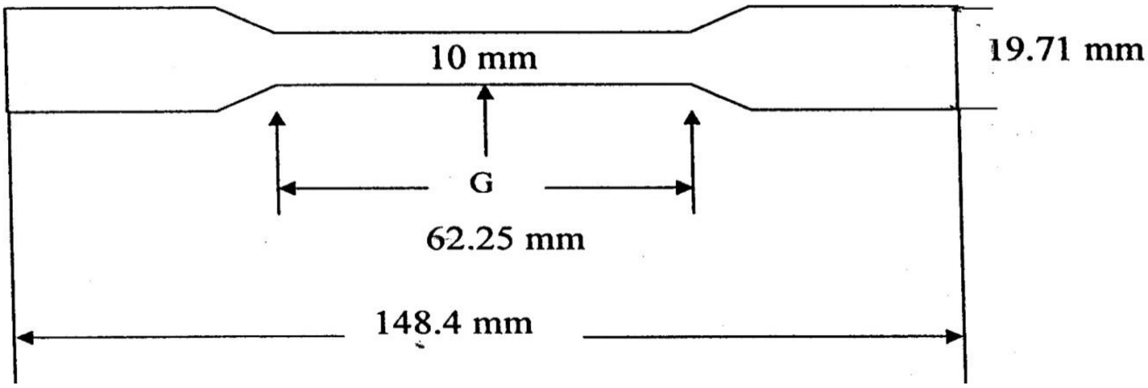


Fig. 3.10: Dimension of tensile test specimen

3.6.2 Determination of tensile strength

When an external force is applied axially on the specimen, an internal force is developed in order to resist the external force. The internal force per unit area at any section is called stress, σ:

$$\sigma = F/A \text{ (MPa)}$$

Where,

F= the force applied on the specimen (in Newton, N)

A=area of cross section (in mm^2)

The minimum stress at which the specimen breaks away is called the tensile strength and its unit is mega Pascal (MPa).

Tensile strength of jute fibre-PP composites was measured by "Universal Testing Machine" in the Laboratory of Mechanical, BUET , Dhaka. The operation process is very much similar to that of jute fibre described in section 3.28. The basic difference is in this case samples of specified dimension (shown in figure 3.10) have been used in place of jute yarn.

The sample (0.5g fibre, 25 cm in length), was fixed in between the two jaw's of the instrument that were placed at a distance of 10 cm apart from each other. One twist per 2 cm was given along the length of fibre between the jaws. Different loads were then applied successively and the operation was started in the instrument. At a certain load the sample yarn was ruptured. This load was breaking load (in Newton) of the yarn.

Tensile strength in lbf/in^2 of sample bar could also be calculated by using the following formula [170]

$$\text{Tensile strength} = \frac{b}{M} \times 0.04733 \text{lbf/in}^2$$

Where,

b=bundle breaking load, lbf and

M= bundle mass, g

Fig 3.11: Universal testing machine

3.6.3 Three point flexural strength test

In case of flexural test the load is applied to the axial direction of sample The static flexural tests of the composites were carried out using the same machine that was used for tensile test only by changing the attachment. Setup of the three point flexural test is shown in figure 3.12. Dimension of flexural test specimen was 79 mm length, 9.5 mm width and 4 mm thickness. Flexural tests were conducted following ASTM D 790-0087

[171]. Injection moulded test specimens shown in figure 3.7 b were used directly to perform the flexural test operation and the operating conditions were similar to that of tensile test. Five specimens of each composition were tested and the average values were reported. The flexural strength (σ_{fs}) and modulus of elasticity (E_B) were calculated by the following equations [171].

Flexural strength, $\sigma_{fs} = 3PL/2bd^2$

Where,

P= Maximum load on the load-deflection curve
L= Support span, 53.7 mm
b= Width of beam tested, 9.5 mm and
d= Thickness of beam tested, 4 mm

Modulus of elasticity, $E_B = L^3m/4bd^3$

Where,
L= Support span, 53.7mm
b= Width of beam tested, 9.5
d= Thickness of beam tested, 4 mm and
m= Slope of the tangent to the initial straight-line portion of the load-deflection curve, N/mm of deflection.

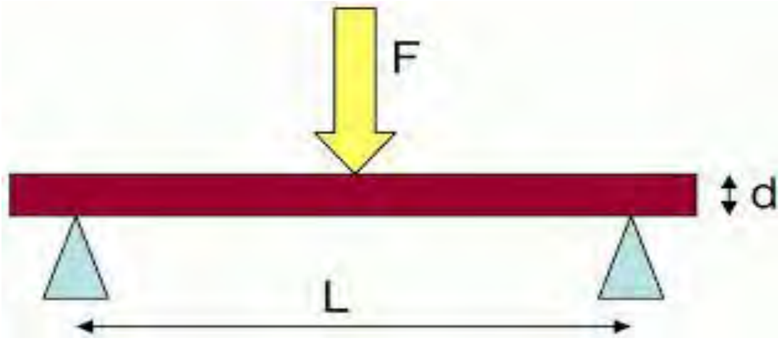


Fig. 3.12: Flexural test with three-point loading

3.6.4 Charpy impact strength test

A freely falling body or a moving mass, that strikes a structure produces dynamic or impact load. The energy absorbed in breaking the specimen is a measure of the impact strength. Charpy introduced this test in 1909. The dynamic Charpy impact tests of the composites were done according to ASTM D 6110-97 [172]. Figure 3.11 shows the photograph of Universal Impact Testing Machine, Type: TIT-30, Tokyo Testing Machine MFG. Co. Ltd., and Japan. This machine was used to perform Charpy impacts of all the samples. Weight of the hammer of this machine was 3.72 kg and span between the supports was 40mm. The Charpy impact test specimens were injection-moulded without having any kind of machining on them. The width, thickness and length of the specimen were 9.5 mm, 4.0 mm and 79 mm respectively. The specimen was placed on an anvil and was broken by a single blow of the pendulum or hammer, which fell from a fixed starting point. In this condition it has a potential energy equal to WH. Where, W is the weight of pendulum and H is the height from the centre of gravity above its lowest point. If the hammer is released from the starting position without setting the specimen, it will rise up to an angle θ_1. Again if the specimen is placed and then the pendulum is released it will rise up to an angle θ_2 after breaking the specimen.

So. the energy absorbed=WH (Cos θ_1 — Cos θ_2)/bd

Where,

b= Width of beam tested, 9.5 mm and

d=Thickness of beam tested, 4 mm

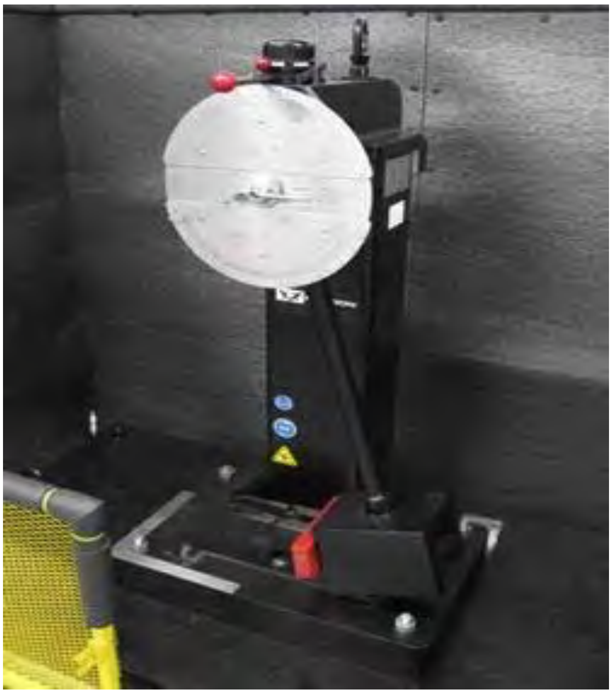


Fig 3.13: Photograph of universal impact testing machine

3.7 Thermal analysis

3.7.1 TG/DTA Machine

Thermo-gravimetric analysis (TGA) of composites was carried in thermo gravimetric analyzer (Model: SEIKO EXTAR TG/ DTSA 6300, Supplier: SEIKO, USA). The analyzer usually consists of a high precision balance with a pan loaded with the sample. The sample was placed in a small electrically heated oven with a thermocouple to accurately measure the temperature. The atmosphere may be purged with an inert gas to prevent oxidation or other undesired reactions. A computer was used to control the instrument.

Fig. 3.14: TG/DTA machine

Thermo-gravimetric / Differential Thermal Analysis of (TG/DTA) several jute-PP composites studied in this work were carried out at the Chemistry Laboratory of Dhaka University.

3.7.2 TG Measurement principle

The TG/DTA module uses a horizontal differential system balance mechanism. Sample weight changes are measured as described below:

Sample balance beam and reference balance beam are independently supported by driving coil/pivot. When a weight change occurs at the beam end, the movement is conveyed to the opposite end of the beam via the driving coil/pivot, where optical sensors detect the changes in the position of a slit. The signal from the optical sensor is sent to the reference side and is converted into weight signal.

3.7.3 DTA Measurement principle

The thermocouple made up of platinum- rhodium (13%) for DTA measurement is incorporated at the end of each of the balance beam ceramic tubes and the temperature difference between the holder on the sample side and the holder on the reference side is detected. This signal is amplified and become the temperature difference signal used to measure the thermal change of the sample. The specification of TG/DTA/DTG machine is given below:

Table 3.2: Specification of TG/DTA/DTG machine

	TG/DTA 6300
Weight Measurement Sample weight	Horizontal differential balance method. Max-200 mg
Temperature range	Room temperature —1500^{0}C
Heating range TG Measurement DTA Measurement	0.01^{0}C/ min – 100^{0}C / min 200 μg (0.2 m g) 600 μV (0.6 mV)
Gas Flow	Max. 1000 ml/min

Biodegradability test of the composites

The biodegradability test of the sample specimens (those have been prepared for the experimental determinations of different mechanical properties mentioned earlier) was carried by keeping 60 of these sample specimens in the waist soil in the similar way that has been applied for the biodegradability test of jute fibre described in section 3.3. After certain interval of time the test sample specimens were taken out from the soil, washed with water and then dried in an over at 80^{0}C. The dried samples were then used for the measurement of different parameters studied in this work.

RESULTS AND DISCUSSION

4.1 General discussion

The jute fibre was collected from Jute Research Institute, Dhaka. The raw jute fibre was taken by removing the lower hard woody and upper soft parts for the present investigation. It was cleaned manually to remove the hard patches. Raw jute fibres were then cut into small pieces of 25 cm length and were divided into bundles of 0.5g each. These were then treated with alkali (NaOH), oxidizing agent ($NaIO_4$) and coupling agent (*p*-nitros DMA, *o-, m-* and *p*-hydroxy benzene diazonium salt).

The tensile strength and percent elongation of raw and treated jute fibre were determined by universal testing mechine. The tensile strength is conventionally expressed in terms of tenacity of jute fibre used in textile industries. The value of tensile strength is converted into tenacity by mathematical formulation (described in experimental sections 3.2.8 and 3.2.9. The percent moisture regain of raw and treated jute fibre was determined by standard method [173]. The percent loss in weight was measured by weighing in an electrical balance and percent shrinkage was determined by measuring the initial and final length of fibre. The obtained results have been discussed in the following sections:

4.2 Effect of 10% (W/V) NaOH solution on physico-mechanical properties of raw jute fibre

The cleaned and small pieces of raw jute fibres (25 cm length) were submerged into 10% w/v NaOH solution and kept for 30 minutes to 4 houres. The fibres were then taken out washed with water dried in air over night. The physico-mechanical properties of these treated jute fibre were measured. The results are presented in table 4.1.

It is observed from table 4.1 that as the reaction period was increased from 0.5 to 4 hr. the tensile strength and tenacity of alkali (10% w/v NaOH solution) treated fibre was found to be decreased gradually. This may be due to dissolution of lignin of jute fibre in NaOH solution. It is to be mentioned here that lignin in jute fibre acts as binding agent. So larger is the amount of lignin dissolved out weaker is the jute fibre in strength.

It is also observed from the table 4.1 that the percent elongation at break, moisture regains properties were increased gradually as the reaction period increased. This may also be due to same reason mentioned above. As the binding agent (lignin) dissolved out, the rigidity of the fibre decreases. This might be cause of the increase elongation of break. Again as the binding agent dissolves out, the fibres become floppy and wooly and thus the moisture regain properties may be increased.

The results presented in the table also show that shrinkage in length was also increased with the passage of reaction time. With the increase in reaction period, the loss in weight of alkali treated jute fibre also increases. These may be due to the fact that as the components particules of jute fibre (such as lignin, hemicellose, fat etc) are dissolved out in alkali solution, both the length (shirinkage in length) and the weight became less.

Table 4.1: Effect of 10% (w/v) NaOH solution on physico-mechanical properties of raw jute fibre

Time of treatment (hrs)	Tensile strength (MPa)	Tenacity (g/D)	Elongation at break (%)	Moisture regain (%)	Shrinkage (%)	Loss in weight (%)
0.5	16.3	3.00	3.6	8.7	1.0	-06
1	16.0	2.50	3.8	9.5	1.3	-08
2	15.6	2.30	4.5	10.2	1.5	-10
3	15.1	2.25	4.9	10.5	1.8	-12
4	14.5	2.10	4.3	18.5	2.3	-15

4.3 Microscopic analysis of raw and treated jute fibre

The raw and treated jute fibre was analysed microscopically by FTIR spectra. The spectra obtained in this study and the probable reactions of the chemical treatment are presented in figures 4.1- 4.9. It is shown from the IR spectra (figures 4.6, 4.8 & 4.9) that the fibres after dyeing with azo compounds show the absorption IR bands at 1520-1530 cm^{-1}. But the IR spectra of raw jute fibre (Fig 4.1) does not show any peak at this position (i.e., (-N=N-) of benzenediazonium salt) for azo group. This is perhaps due to the incorporation of azo group (-N=N-) compound (benzene-diogonium salts) in jute fibre during the treatment.

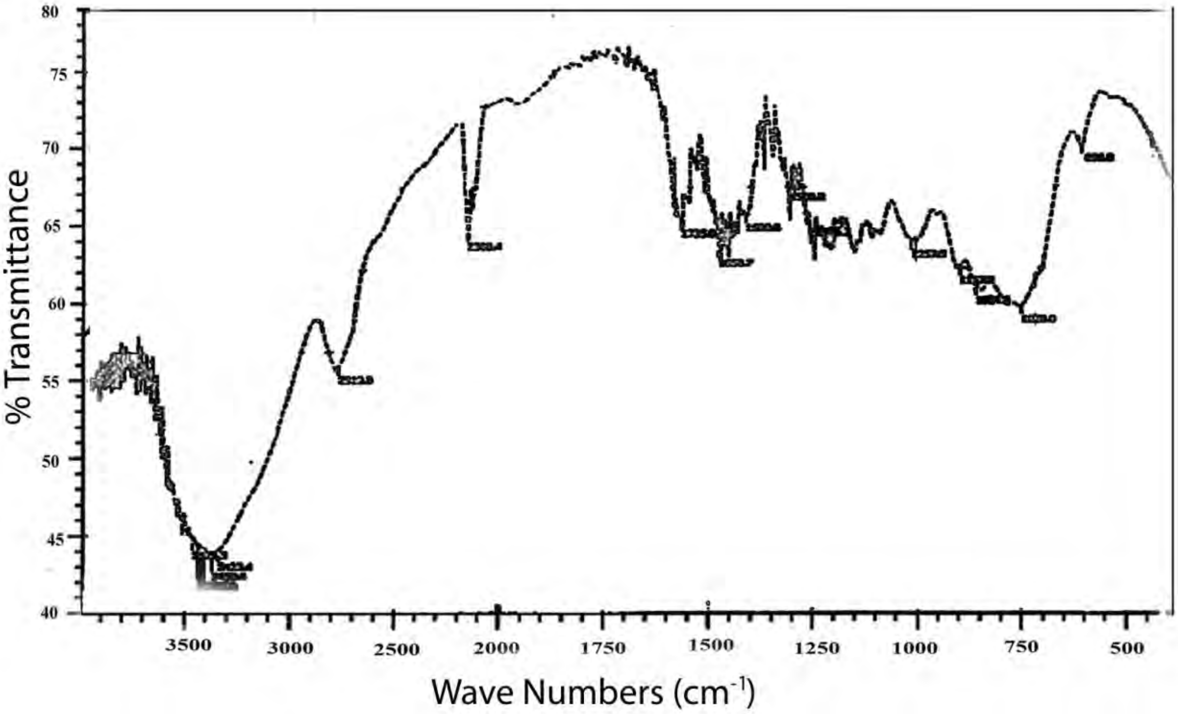


Fig. 4.1: IR spectre of raw jute fibre

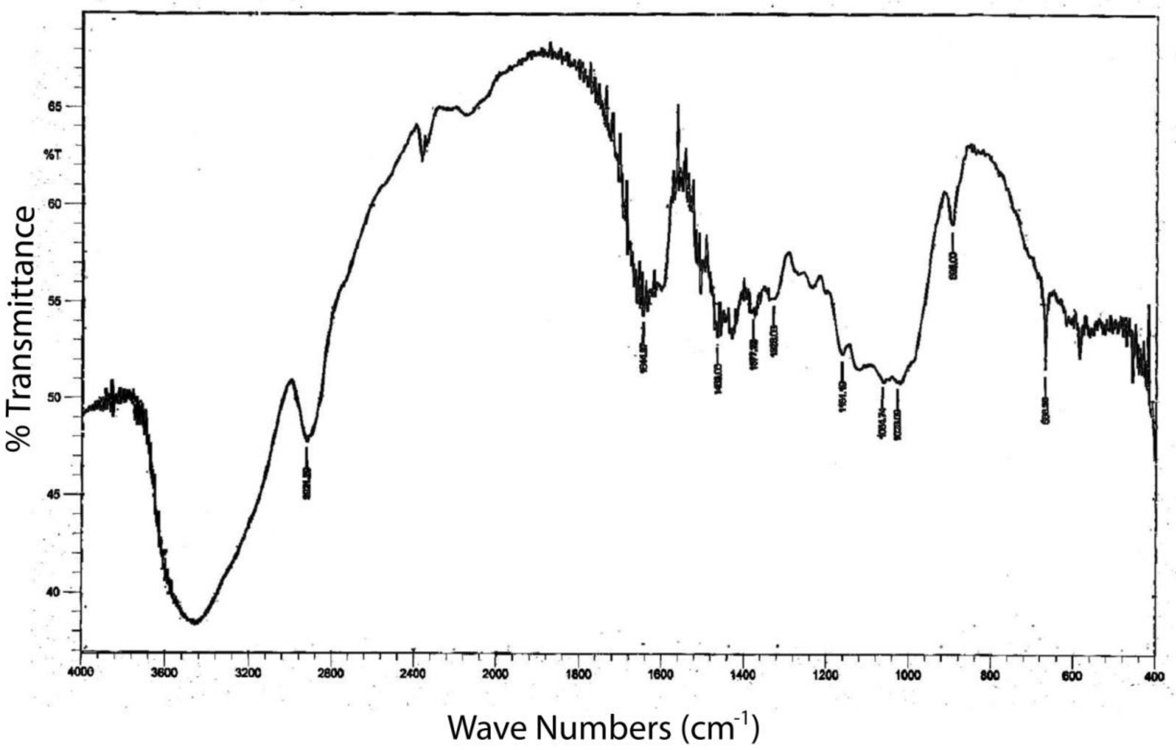
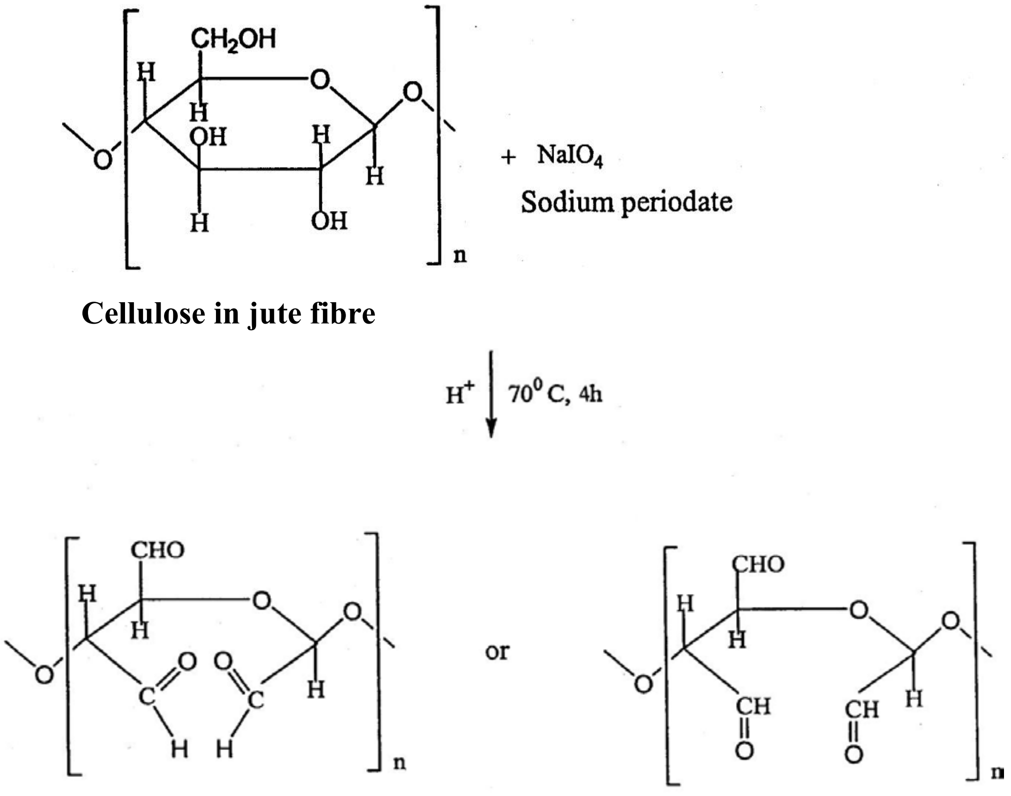


Fig.:4.2 IR spectre of alkali (NaOH) treated raw jute fibre

4.4 Surface modification of alkali bleached jute fibre by oxidation reaction

Alkali (NaOH) bleached raw jute fibres were taken to modify its surface by sodium periodate oxidation process to creat it more active sites for the coupling agent. The reaction of sodium periodate with cellulose in raw jute fibres at 70°C yielded the oxidized product 2,3-dialdehyde cellulose (jute), as illustrated in figure 4.3. Depending on the type of oxidizing agent and pH of the reaction medium, cellulose of jute fibre is oxidized into two products. One is the reducing oxycellulose in which hydroxyl groups have been converted to carbonyl groups or aldehydes and the other is the acidic oxycellulose in which the hydroxyl groups have been converted to carboxyl groups or acids. The oxidation product is dependent on the class of oxidizing agent and pH of the reaction medium. Three hydroxyl groups are there on cellulose anhydroglucose unit, one is a primary hydroxyl group (at C6) and other two are secondary hydroxyl groups (at C2 and C3). Though primary alcohols are more reactive than secondary alcohol but periodic acid and periodate salts break the anhydroglucose ring between carbon atoms 2 and 3 and convert the two secondary hydroxyl groups into aldehyde groups. On the basis of this fact we have selected sodium periodate as oxidizing agent to oxidize cellulose (69%) of raw jute to dialdehyde cellulose. The reaction scheme of oxidation of alkali bleached jute fibre is shown in figure 4.3.



Cellulose in jute fibre

Dialdehyde cellulose in jute fibre

Fig. 4.3: Oxidation of alkali bleached jute fibre with sodium periodate

4.5 FT-IR Spectroscopic characterization of alkali bleached oxidized jute fibre

The oxidized product (2, 3-dialdehyde cellulose) was characterized by infrared spectroscopic analysis. The IR spectrum of oxidized jute fibre is presented in figure 4.4. The IR spectrum shows characteristic bands at the region of ~2921 cm^{-1} .These may be considered as the characterstic band due aldehyde group and also due to C-H stretching and at the region of near 1700 cm^{-1} -1600 cm^{-1} due to carbonyl stretching. Untreated jute fibres show the absorption band at this range. This is due to the carbonyl group of acetyl ester in hemicellulose and carbonyl aldehyde in lignin. In the IR-spectra the absoption for –CHO and >C=O group appear at ~ 1750, ~ 1718 cm^{-1} respectively. In oxidized the position has been shifted forward wave number region. This may be due to other unknown groups present in jute fibre. Jute fibre itself is a complex composite material. In the oxidized jute fibres, there is an increased absorption band near 1700 cm^{-1} is found as compared to the untreated jute fibres. This may be due to the conversion of secondery alcohol group of raw jute fibre into carbonyl aldehyde or dialdehyde by periodate oxidation of cellulose. Jute fibre bleached by sodium hydroxide shows better result in oxidation than the sodium bicarbonate bleached fibre. This may be due to the strong bleaching action of NaOH than $NaHCO_3$ in the removal of lignin, hemicelluloses and fats of raw jut fibre.

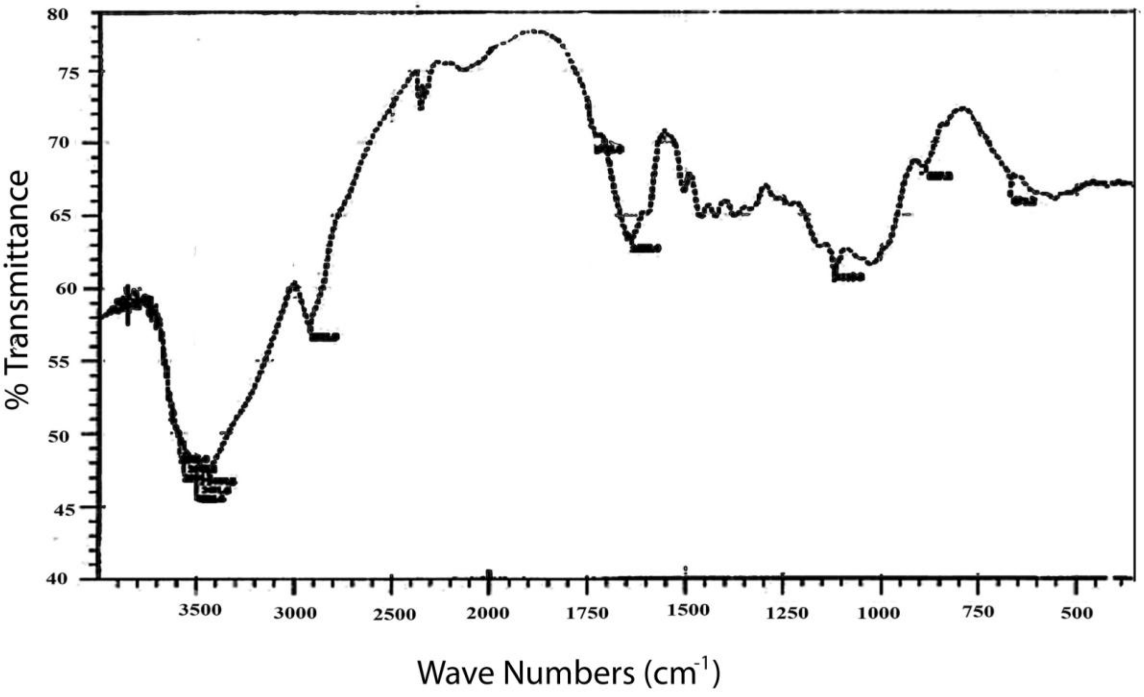


Fig. 4.4: FT-IR spectrum of alkali (NaOH) bleached oxidized jute fibre

4.6 Modification of alkali bleached oxidized jute fibre with benzene diazonium chloride

Alkali bleached oxidized jute fibre was further treated with benzene diazonium chloride in order to have better compatibility of the jute fibre with the polypropylene matrix. The proposed reaction scheme of azo group of benzene diazonium chloride with dialdehyde cellulose is shown in figure 4.5. This is to some extent supported by FT-IR spectra of *p*-nitroso *N,N* -dimethyl aniline and *o*-hydroxy benzene diazonium chloride treated oxidized jute fibre (figure 4.6, 4.8 and 4.9). The IR-spectra also show the presence of characteristic band of -NO group in the region of 1504 cm^{-1} to 1659cm^{-1}. The peaks at 1373cm^{-1} and 1334cm^{-1} are due to the -N=N- moiety of diazo group.

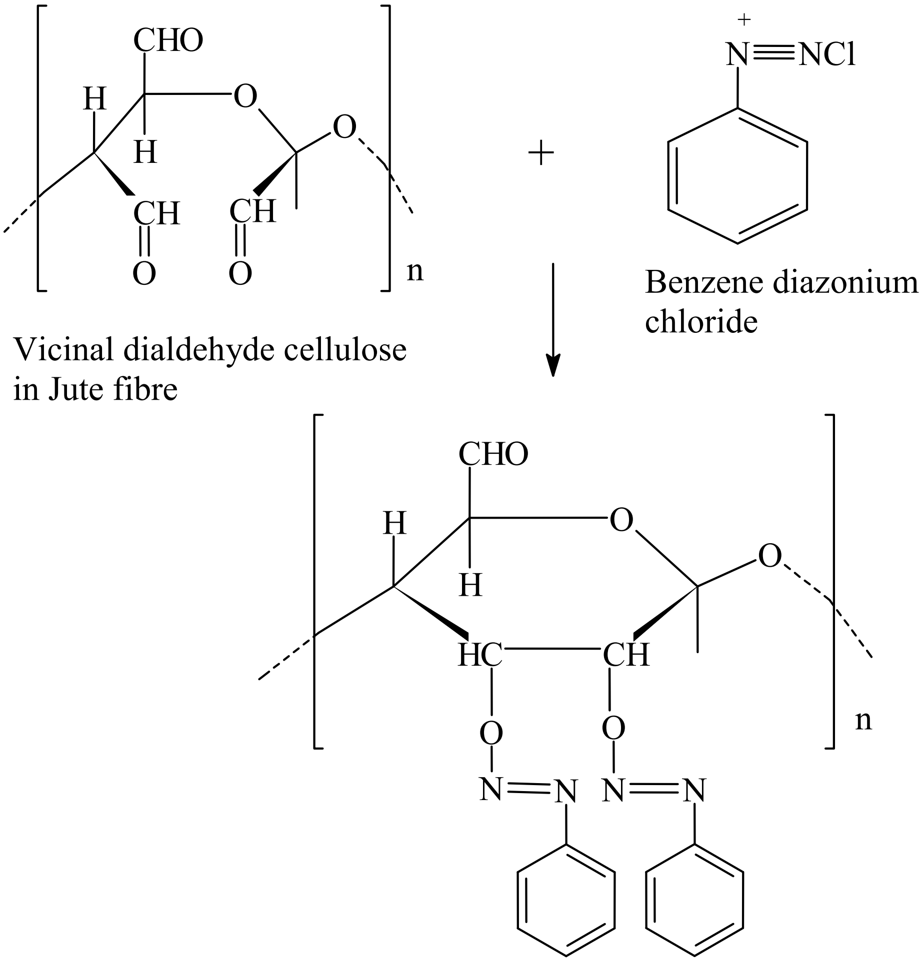


Fig. 4.5: Proposed reaction scheme between alkali bleached oxidized jute fibre with benzene diazonium chloride

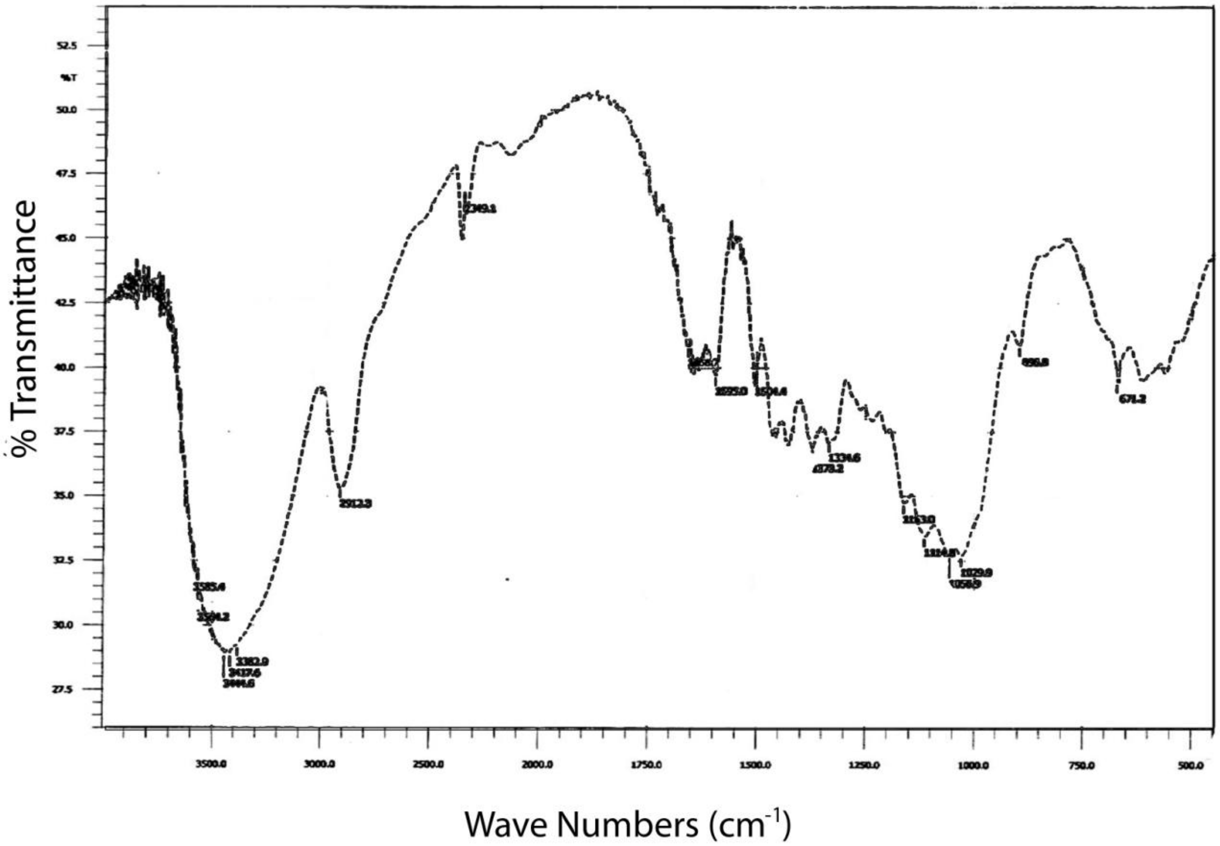


Fig. 4.6: FT-IR spectrum of alkali (NaOH) bleached oxidized BDC treated jute fibre

4.7 Modification of alkali bleached oxidized jute fibre with *p*-nitroso *N,N*-dimethyl aniline

Oxidized jute fibre was further treated with *p*-nitroso *N, N*-dimethyl phenylamine in order to increase the compatibility of the jute fibre with the polypropylene matrix. The probable interacting reaction of nitroso group of benzene diazonium chloride with dialdehyde of cellulose is shown in Figure 4.7. This is supported to some extent by FT-IR spectra of *p*-nitroso *N,N*-dimethyl phenylamine treated oxidized jute fibre presented in figure 4.6 & 4.8). The characteristic band of –N-O-O- group is found in the region of 1508 cm^{-1} to 1552cm^{-1}.

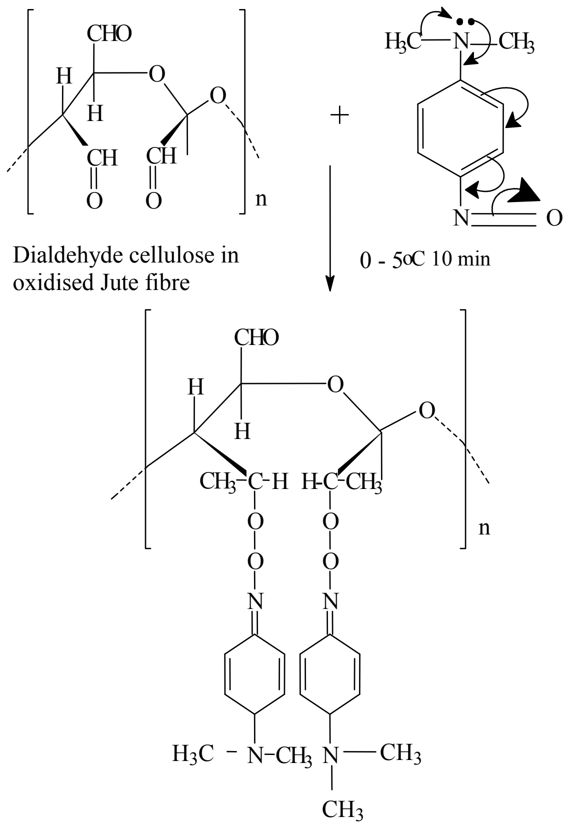


Fig. 4.7: Probable reaction between alkali bleached oxidized jute fibre with *p*-nitroso *N, N*-dimethyl phenylamine

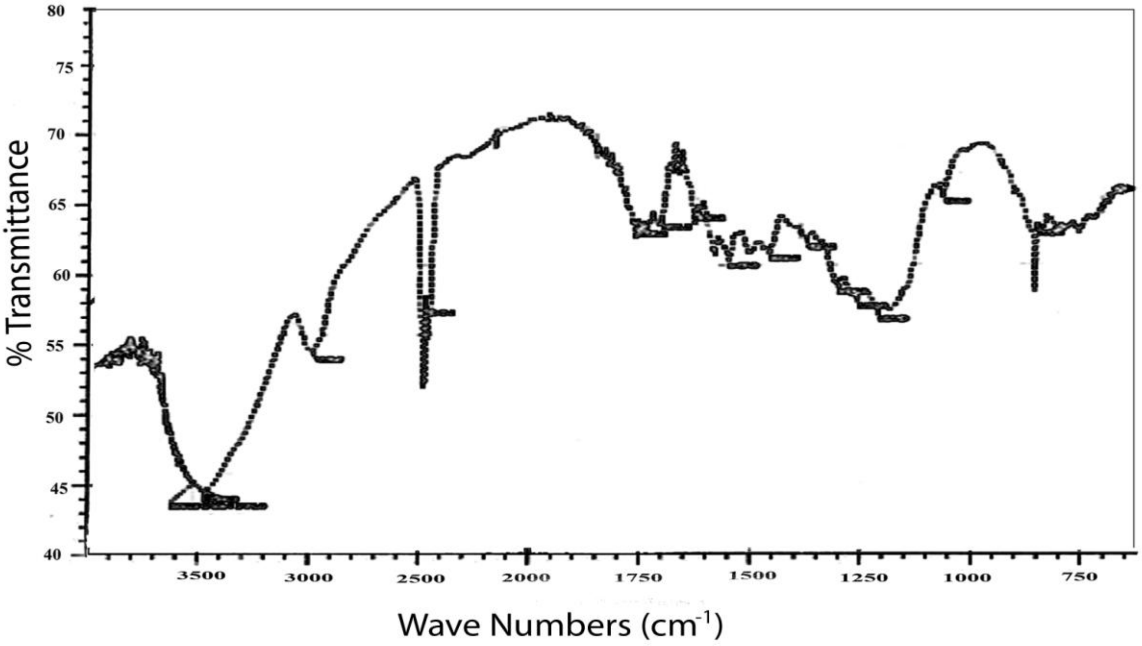


Fig. 4.8: FT-IR spectrum of alkali (NaOH) bleached oxidized *p*- nitroso *N, N*- DMA treated jute fibre

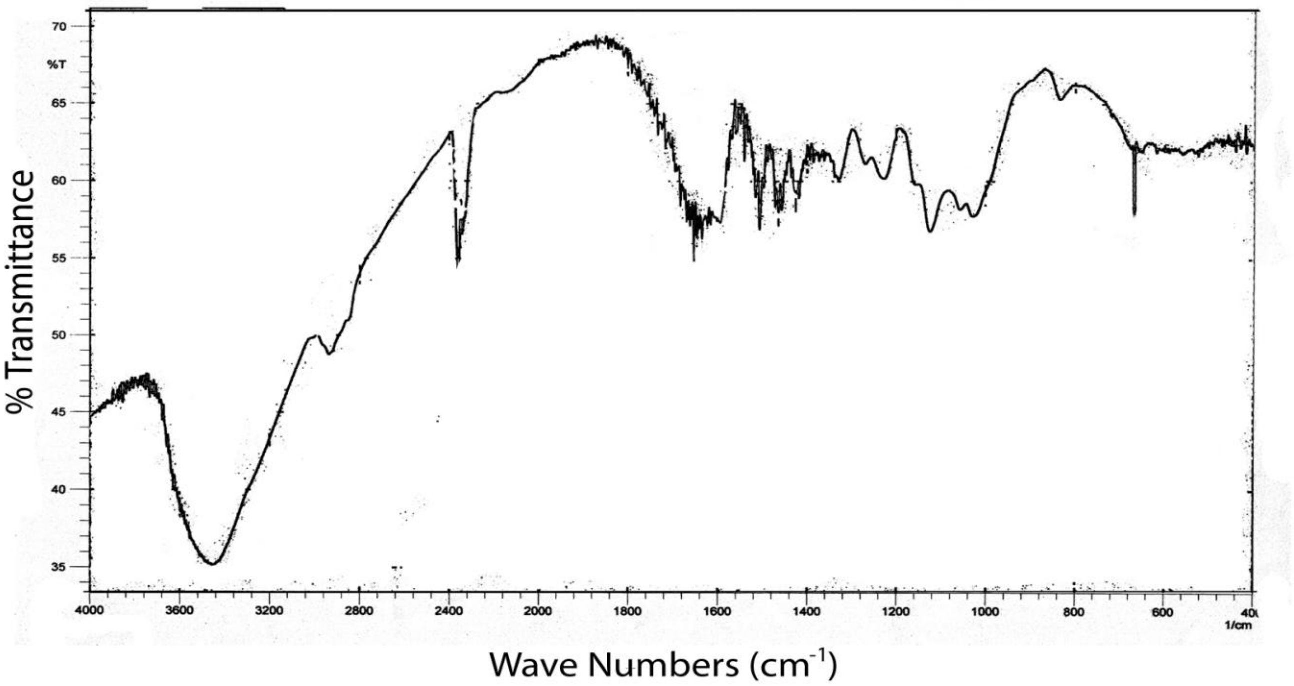


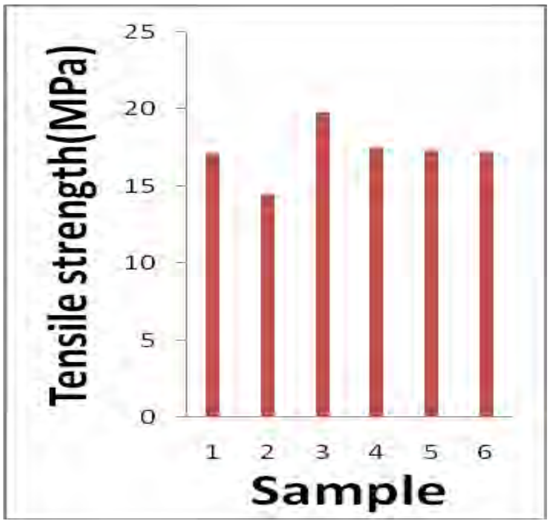
Fig. 4.9: FT-IR spectrum of alkali (NaOH) bleached oxidized *o*-HBDC treated jute fibre

4. 8 Physico- mechanical properties

Tensile strength, elongation at break, moisture regain properties of the raw and oxidized jute fibre have been determined following the ASTM method described in the experimental sections 3.2.8 and 3.2.9. The results obtained in this study are presented below

Tensile strength

Investigations were carried out on raw jute fibres and alkali bleached jute fibre, *p*-nitroso *N, N* -dimethyl aniline treated jute fibre and *o*-, *m* and *p*- hydroxybenzenediazonium salts treated jute fibre. The results of tensile strength are presented in figure 4.10 and table 4.2.



Sample 1 : raw jute fibre
Sample 2 : alkali treated jute fibre
Sample 3 : ***p***-nitroso *N, N*-DMA treated jute fibre
Sample 4 : *o*-HBDC treated jute fibre
Sample 5 : *m*- HBDC treated jute fibre
Sample 6 : *p*- HBDC treated jute fibre

Fig. 4.10: Tensile strength of raw, alkali treated *p*-nitroso *N, N*-dimethyl aniline and *o*-, *m*- and *p*- hydroxybenzenediazonium chloride treated jute fibre.

It is observed from the figure that the tensile strength of alkali bleached juted fibre has been decreased from 17.1 MPa to 16.3 MPa. The decrease in tensile strength to a large extent is probably caused by the fact that lignin (the binding material of jute fibre) is dissolved out in alkali solution as phenols dissolve in alkali. In addition to this, cellulose is also partially soluble in alkali solution that leads to the formation of alkali cellulose. Hemicellulose of jute fibre is also dissolved out in sodium hydroxide. Fats and waxes of jute fibre are also hydrolyzed in alkaline media [174]. Through such dissolutions of the components of jute fibre, its compactness and crystallinity are partially lost, resulting in the decrease of tensile strength.

The figure also shows that the tensile strength of *p*-nitroso *N, N*- dimethyl aniline treated jute fibre is much higher than the raw jute fibre. This may be due to interaction between the hydroxyl and carbonyl group of jute fibre with the *p*- nitroso *N,N*- dimethyl group of aniline. The possible mechanism of this interaction has been proposed in section 4.8. It is observed from the result presented in the figure 4.10 that the tensile strength of *o*-hydroxy benzene diazonium salt treated jute fibre is slightly lower than the *p*-nitroso *N, N* -dimethyl aniline treated jute fibre. But it is still higher than that of raw jute fibre. This is perhaps due to lower extent interaction of hydroxyl and carbonyl group of jute fibre with *o*-hydroxy benzene diazonium salt than that between *p*-nitroso *N, N*-dimethyl aniline with the hydroxyl and carbonyl group of jute fibre. This may be due to strong chemical interaction between nitroso group of *N,N*-dimethyl aniline with the carbonyl group of jute fibre as shown in figure 4.7.

The tensile strengths of treated fibres with benzenediazonium salt were found to be decreased (shown in Fig. 4.10) in the following order: *p*-nitroso *N, N* -dimethyl aniline > *o*-

hydroxybenzenediazonium salt > *m*- hydroxybenzenediazonium salt > *p*-hydroxybenzenediazonium salt.

This might be due to the formation of hydrogen bond between hydroxy group of *o*-hydroxybenzenediazonium salt with that of jute fibre which seems to be as the distance between –OH and diazonium salt ($-N^+_2Cl^-$) increases in the *o*- > *m*- > *p*-. The positive charge on diazonium has greater influence as closour to –OH group. Therefore, coupling reaction of *o*-substituted bezene diazonium salt with jute fibre may likely to occur in higher extent than those of *m*-and *p*-substituted benzenediazonium salt.

It is expected that higher is the interaction between the functional groups of jute fibre with treating agent, greater is the tensile strength. So, the order of tensile strength of treated jute fibre is: *p*-nitroso *N, N*-DMA > DC (ortho) > DC (meta) > DC (para) > raw jute fibre > alkali treated jute fibre.

The probable mechanism of coupling benzene diazonium salt with lignin of jute fibre to produce azo dye on jute fibre is shown below: The unit structure of lignin and diazo compound of treated jute fibre is

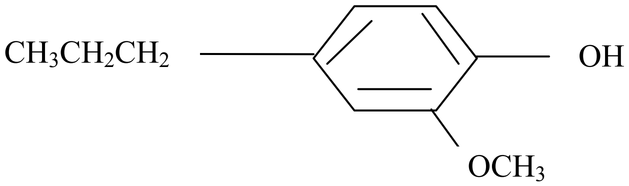
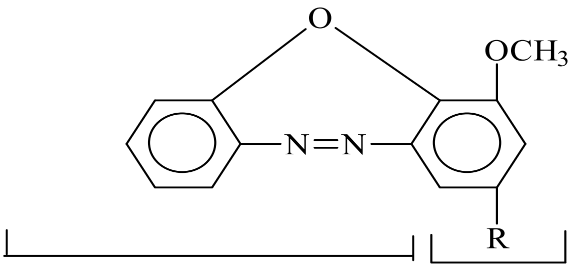


Fig. 4.11: Unit structure of lignin (4-propyl 2-methoxy phenol).

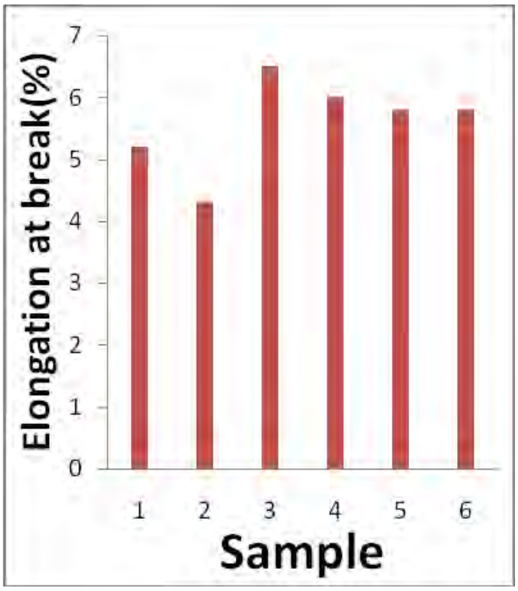


***o*-hydroxy diazo part** **Lignin part**

Fig. 4.12: Diazo compound on treated jute fibre

Elongation at break

The elongation at break of raw and treated jute fibre was determined using the standard method described in section 3.2.10. The experimental results are presented in figures 4.13. It is seen from the figure that the elongation at break of *p*-nitroso *N, N*-dimethyl aniline and the three different hydroxybenzenediazonium salts treated jute fibre were found higher than those of the raw and alkali treated jute fibre. This may due to the fact that on treatment of *p*-nitroso *N, N*-dimethyl aniline, *o*-,*m*-,and *p*-hydroxy benzene diazonium chloride shrinkage in length of the jute fibre the increase of thickness of fibre cell wall [175] of the jute fibre. In addition to these, the flexibility of jute fibre may also be increased by the treatment with *p*-nitroso *N, N*-dimethyl aniline, *o*-,*m*- and *p*- HBDC. It is also found that the value of elongation at break of raw jute, alkali treated jute and *p*-HBDC treated jute fibre are almost same.



Sample 1 : raw jute fibre
Sample 2 : alkali treated jute fibre
Sample 3 : *p*-nitroso *N, N*-DMA treated jute fibre
Sample 4 : *o*-HBDC treated jute fibre
Sample 5 : *m*- HBDC treated jute fibre
Sample 6 : *p*- HBDC treated jute fibre

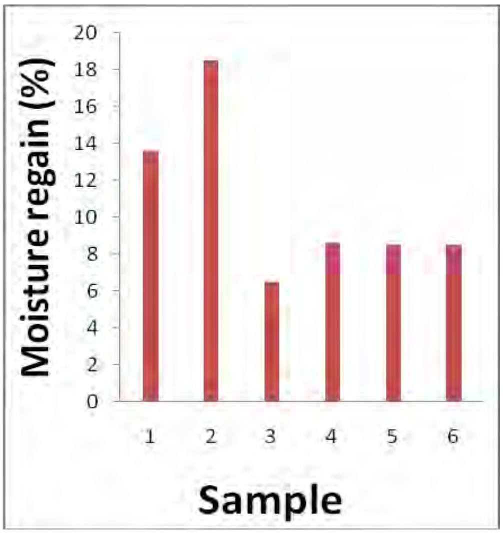
Fig. 4.13: Elongation at break of raw jute fibre and jute fibre treated with alkali, *p*-nitroso *N, N*-DMA ,*o*-,*m*- and *p*-HBDC.

Moisture regains property

The moisture regains property of raw and treated jute fibre was calculated following the standard procedure described in section 3.2.11. The results are presented in figure 4.14. It is observed from the figure that the moisture regain properties of *p*-nitroso *N, N*-dimethyl aniline and *o*-, *m*- and *p*- hydroxybenzenediazonium salts are lower in every case than that of raw alkali treated jute fibre. This may be due to coupling of benzenedioznium salts with jute fibre as presented as figure 4.5. The coupling reaction formation reduces the percentage of hydrophilic hydroxyl group and thereby increases the ratio of hydrophobic benzene ring in the treated jute fibre. The moisture regain of jute fibre is believed to be carried out by the presence of hydrophilic hydroxyl group. The order of moisture regain (%) of hydroxybenzenediazonium salt treated jute fibre is as follows:

p-H B D C treated jute fibre > *m*-H B D C treated jute fibre > *o*- H B D C treated jute fibre > *p*-nitroso *N, N* -DM A treated jute fibre.

It has been established by the fact that diazo coupling with jute fibre goes better with *p*-nitroso *N, N* -dimethyl aniline. Better is the coupling, lesser will be the moisture regain. The higher value of moisture absorbing capacity of alkali treated jute fibre may be due to removal of lignin and fatty meterials from jute fibre. As a result the hydroxyl groups of cellulose become free for absorbing moisture.



Sample 1 : raw jute fibre
Sample 2 : alkali treated jute fibre
Sample 3 : ***p***-nitroso *N, N*-DMA treated jute fibre
Sample 4 : *o*-HBDC treated jute fibre
Sample 5 : *m*- HBDC treated jute fibre
Sample 6 : *p*- HBDC treated jute fibre

Fig.4.14: Moisture regain properties of raw jute fibre and jute fibre treated with alkali, *p*-nitroso *N, N*- DMA and *o*-, *m* and *p*- HBDC.

Shrinkage

The treated jute fibre in alkaline media shows some what higher shrinkage in length. This may be in alkaline media lignin and other constituents of jute fibre are removed by dissolution in alkali solution thereby contraction of length of the jute fibre takes place to a larger extent. In case of other samples, the shrinkage is almost neglagable.

Loss in weight

Loss in weight of treated jute fibres was measured. The results are presented in table 4.2.
It is observed from the table that the jute fibre losses its weight after treating it with alkali. This is due to dissolution of major components (cellulose, hemicellulose and lignin) of jute fibre in alkali solution. In the case of other treatment jute fibre slightly gain their weights. This indicates that positive interactions between jute fibre and other reagents have been occurred.

Table 4.2: Effect of coupling agents on physico-mechanical properties of jute fibre

Raw and treated jute fibre	Colour produced on jute fibre	Tensile strength (MPa)	Tenacity (g/D)	Elongation (%)	Moisture regain (%)	Shrinkage (%)	Weight changed (%)
Raw jute	Yellowish	17.12	2.28	5.2	13.6	1.0	0
NaOH treated jute fibre	Light yellow	14.5	2.10	4.3	18.5	2.3	-15
p- nitroso *N,N*-DMA	Golden	19.8	4.20	6.5	3.5	0.7	-1.5
o- HBDC	Magenta	17.5	2.40	6.0	8.6	0.6	-1.1
m- HBDC	Orange	17.3	2.35	5.8	8.5	0.6	-1.1
p- HBDC	Brown	17.2	2.30	5.8	8.5	0.6	-1.1

The results preseuted in tables 4.2 have been discussed in the previous section. However, the fillowing prints may be added as the suplimentary finding of the previous discussion.

Table 4.2 also represents the tensile strength of jute fibre treated with different reagents such as, *p*-nitroso *N, N* -dimethyl aniline, *o*-HBDC, *m*-HBDC and *p*-HBDC in basic media. In basic media phenolic group is ionized and thereby activates the benzene ring to attack the electrophile (ArN_2^+) and thus diazonium salt behaves electrophile in basic media.

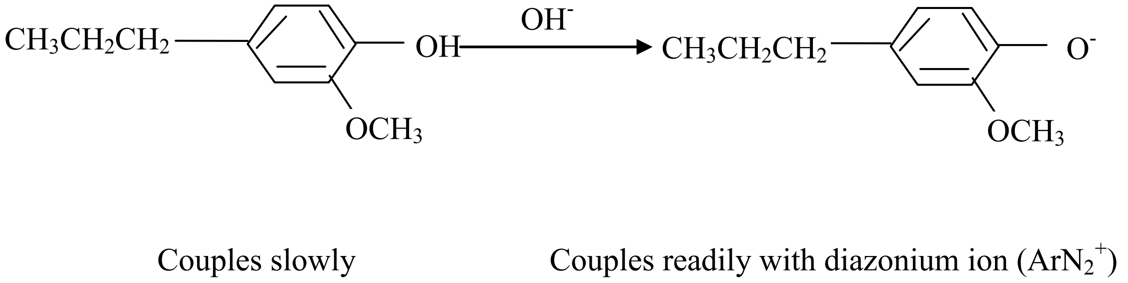


Fig. 4.15: Ionization of unit structure of lignin

Thus the mechanical properties of the treated jute fibre have been improved. The tensile strengths of treated fibres with benzenediazonium salt is found to decrease in the following order (shown in Table 4.2): *p*-nitroso *N, N* dimethyl aniline >

o-hydroxybenzenediazonium salt > *m*-hydroxybenzenediazonium salt > raw jute fibre.

4.9 Physico-mechanical properties of jute-polypropylene (PP) composites

4.9.1 Results on physico-mechanical properties of raw jute fibre-PP and treated jute fibre-PP composites

One of the modern and important applications of jute fibre is its use in manufacturing jute fibre reinforced plastic composites. In this study treated jute fibre along with raw jute fibre have been used for the manufacturing jute fibre reinforced-PP composites. The composites were then studied by measuring their physico-mechanical properties.
The obtained results have been presented in the following sections.

The mechanical properties of above mentioned jute fibre-PP composites were measured and the results are presented in tables 4.3-4.8 and also in figures 4.16-4.21. It is observed from table 4.3 that the tensile strength of raw jute fibre-PP composite is hundred percent greater than the reported result on wood-PP composite and the tensile strength of treated jute fibre-PP composite presented in tables 4.4-4.8 is approximately two hundred percent higher than the reported result on wood-PP composite [176].

This may be due to two reasons: (1) The mechanical entanglement of the jute fibre and polymer matrix particles, which may not be occured in globular like wood particles. (2) The better compatibility of treated jute fibre with the polymer matrix.

Fig. 4.16 and 4.17 represent the tensile strength and tensile modulus respectively of raw jute and treated jute fibre reinforced composiles against the variation of fibre loading (0-35%w/w). The results presented in figures 4.16 and 4.17 show that the tensile strength and tensile modulus of treated jute fibre-PP composites are considerable higher than that of raw jute fibre-PP composite. This may due to the fact that in raw jute fibre, cellulosic hydroxyl groups of jute fibre form intermolecular hrdrogen bonds among themselves and so are weakly dispersed in the raw jute fibre-PP composite. As a result, the compatibility of raw jute fibre with polymer matrix is low. But because of coupling reaction between group of cellulose and hydroxy diazonium salt in treated jute fibre there is less possibility to form intemolecular hydrogen bonds. This may increase the adhesion of treated jute fibre to PP matrix. As a result, interfacial bonding between treated jute fibre and PP matrix in the treated jute fibre-PP composite may also be improved.

It is observed from the figure that *p*-nitroso *N, N*-dimethyl aniline treated jute fibre -PP composites show higher tensile strength and tensile modulus than those of *o*-, *m*- and *p*-hydroxybenzenediazonium salt treated jute fibre - PP composite. This is probabily due to better coupling reaction of *N, N*-dimethyl aniline than *o*-, *m*- and *p*-hydroxy benzenediazonium salt with the jute fibre.

The coupling of jute fibre reduces the hydrophilic nature, which indirectly influences the compability of jute fibre with hydrophobic PP-matrix. Since the extent of coupling reaction between *o-, m-* and *p*-hydroxybenzenediazonium are less than that of *p*- nitroso *N,N*-dimethyl aniline that is why the compatibility of jute fibre (treated with *o*-, *m*-and *p*-hydroxybenzenediazonium salt) with PP matrix is also less. As a result the tensile strength and tensile modules of treated (with *p*-nitroso *N,N*-dimethyl amiline) jute -PP composites are higher than those of treated (with 0-, m-and p-hydroxy benzene diazonium salt) jute- PP composites. The probable mechanism of coupling reactions of jute fibre with *p*-nitroso *N,N*-dimethyl aniline and hydroxy benzene diagonium salt have been shown in figure 4.7 and 4.12 respectively.

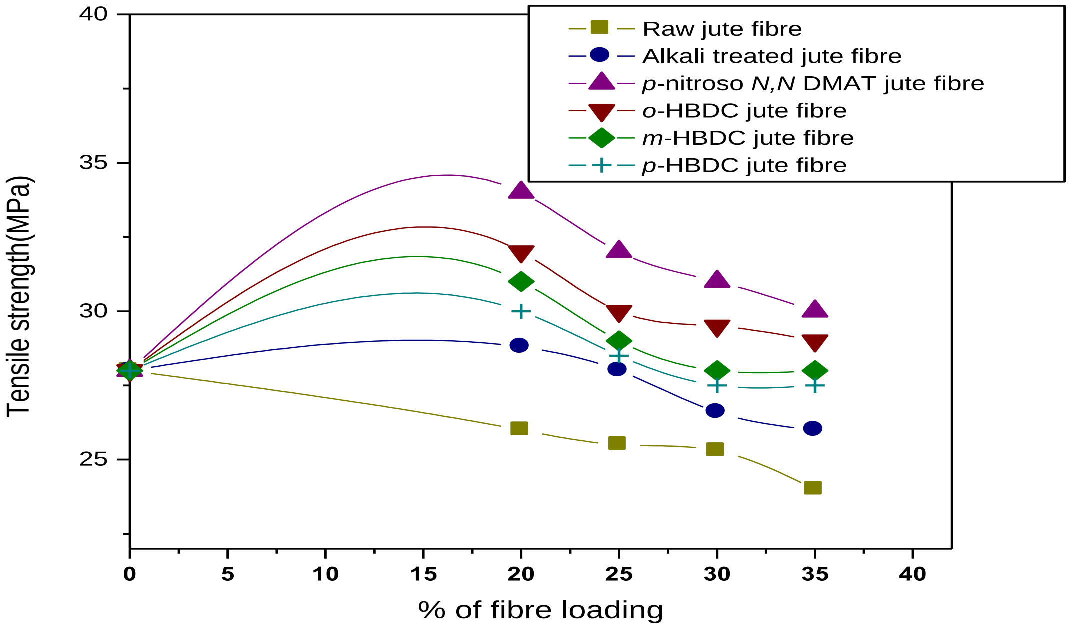


Fig. 4.16: Tensile strength of raw jute and treated jute fibre-pp composites at different fibre loading

It is also observed from the data presented in tables 4.3-4.8 and also in figures 4.16 and 4.17 that the tensile strength and tensile modulus of raw jute fibre-PP and treated jute fibre-PP composites also decrease with the increase in fibre loading to the composites. However, the values are higher in case of alkali treated, HBDC treated and DMA treated jute fibre-PP composites than PP matrix particularly at 20% fibre loading, although the results also show that with the further increase of fibre loading in the composites the value of tensile strength and tensile modulus decreases to a limited extent in all cases. It is to be mentioned here that it was not possible to prepare composite containing higher than 35% fibre loading.

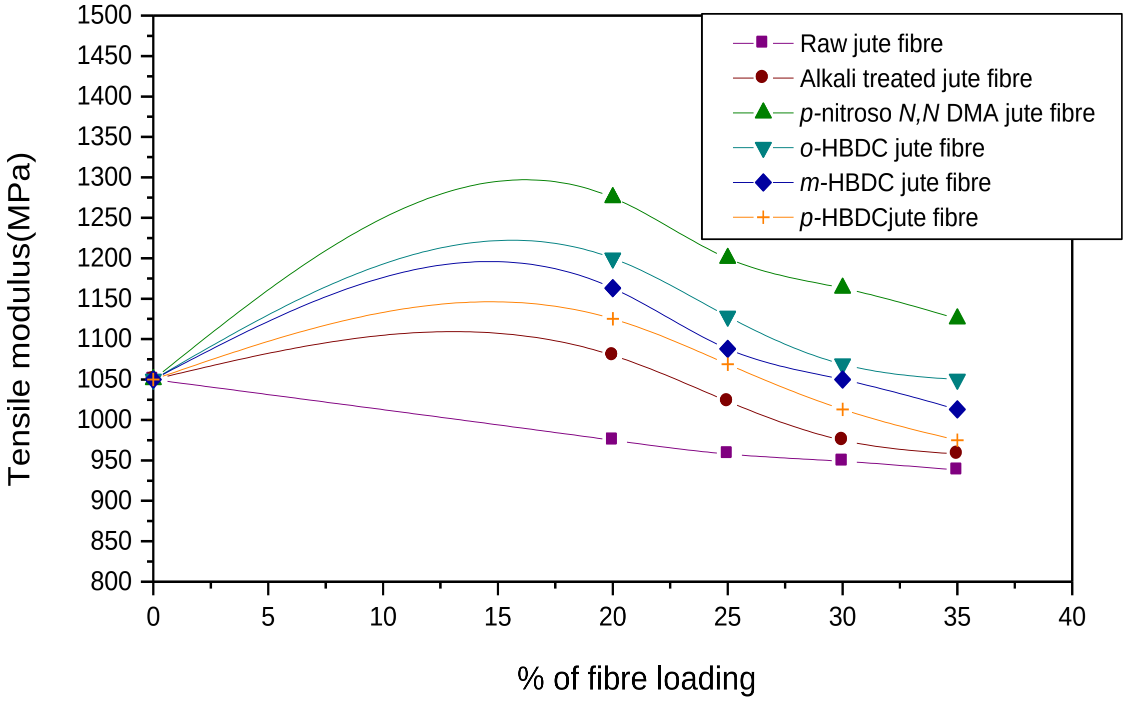


Fig. 4.17: Tensile modulus of raw and treated jute fibre-PP composites at different jute fibre loading.

The results on elongation at break of different composites investigated in this study have been presented in tables 4.3-4.8 and in figures 4.18. The composites investigated were raw jute fibre-

PP composites and treated jute (with alkali, *p*-nitroso *N, N* -dimethyl aniline, *o*-, *m*- and *p*-hydroxybenzenediazonium salt -PP composites of different compositions.

It is seen from the results that the elongation at break of all the studied composites decreases to a large extent with the fibre loading. This indicates the positive interaction (reinforcement) of ploymer matrix with jute fibre. The interaction between jute fibre and polypropylene may be mechanical as well as chemical.The mechanical interaction arises from the entanglement of polymer matrix with jute fibre. The chemical interaction arises from the surface modification of jute fibre by the chemical treatment.

Because of the positive interaction of jute fibre with polymer matrix, the flexibility of all composites investigated under this study decreases with the fibre loading. Since elongation at break of composites was decreased to a very low value, even at the lowest percentage of fibre loading (20%) that is why the effect of the increase of fibre loading was not found appreciable. It is also observed in the figure (4.17) that the elongation at break of chemically treated jute fibre particularly with *p*-nitroso *N, N*-dimethyl aniline are higher than raw jute fibre at all percentage of fibre loading. Therefore, it may be said that by the chemical treatment with *p*-nitroso *N, N*-dimethyl aniline the compatibility between jute fibre and PP has been increased. This made the composite more flexible.

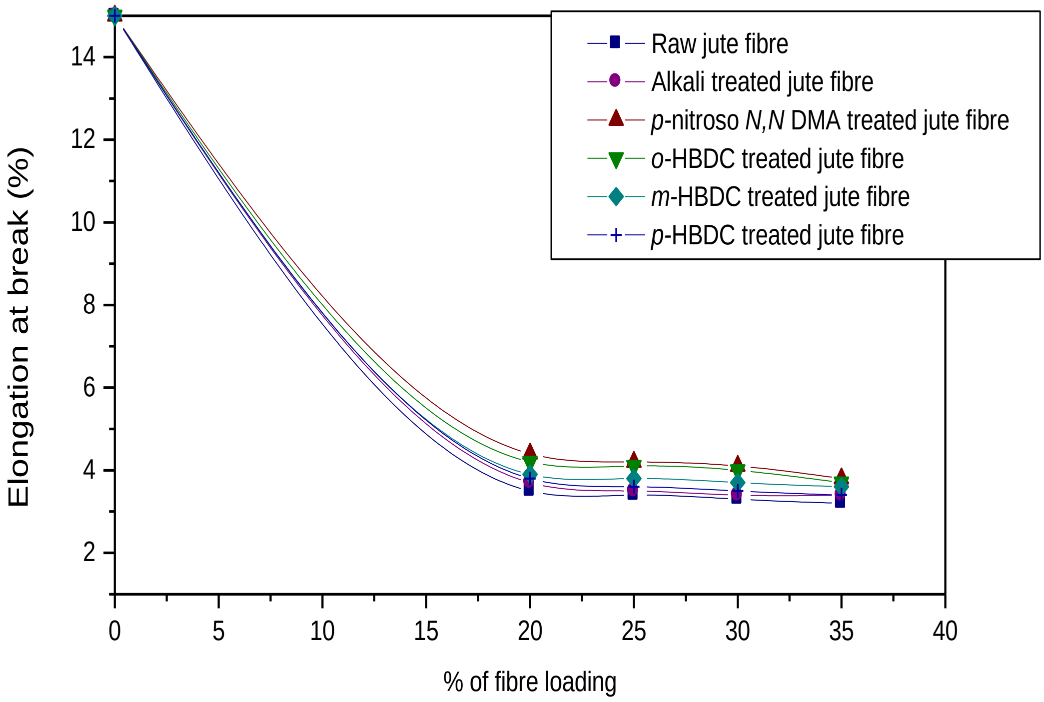


Fig. 4.17: Percent of elongation at break of raw jute, alkali, *p*-nitroso *N, N* -DMA, *o*-HBDC, *m*-HBDC, and *p*-HBDC treated fibre-PP composites at different % of fibre loading

(c) Flexural strength and flexural modulus

The results on flexural strength and flexural modulus of raw jute fibre-PP composites and treated jute (with alkali, *p*-nitroso *N, N*-dimethyl aniline, *o*-, *m*- and *p*-hydroxy benzene diazonium chloride)-PP composites at different compositions are presented in tables 4.3-4.8 and also in figures 4.20 and 4.21. It is evident from the figures that like tensile strength and tensile modulus the flexural strength and flexural modulus also increase with the incorporation of fibre into the polymer matrix. However, at higher percentage of fibre loading the values of flexural strength and flexural modulus decrease to a limited extent. The increases flexural strength and flexural modulus may be due to the mechanical entanglement and crosslinking of jute in the polymer matrix thereby increase the compressive strength of the composite. The decrease of flexural strength and flexural modulus at higher percentage of fibre loading (by weight fraction) may be due to lack of sufficient space for interfacial bonding. Similar effect is observed in the case reinforced cement concrete.

A careful observation of the data presented in these tables that the values of flexural strength and flexural modulus of all composites were higher than those of 100% polymer matrix. The order of the increase of flexural strength and flexural modulus is:
Polymer (PP) matrix < raw jute fibre-PP composites < alkali treated jute fibre -PP composites < *p*-HBDC treated jute fibre-PP composites < *m*-HBDC treated jute fibre-PP composites < *o*-HBDC < *p*- nitroso *N, N*-DMA treated jute fibre-PP composites. This may be primerely due to the reinforcement of PP matrix with jute fibre as well as alkali treatment of jute fibre might have created space (by washing out lignin, hemicellulose and fats) in jute fibre for better incorporation of PP molecule. From the results presented in table 4.3-4.8 it is evident that treatment with *p*-nitroso *N, N*-DMA and *o*- HBDC increase the extent of interfacial bonding between jute fibre and PP matrix.This is also supported by the results of SEM analysis presented in figures 4.18 - 4.19. The detail results of SEM analysis have been presented in section 4.12 (Page: 159-161).

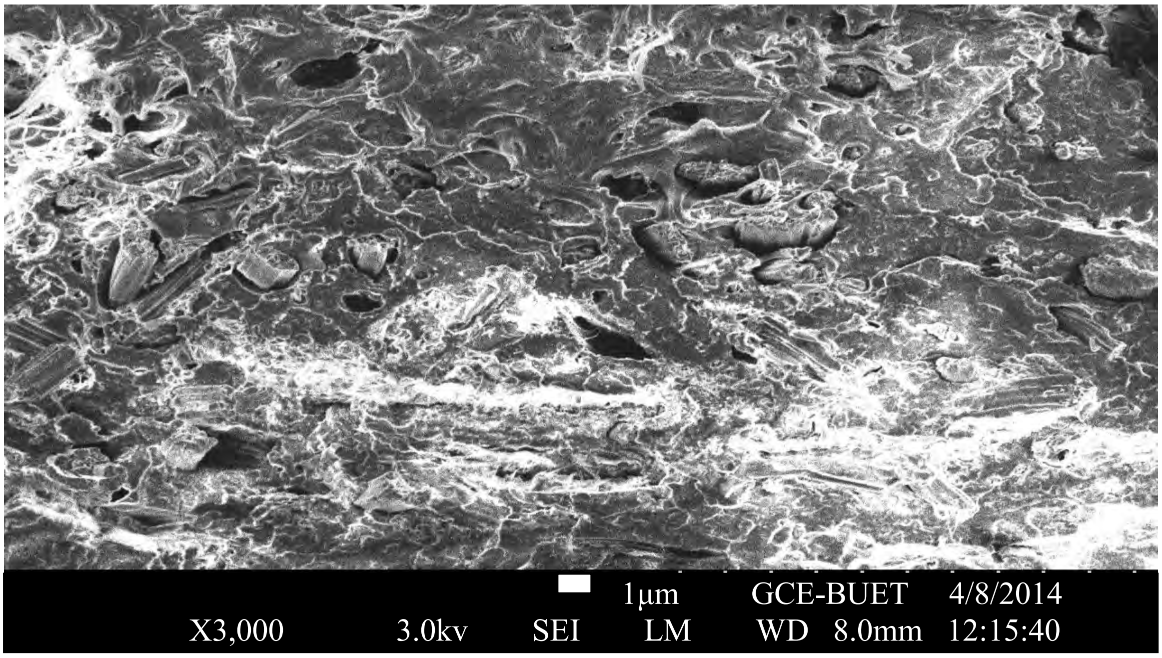


Fig. 4.18: SEM micrograph of raw jute fibre-PP composites

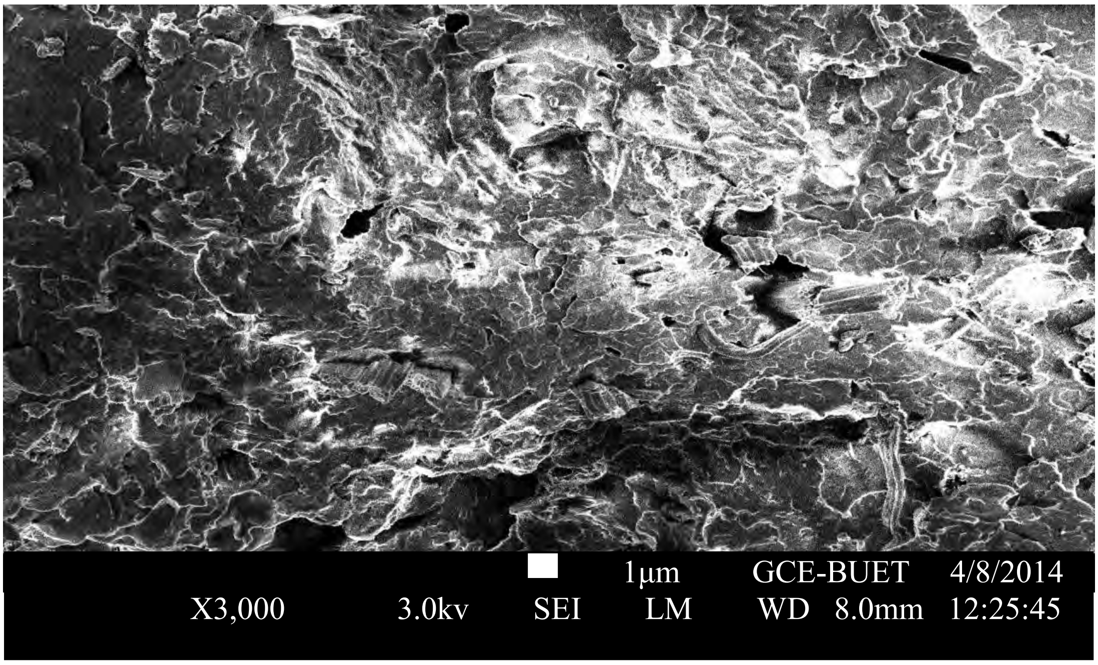


Fig. 4.19: SEM micrograph of alkali (NaOH) bleached oxidized *p* –nitroso *N,N*-DMA treated jute fibre-PP composites

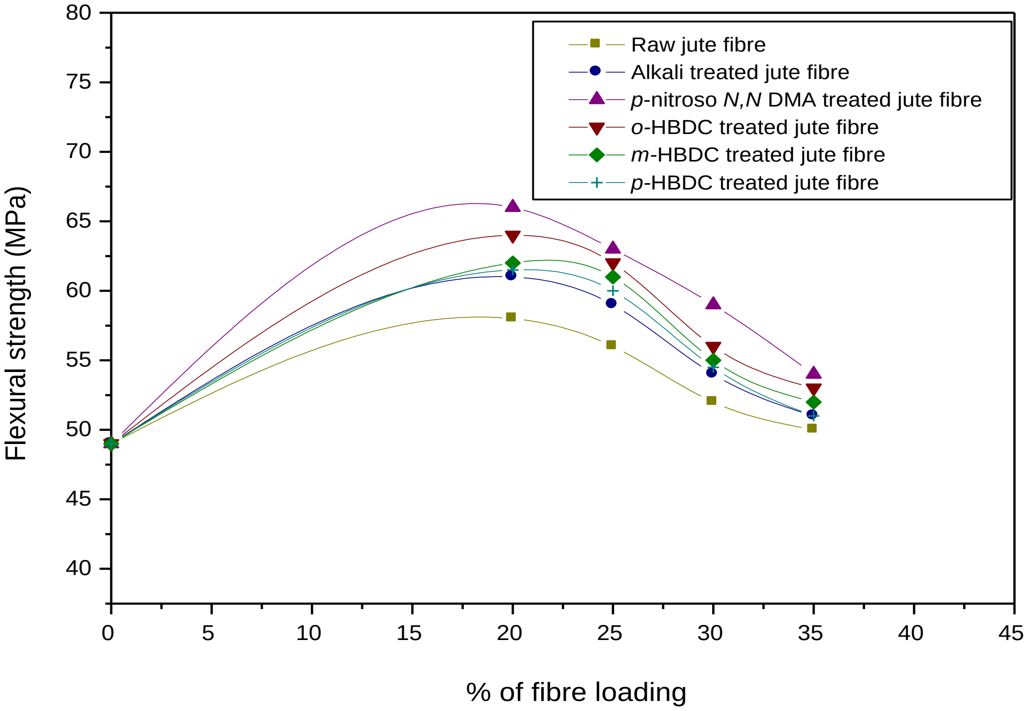


Fig. 4.20: Effect of treatment of flexural strength of raw, alkali, *p*-nitroso *N, N*-DMA *o*-HBDC, *m*-HBDC and *p*-HBDC treated jute fibre-PP composites at different fibre loading

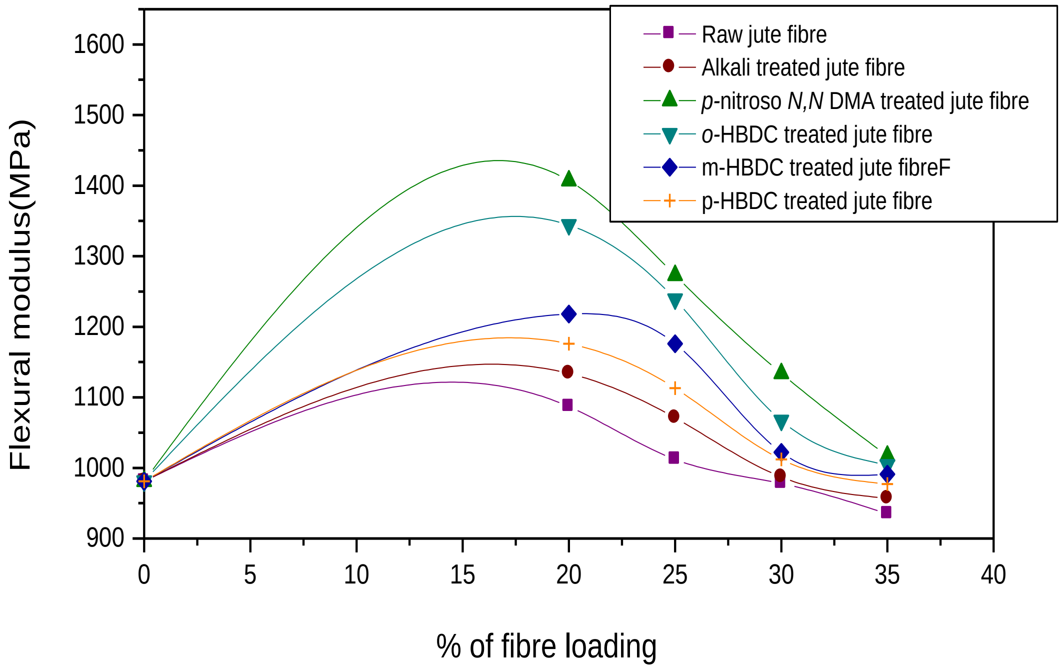


Fig. 4.21: Effect of treatment of flexural modulus of raw, alkali, *p*-nitroso *N, N*-DMA, *o*-HBDC, *m*-HBDC and *p*-HBDC treated jute fibre-PP composites at different % of fibre loading

(d) Charpy impact strength

The results on Charpy impact strength of raw and treated jute fibre-PP composites investigated in this study are presented in tables 4.3-4.8 and also in figures 4.22**.** It is observed from the tables and figures that Charpy impact strength of the composites increases with the jute fibre loading. However, at higher percentage of jute fibre loading the values of Charpy impact strength are found to be decreased. One of the factors of impact failure of a composite may be the fibre pull out. With the increase of jute fibre loading the possibility of fibre pulls out of the composites increases and because of this at higher than 35% fibre loading composite could not be prepared. So fibre pull out from the composite may be the cause of decreasing Charpy impact strength at higher percentage (>20%) of fibre loading in the comosites. It is also observed from the results presented in tables 4.3-4.8 and figure 4.22 shows that the values of Charpy impact strength of raw and alkali treated jute fibre-PP composites are very close to those of polymer matrix only. On the other hand, the values of *p*-nitroso *N, N* DMA and *o*-, *m*- or *p*- HBDC treated jute fibre-PP composites are considerably higher than that of 100% PP. The higher values of chemically treated jute fibre-PP composites may be perhaps due to better compatibility of treated jute fibre with PP matrix. The high compatibility reduses the extent fibre pull out in treated jute fibre from the composites.

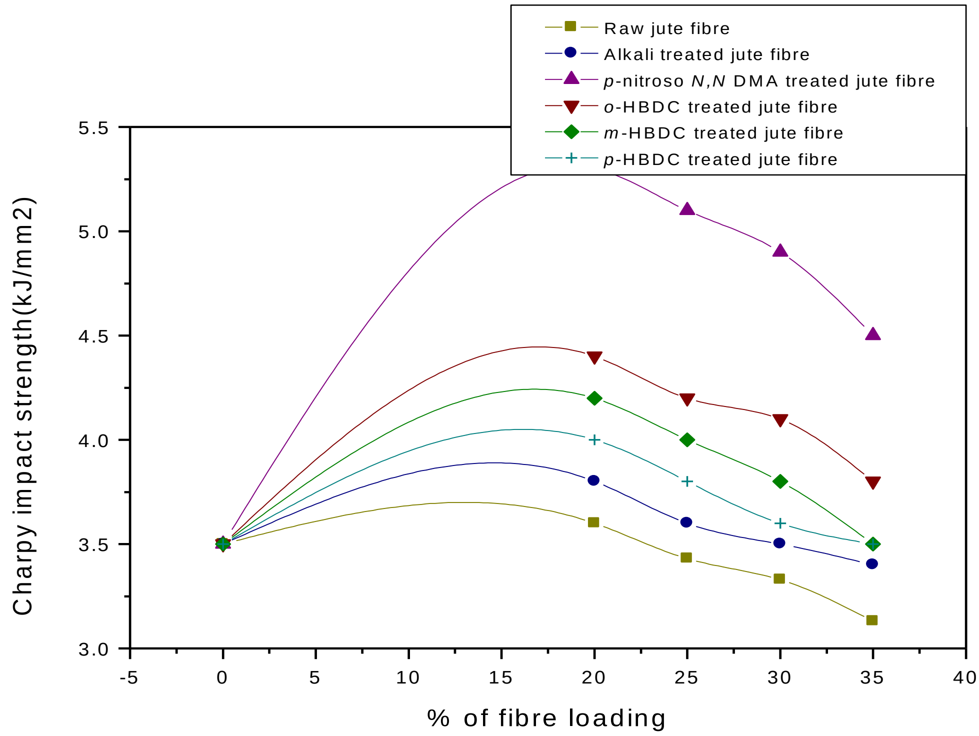


Fig. 4.22: Effect of treatment of Charpy impact strength of raw, alkali, *p*-nitroso *N, N* -DMA, *o*-HBDC, *m*-HBDC and *p*-HBDC treated jute fibre-PP composites at different % of fibre loading

Table 4.3: Results on physico-mechanical properties raw jute fibre-pp composites of different composition

Composite materials	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation at break (%)	Flexural strength (MPa)	Flexural modulus (MPa)	Charpy impact strength (kJ/mm^2)
PP only	28.0	1050	15.0	49	981	3.5
20% raw jute+80% PP	26.0	1760	3.5	58	1087	3.6
25% raw jute+75% PP	25.55	1753	3.4	56	1012	3.43
30% raw jute+70% PP	25.29	1747	3.3	52	978	3.33
35% raw jute+65% PP	25.04	1732	3.2	50	935	3.13

*20% saw dust +80% PP: Tbe reported value of tensile strength is 12.7 MPa [1]

Table 4.4: Results on physico-mechanical properties of alkali treated jute fibre -PP composites of different composition

Composite materials	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation at break (%)	Flexural strength (MPa)	Flexural modulus (MPa)	Charpy impact strength (kJ/mm^2)
PP only	28	1050	15.0	49	981	3.5
20% treated jute+80% PP	28.8	1978	3.7	61	1134	3.8
25% treated jute+75% PP	28.6	1943	3.5	59	1071	3.6
30% treated jute+70% PP	27.6	1911	3.4	54	987	3.5
35% treated jute+65% PP	27.4	1895	3.4	51	957	3.4

Table 4.5: Results on physico-mechanical properties of *p*-nitroso *N, N* -dimethyl aniline treated jute fibre-PP composites of different composition

Composite materials	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation at break (%)	Flexural strength (MPa)	Flexural modulus (MPa)	Charpy impact strength (kJ/mm^2)
PP only	28	1050	15	49	981	3.5
20% treated jute+80% PP	34	2475	4.4	66	1407	5.3
25% treated jute+75% PP	32	2356	4.2	63	1273	5.1
30% treated jute+70% PP	31	2248	4.1	59	1134	4.9
35% treated jute+65% PP	30	2157	3.8	54	1017	4.5

Table 4.6: Results on physico-mechanical properties of *o*-hydroxybenzene diazonium salts treated jute fibre-PP composites of different composition

Composite materials	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation at break (%)	Flexural strength (MPa)	Flexural modulus (MPa)	Charpy impact strength (kJ/mm^2)
PP only	28	1050	15	49	981	3.5
20% treated jute+80% PP	32	2315	4.2	64	1344	4.4
25% treated jute+75% PP	29	2228	4.1	62	1239	4.2
30% treated jute+70% PP	28.5	2115	4	56	1067	4.1
35% treated jute+65% PP	28	2100	3.7	53	1004	3.8

Table 4.7: Results on physico-mechanical properties of *m*-hydroxybenzene diazonium salts treated jute fibre-PP composites of different composition

Composite materials	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation at break (%)	Flexural strength (MPa)	Flexural modulus (MPa)	Charpy impact strength (kJ/mm^2)
PP only	28	1050	15	49	981	3.5
20% treated jute+80% PP	31	2228	3.9	62	1218	4.2
25% treated jute+75% PP	29	2135	3.8	61	1176	4.0
30% treated jute+70% PP	28	2120	3.7	55	1022	3.8
35% treated jute+65% PP	28	2040	3.6	52	991	3.5

Table 4.8: Results on physico-mechanical properties of *p*-hydroxybenzene diazonium salts treated jute fibre-PP composites of different composition

Composite materials	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation at break (%)	Flexural strength (MPa)	Flexural modulus (MPa)	Charpy impact strength (kJ/mm^2)
PP only	28	1050	15	49	981	3.5
20% treated jute+80% PP	30	2184	3.8	61.5	1176	4.0
25% treated jute+75% PP	28.5	2144	3.6	60	1113	3.8
30% treated jute+70% PP	28	2128	3.5	54.5	1012	3.6
35% treated jute+65% PP	27	2080	3.4	51	977	3.5

4.10 Results on physico-mechanical properties of raw jute, alkali treated, *p*-nitroso *N, N* -DMA and *o*-, *m*-, *p*-HBDC treated jute fibre along with carrot powder - PP composites

In the foregoing presentation of this study it has been found that composites containing less than 65% non bio-degredable components (PP in this study) could not be prepared. In the literature also I have not seen any work in which less than 65% non biodegradable materials (plastic materials) have been used. Therefore, with an aim to prepare composites containing less than 65% non-biodegredable (PP) matrix in other words to increase the percentage of biodegredable materials in the composites an attempt of incorporating carotene into the above studied (jute fibre-PP) composite has been made. As the source of carotene carrot (one of cheapest food stuff in Bangladesh at the same time highly biodegradable fibrous materials in nature) has been used. Chemically, carotene is an unsaturated hydrocarbon containing large number of conjugated double bond in its linear long chain structure. In selecting carrot as the source of carotene, the conjugation in the long linear was considered. Keeping this in mind we thought that is would enhance the compatibility between jute fibre and polymer matrix due to easy polarization of conjugated π bonds.

Experiments were carried on the physico-mechanical properties of raw, alkali treated *p*-nitroso *N, N*- DMA and *o*-, *m*- and *p*-HBDC treated jute fibre-PP composites along with different percentage of carrot powder. The functional groups of carotene have high potential to interact with both cellulose of jute fibre and hydrocarbons of PP. The incorporation of carrot powder in the composite in one way will reduce the percentage of non bio-degredable component (PP) on the other way it will improve the mechanical properties of jute fibre –PP composite. Thus in this study an attempt was made to incorporate the maximum possible amount of carrot powder into the composite. The compositions of the studied composites have been presented in table 3.1.

Physico-mechanical properties of these composites have been investigated in the light of foregoing presentation of jute reinforced- PP composites without carrot powder. The results are presented in the following sections. The experimental results on jute (both raw and treated) reinforced- PP composites containing different percentage of carrot powder are presented in figures 4.23-4.46 and also in table 4.9-4.32.

It is seen from tables 4.9-4.32 that in general the mechanical properties (such as tensile strength, tensile modulus, elongation at break, flexural strength, flexural modulus and Charpy impact strength) have been increased with the increase of carrot powder in all composites studied in this work. However, an optimum value of carrot powder (15%) is obtained at which the above mentioned mechanical properties have been enhanced to a maximum level. This is perhaps due to the presence of high conjugation of carotene that is present in large percentage in carrot powder. The large number of conjugated double bonds plays an important role in positive interaction between the components of the composites. The optimum value that arised in all mechanical properties may be the appearance of saturation point in interaction. A careful examination of the results presented in these figures (4.23-4.46) also reveals that among all composite materials studied in this research work the composite material made by using chemically treated jute fibre with *p*-nitroso *N, N* -dimethyl aniline along with 15% carrot powder have highest mechanical properties (i.e., tensile strength, tensile modulus, elongation at break, flexural strength, flexural modulus and Charpy impact strength). The order of mechanical properties of chemically treated jute fibre-carrot-PP composites is: *p*-nitroso *N, N*-DMA > *o*-HBDC > *m*-HBDC > *p*-HBDC > alkali treated > raw jute fibre.

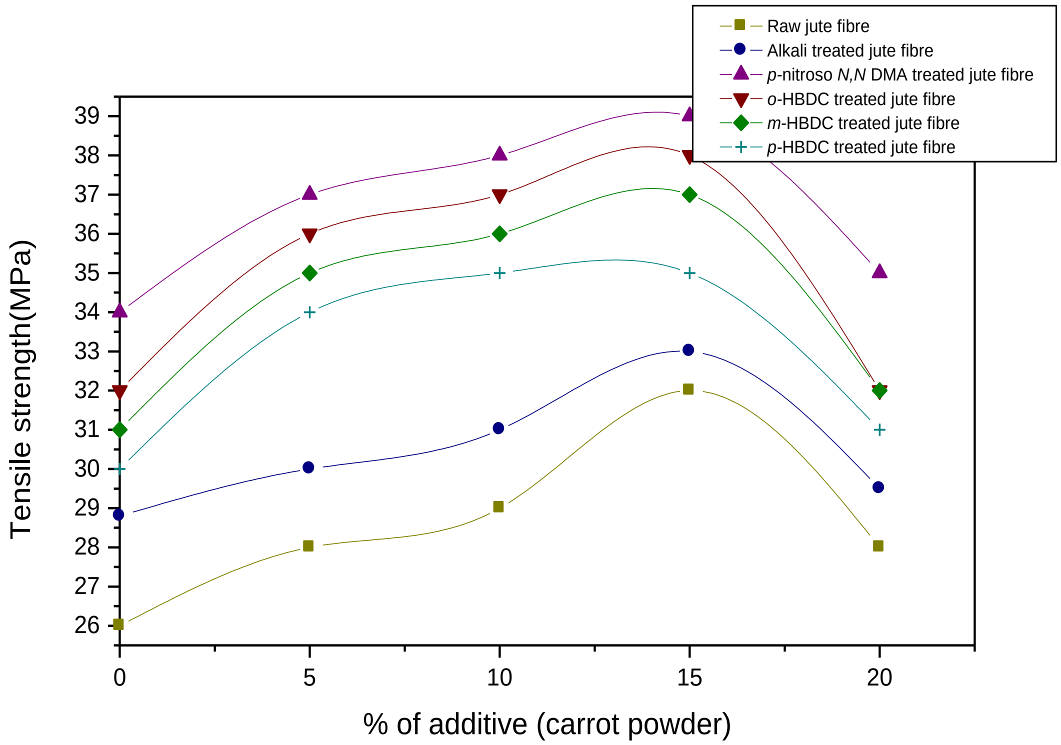


Fig.4.23: **Effect of additive carrot powder on tensile strength of 20 %raw, alkali, *p*-nitroso *N, N* -DMA, *o*-HBDC, *m*-HBDC and *p*-HBDC treated jute fibre-PP composites**

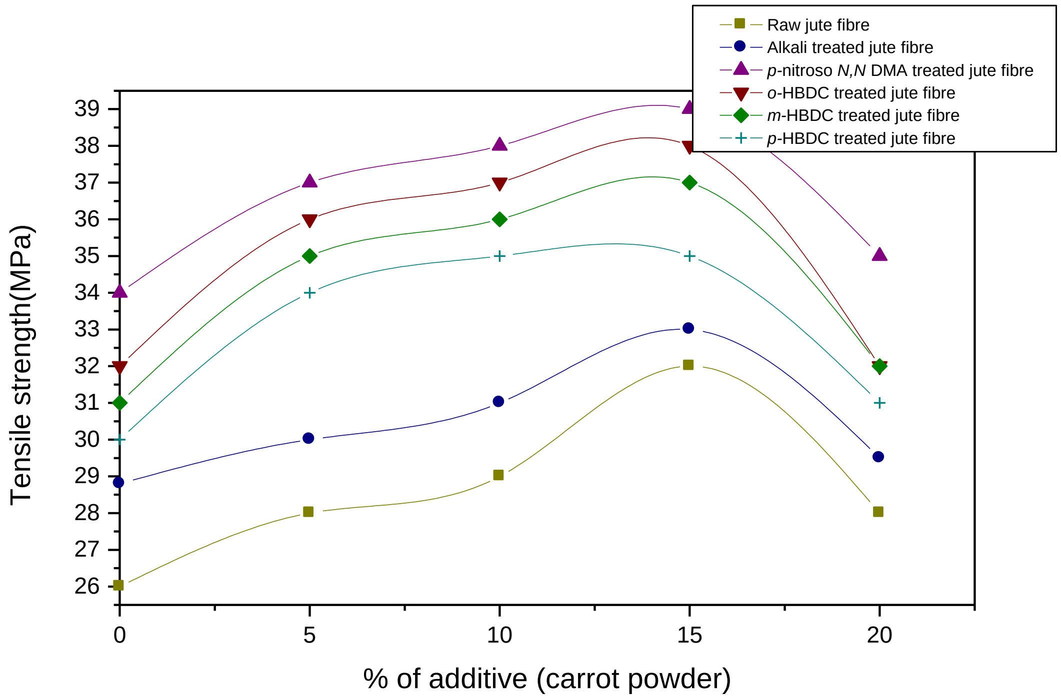


Fig.4.24: **Effect of additive carrot powder on tensile strength of 25 %raw, alkali, *p*-nitroso *N, N* -DMA, *o*-HBDC, *m*-HBDC and *p*-HBDC treated jute fibre-PP composites**

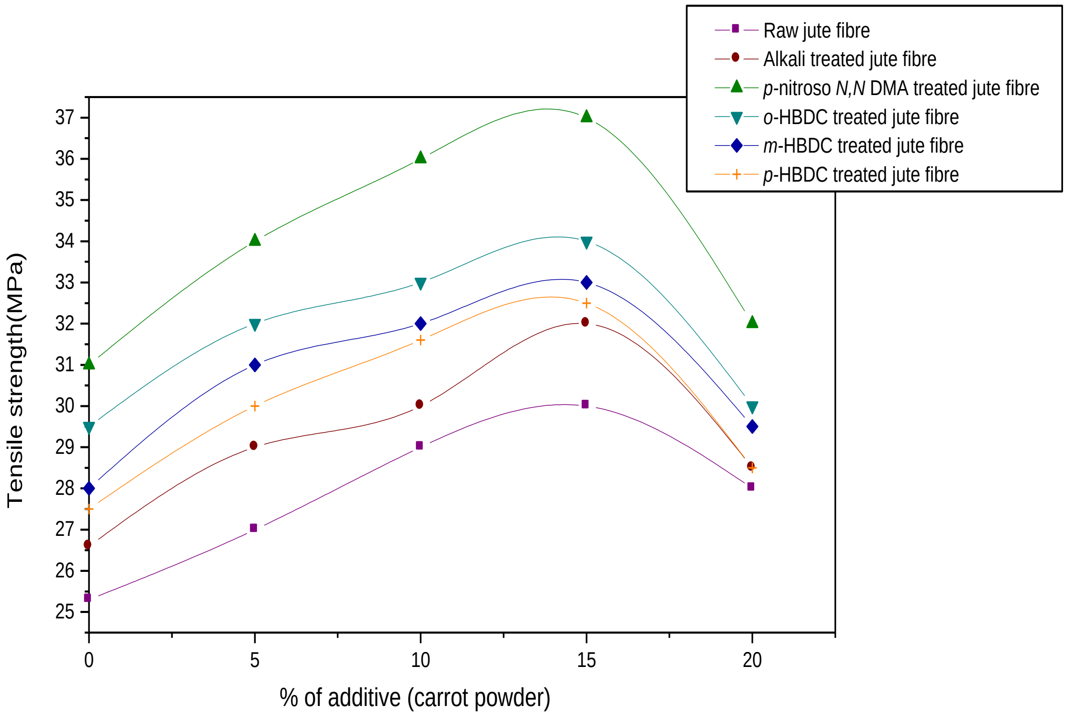


Fig.4.25: Effect of additive carrot powder on tensile strength of 30 %raw, alkali, *p*-nitroso *N, N* -DMA, *o*-HBDC, *m*-HBDC and *p*-HBDC treated jute fibre-PP composites

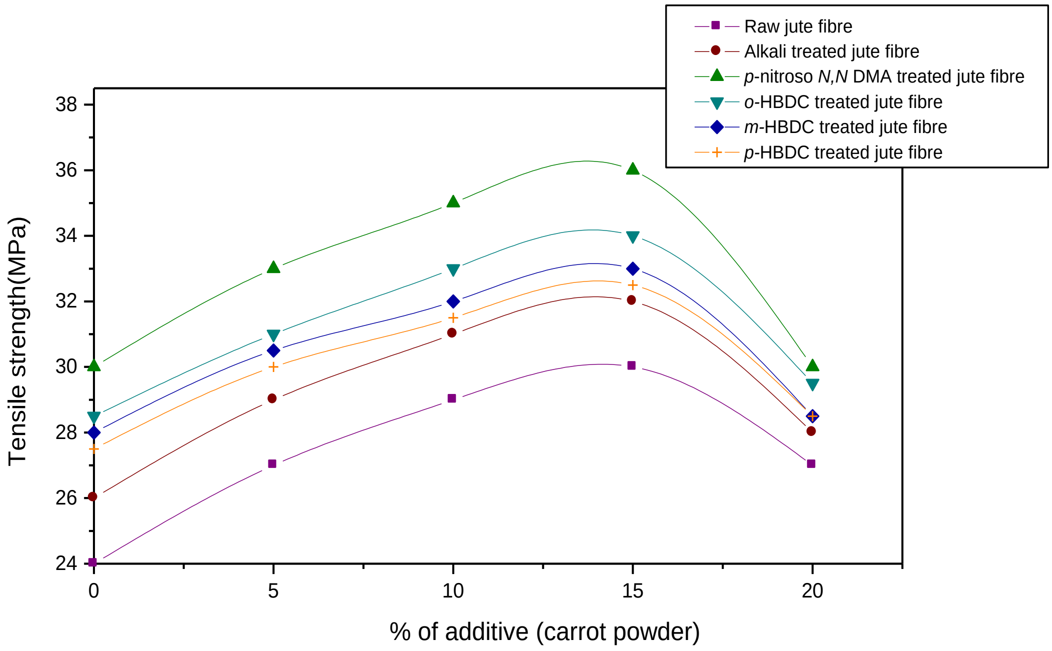


Fig.4.26: Effect of additive carrot powder on tensile strength of 35 %raw, alkali, *p*-nitroso *N, N* -DMA, *o*-HBDC, *m*-HBDC and *p*-HBDC treated jute fibre-PP composites

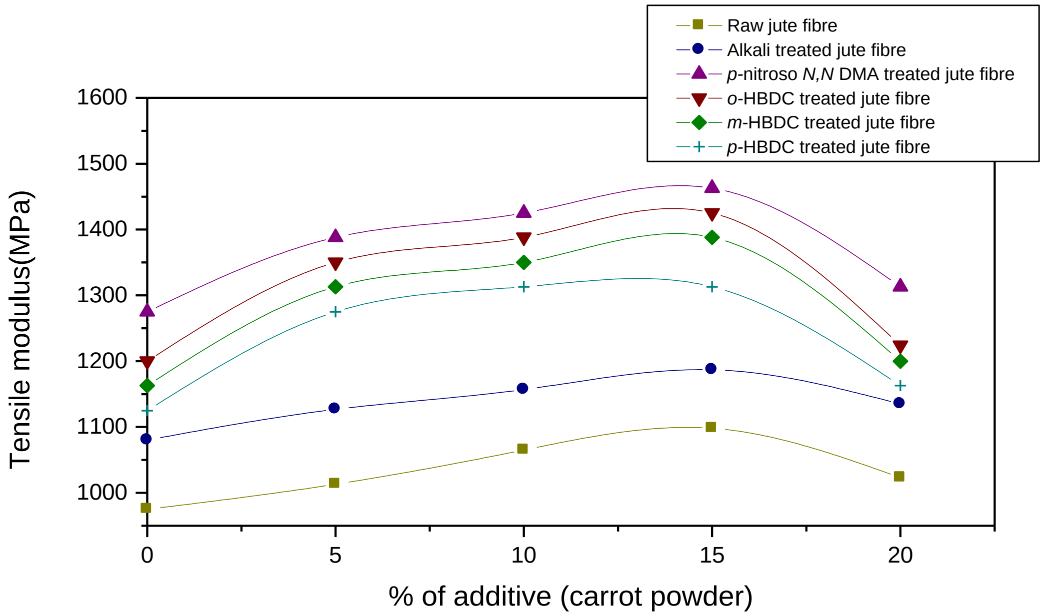


Fig. 4.27: Effect of additive carrot powder on tensile modulus of 20 %raw, alkali, *p*-nitroso *N, N* -DMA, *o*-HBDC, *m*-HBDC and *p*-HBDC treated jute fibre-PP composites

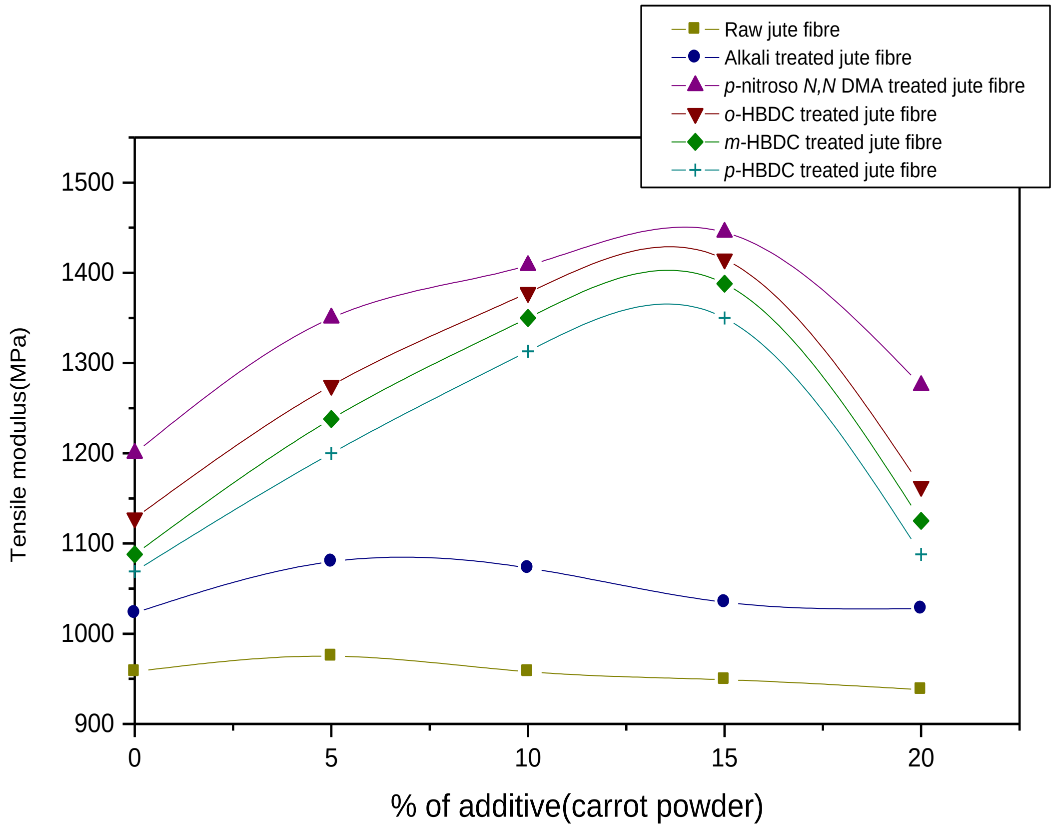


Fig. 4.28: Effect of additive carrot powder on tensile modulus of 25 %raw, alkali, *p*-nitroso *N, N* -DMA, *o*-HBDC, *m*-HBDC and *p*-HBDC treated jute fibre-PP composites

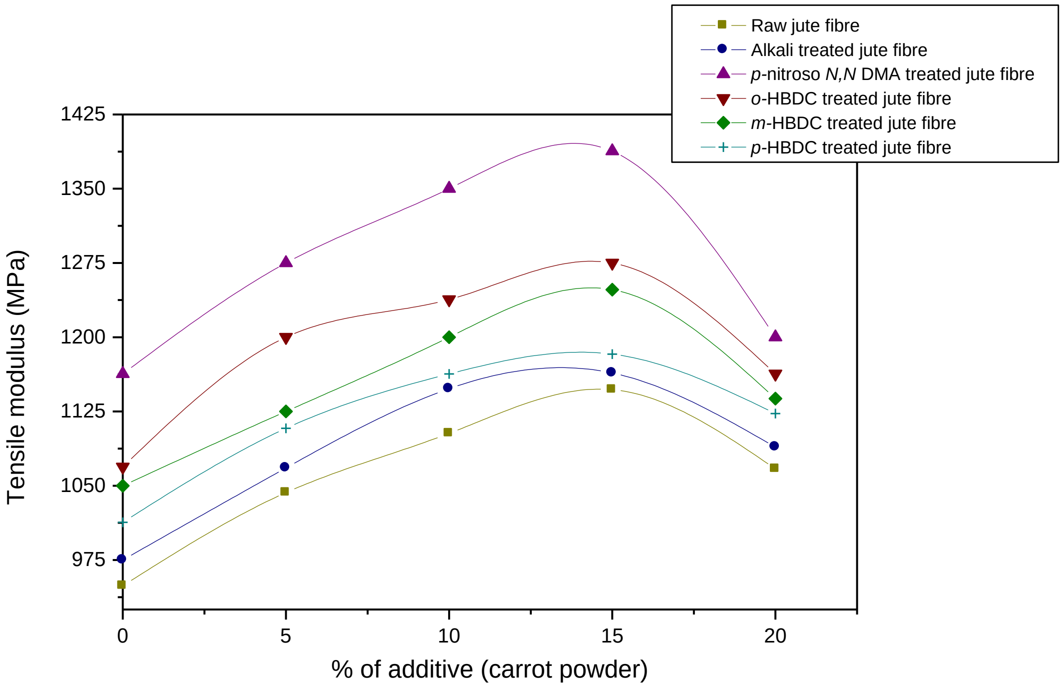


Fig. 4.29: Effect of additive carrot powder on tensile modulus of 30 %raw, alkali, *p*-nitroso *N, N* -DMA, *o*-HBDC, *m*-HBDC and *p*-HBDC treated jute fibre-PP composites

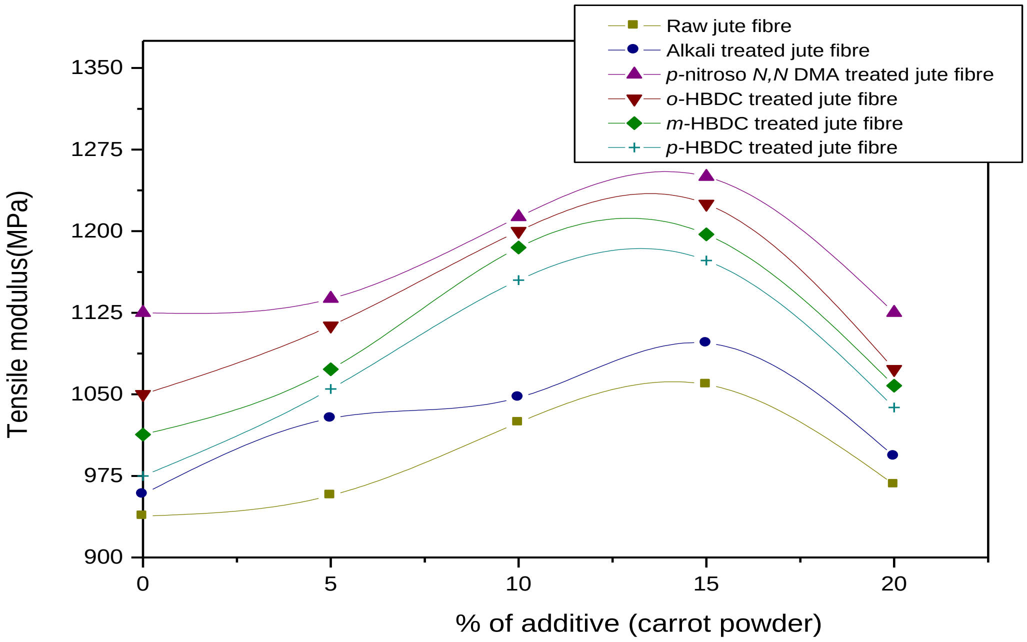


Fig. 4.30: Effect of additive carrot powder on tensile modulus of 35% raw, alkali, *p*- nitroso *N, N* -DMA, *o*-HBDC ,*m*-HBDC and *p*-HBDC treated jute fibre-PP composites

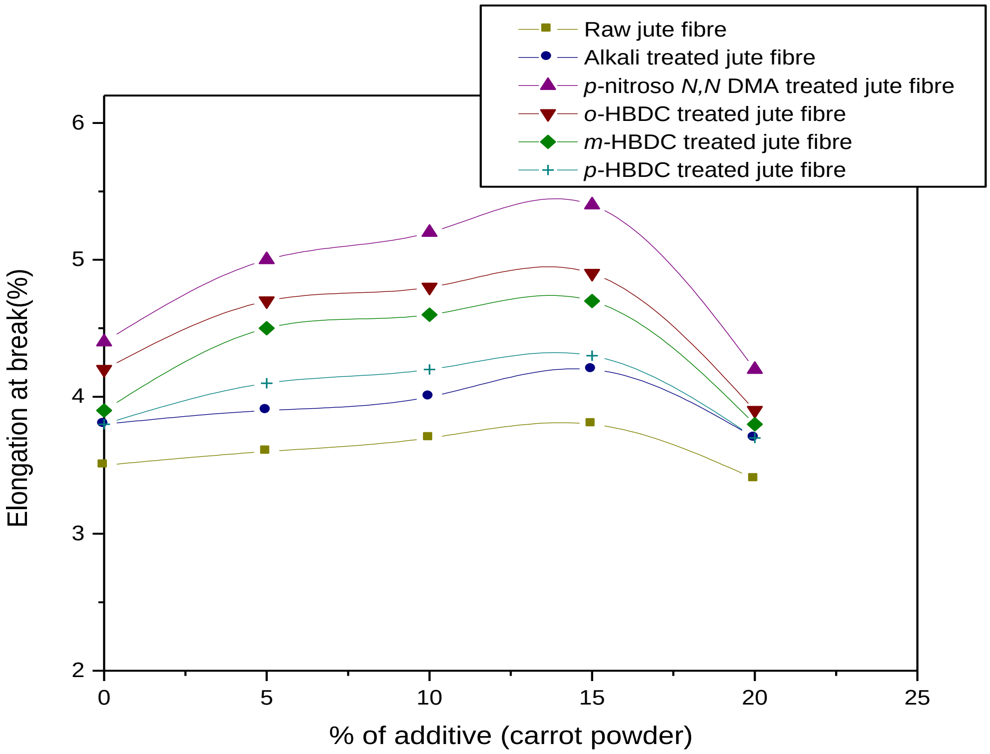


Fig. 4.31: Effect of additive carrot powder on elongation at break of 20% raw, alkali, *p*- nitroso *N, N* -DMA, *o*-HBDC, *m*-HBDC and *p*-HBDC treated jute fibre-PP composites

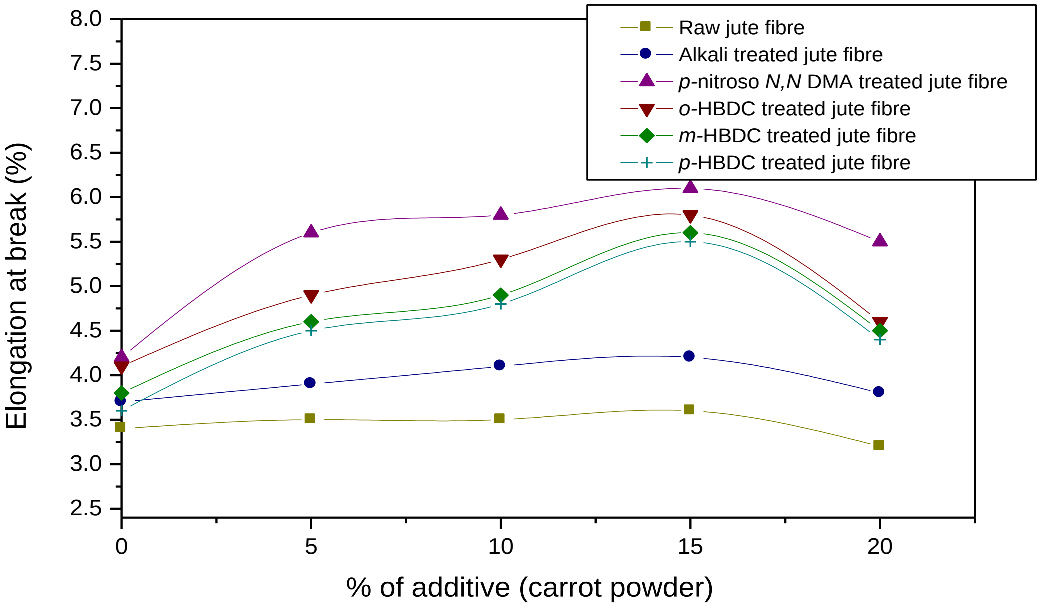


Fig. 4.32: Effect of additive carrot powder on elongation at break of 25% raw, alkali, *p*- nitroso *N, N* -DMA, *o*-HBDC, *m*-HBDC and *p*-HBDC treated jute fibre-PP composites

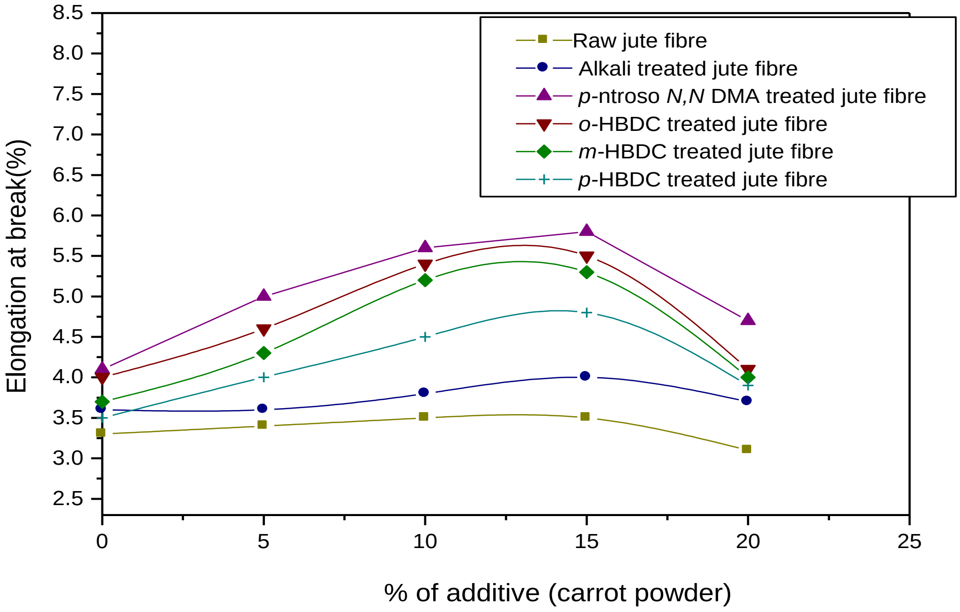


Fig. 4.33: Effect of additive carrot powder on elongation at break of 30% raw, alkali, *p*- nitroso *N, N*- DMA, *o*-HBDC, *m*-HBDC and *p*-HBDC treated jute fibre-PP composites

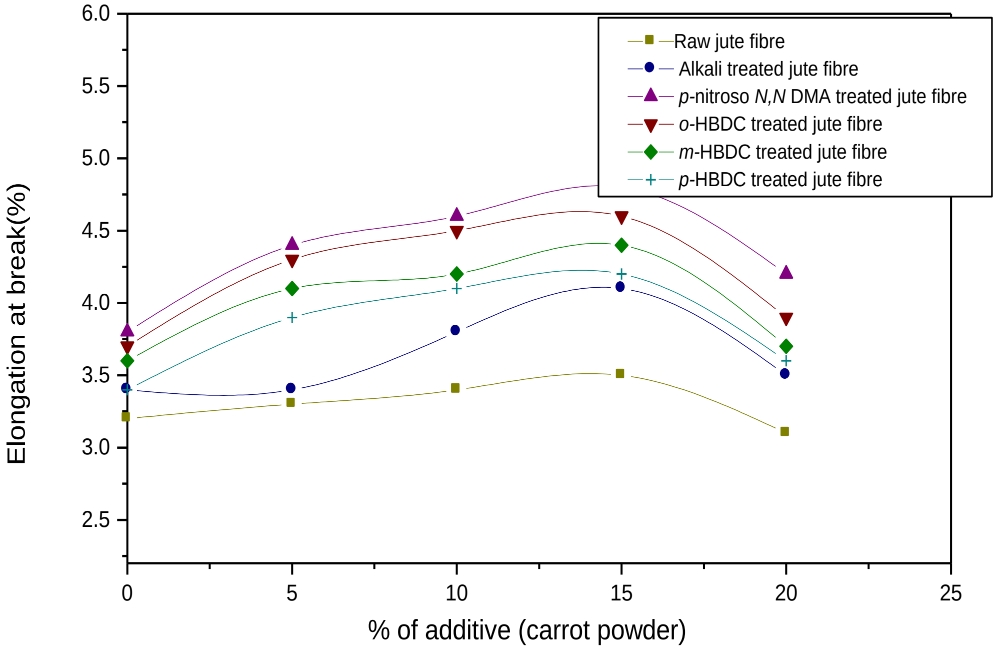


Fig 4.34: Effect of additive carrot powder on elongation at break of 35% raw, alkali, *p*- nitroso *N, N* -DMA, *o*-HBDC, *m*-HBDC and *p*-HBDC treated jute fibre-PP composites

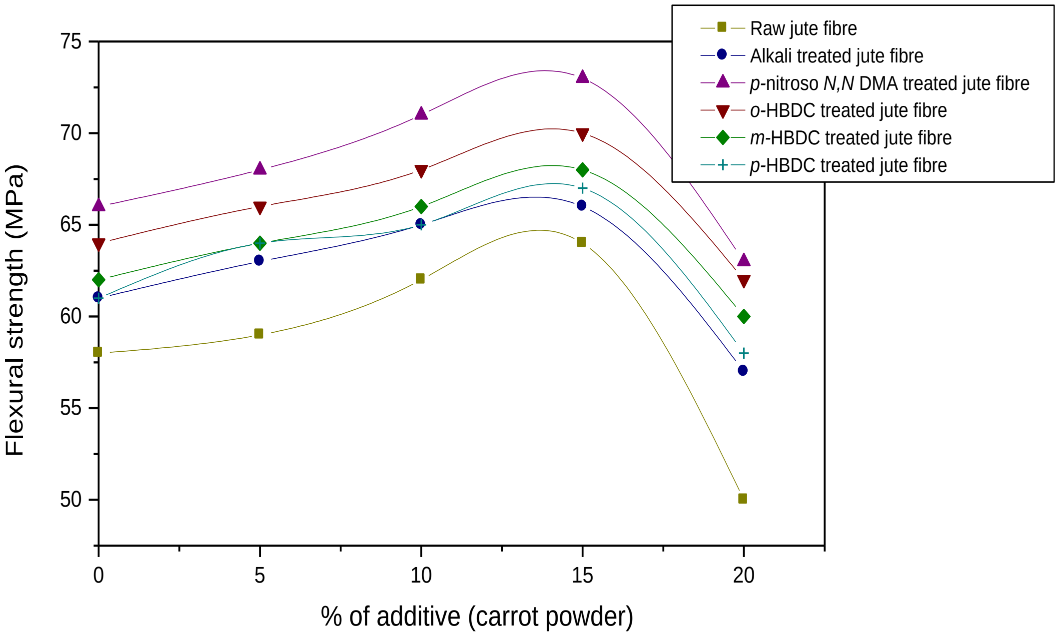


Fig. 4.35: Effect of additive carrot powder on flexural strength of 20% raw, alkali, *p*- nitroso *N, N*- DMA, *o*-HBDC, *m*-HBDC and *p*-HBDC treated jute fibre-PP composites

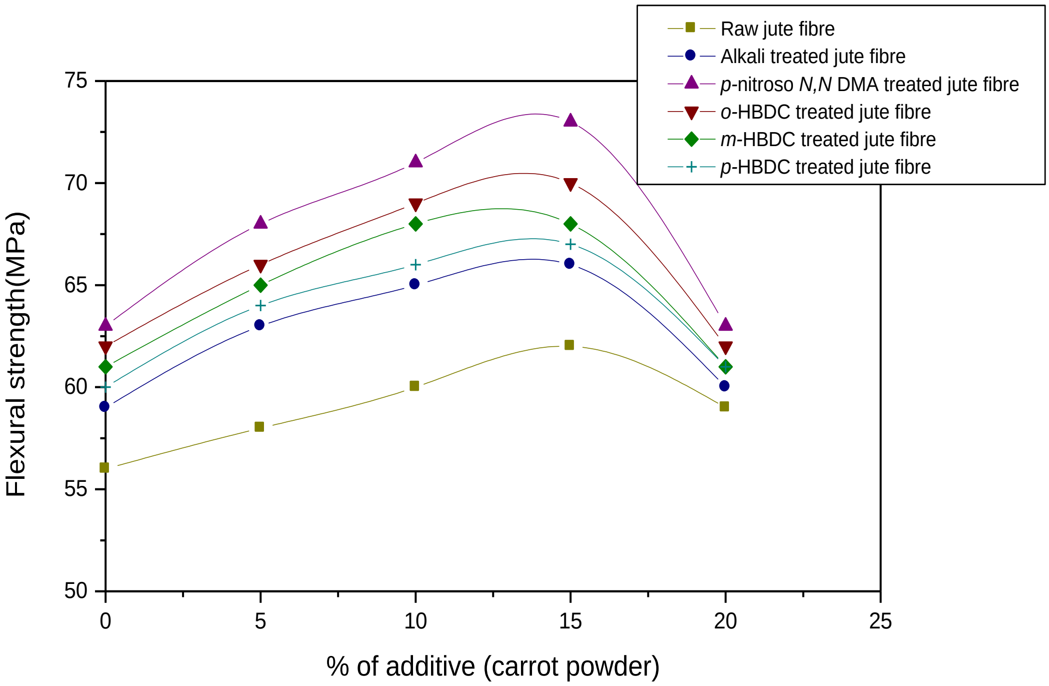


Fig. 4.36: Effect of additive carrot powder on flexural strength of 25% raw, alkali, *p*-nitroso *N, N* -DMA, *o*-HBDC, *m*-HBDC and *p*-HBDC treated jute fibre-PP composites

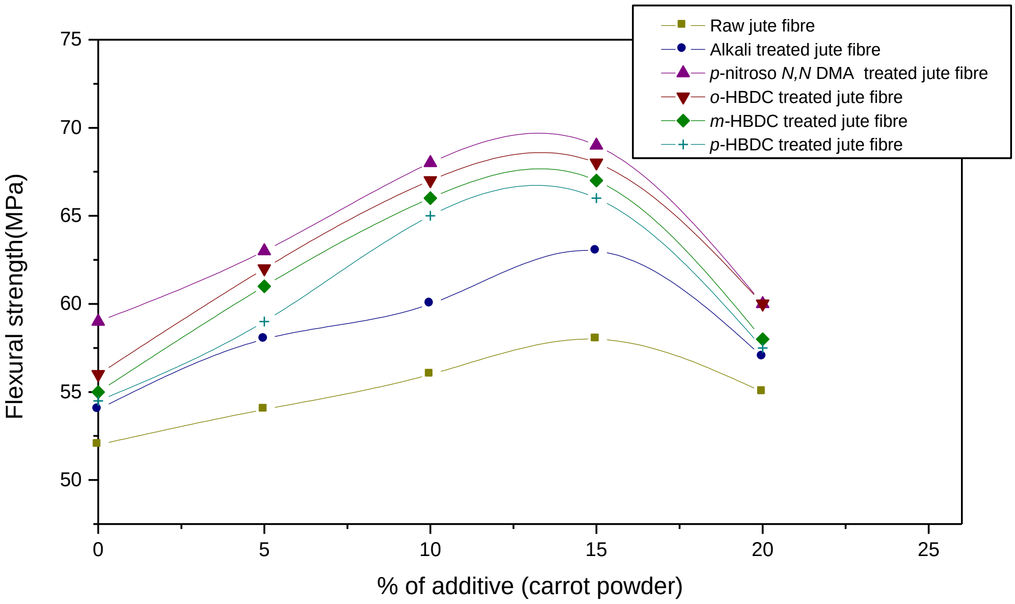


Fig. 4.37: Effect of additive carrot powder on flexural strength of 30% raw, alkali, *p*-nitroso *N, N* -DMA, *o*-HBDC, *m*-HBDC and *p*-HBDC treated jute fibre-PP composites

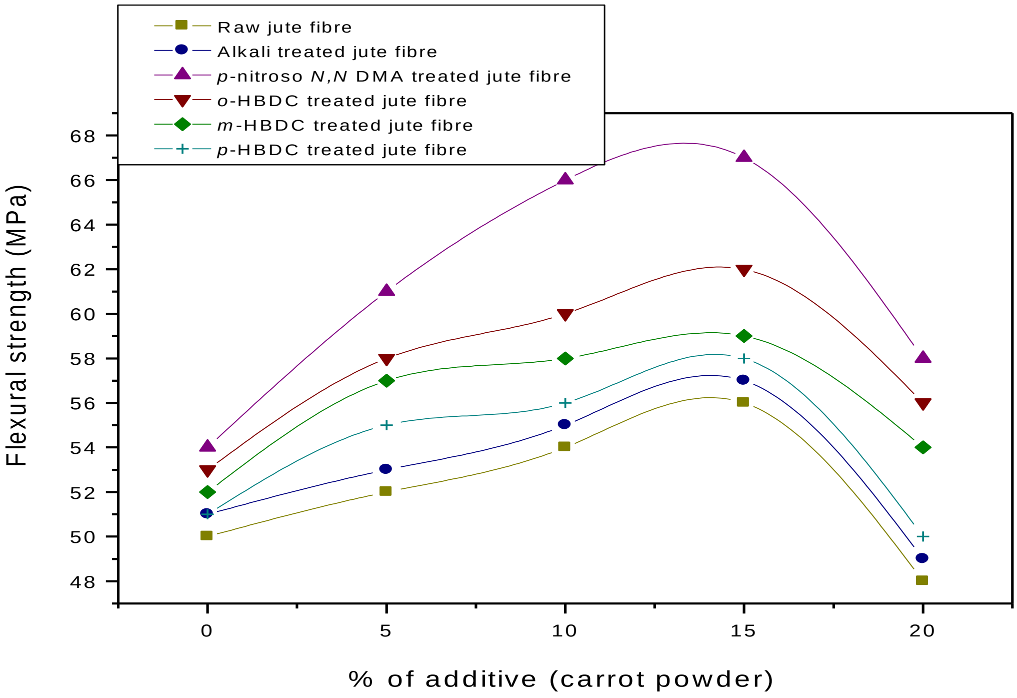


Fig. 4.38: Effect of additive carrot powder on flexural strength of 35% raw, alkali, *p*- nitroso *N, N* -DMA, *o*-HBDC, *m*-HBDC and *p*-HBDC treated jute fibre-PP composites

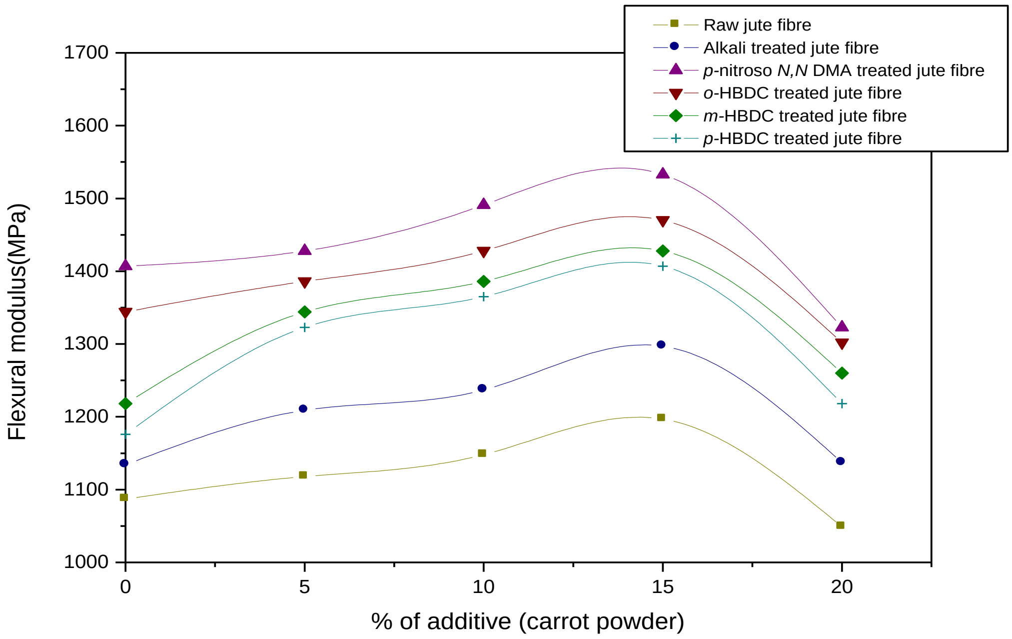


Fig. 4.39: Effect of additive carrot powder on flexural modulus of 20% raw, alkali, *p*- nitroso *N, N* -DMA, *o*-HBDC, *m*-HBDC and *p*-HBDC treated jute fibre-PP composites

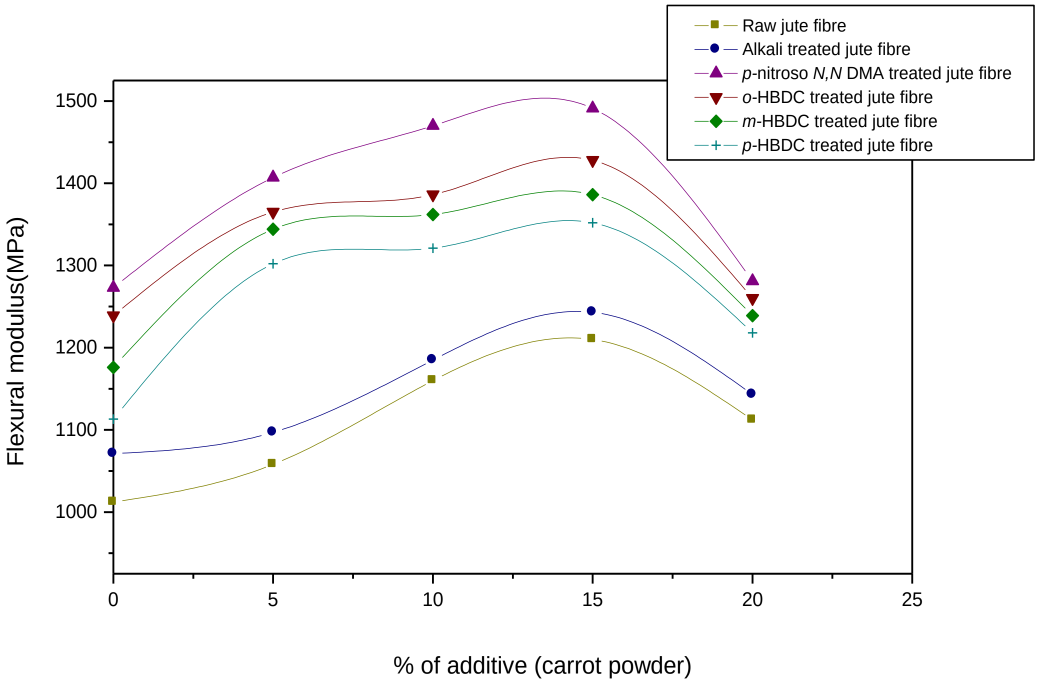


Fig. 4.40: Effect of additive carrot powder on flexural modulus of 25%raw, alkali, *p*-nitroso *N, N*- DMA, *o*-HBDC, *m*-HBDC and *p*-HBDC treated jute fibre-PP composites

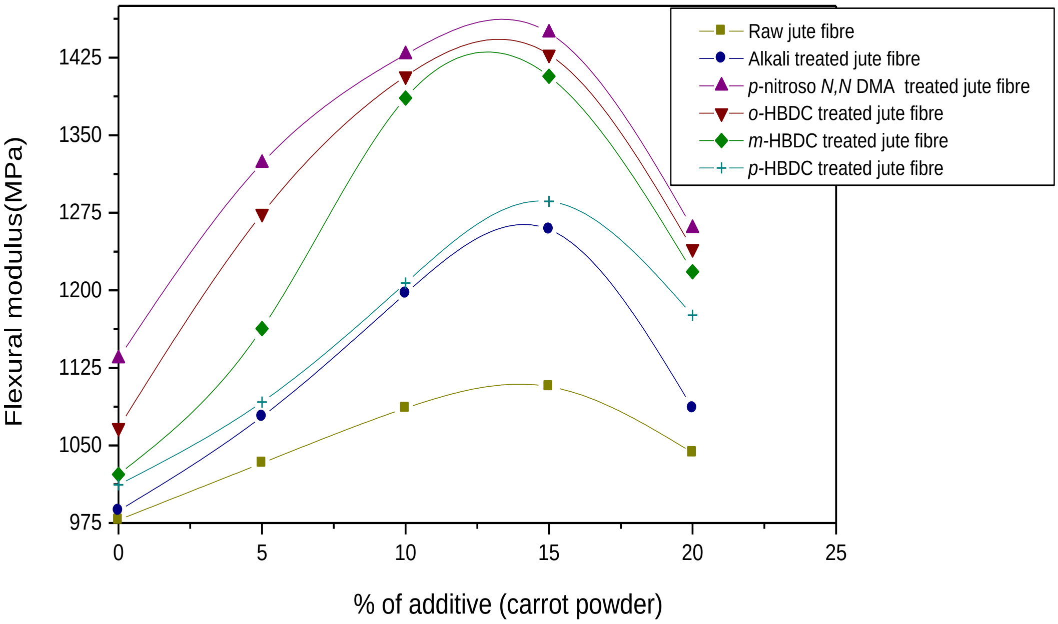


Fig. 4.41: Effect of additive carrot powder on flexural modulus of 30% raw, alkali, *p*- nitroso *N, N*- DMA, *o*-HBDC, *m*-HBDC and *p*-HBDC treated jute fibre-PP composites

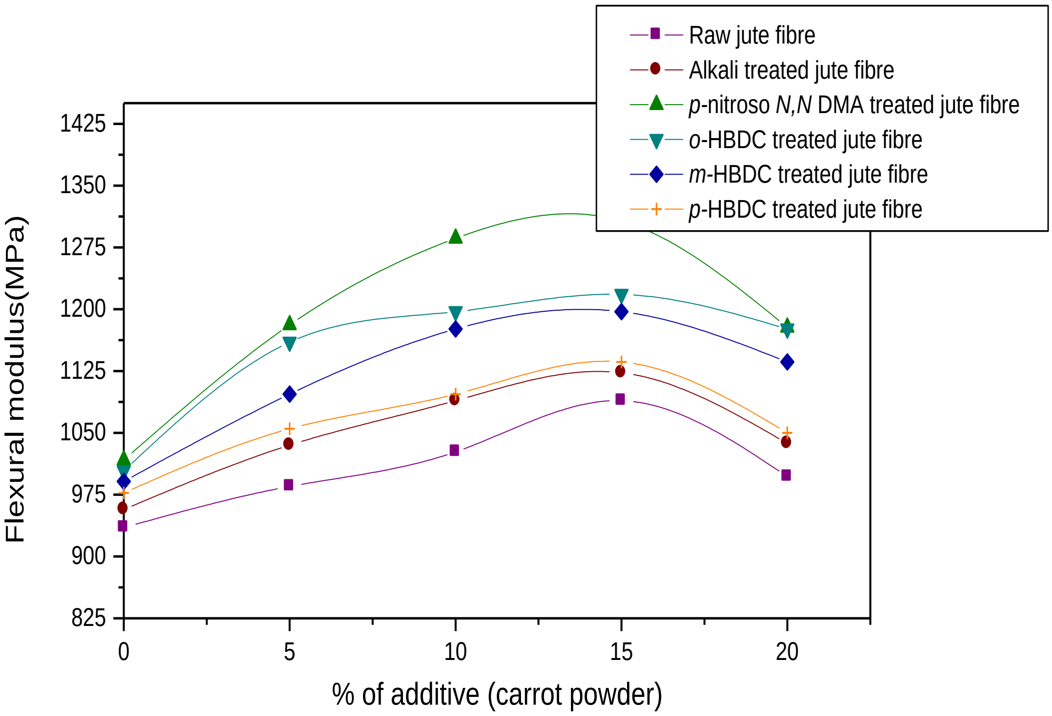


Fig. 4.42: Effect of additive carrot powder on flexural modulus of 35% raw, alkali, *p*- nitroso *N, N* -DMA, *o*-HBDC, *m*-HBDC and *p*-HBDC treated jute fibre-PP composites

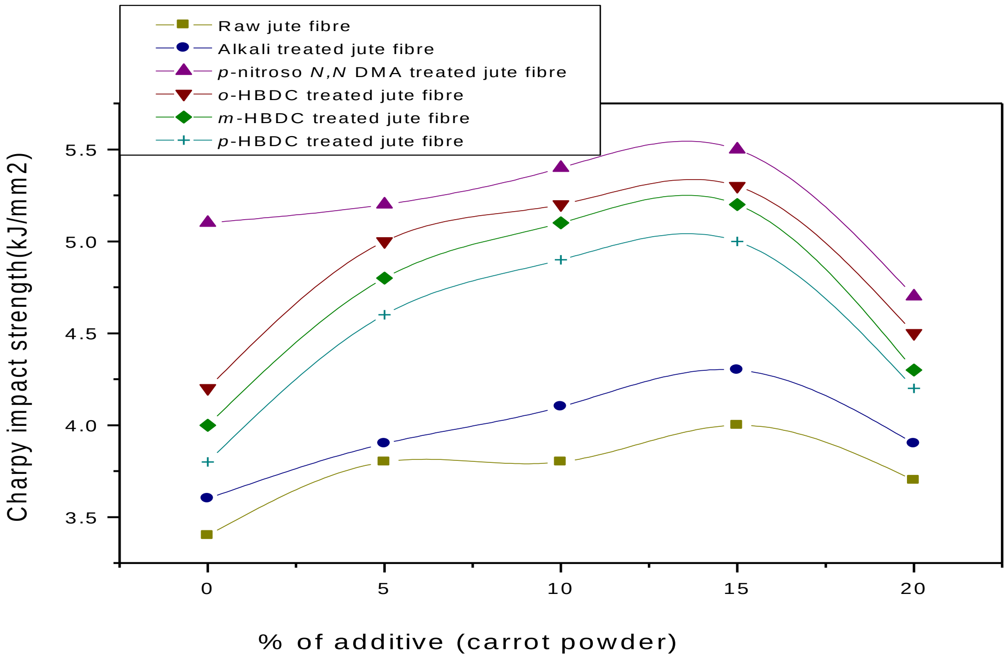


Fig. 4.43: **Effect of additive carrot powder on Charpy impact strength of 20% raw, alkali, *p*- nitroso *N, N*- DMA, *o*-HBDC, *m*-HBDC and *p*-HBDC treated jute fibre-PP composites**

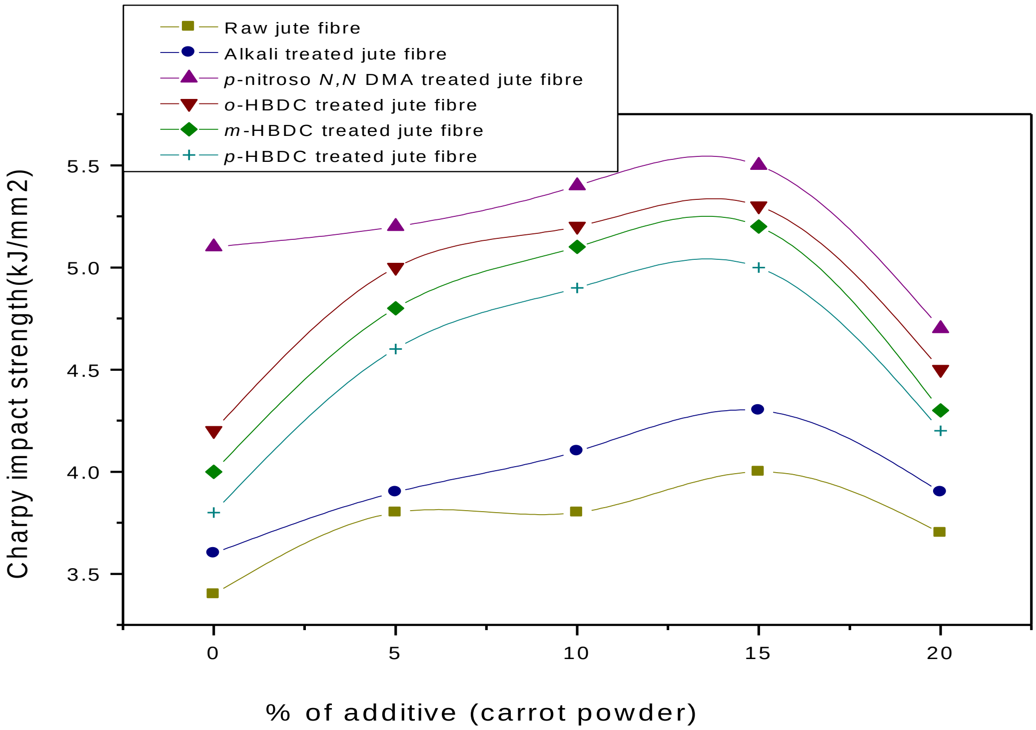


Fig. 4.44: **Effect of additive carrot powder on Charpy impact strength of 25% raw, alkali, *p*- nitroso *N, N*- DMA, *o*-HBDC, *m*-HBDC and *p*-HBDC treated jute fibre-PP composites**

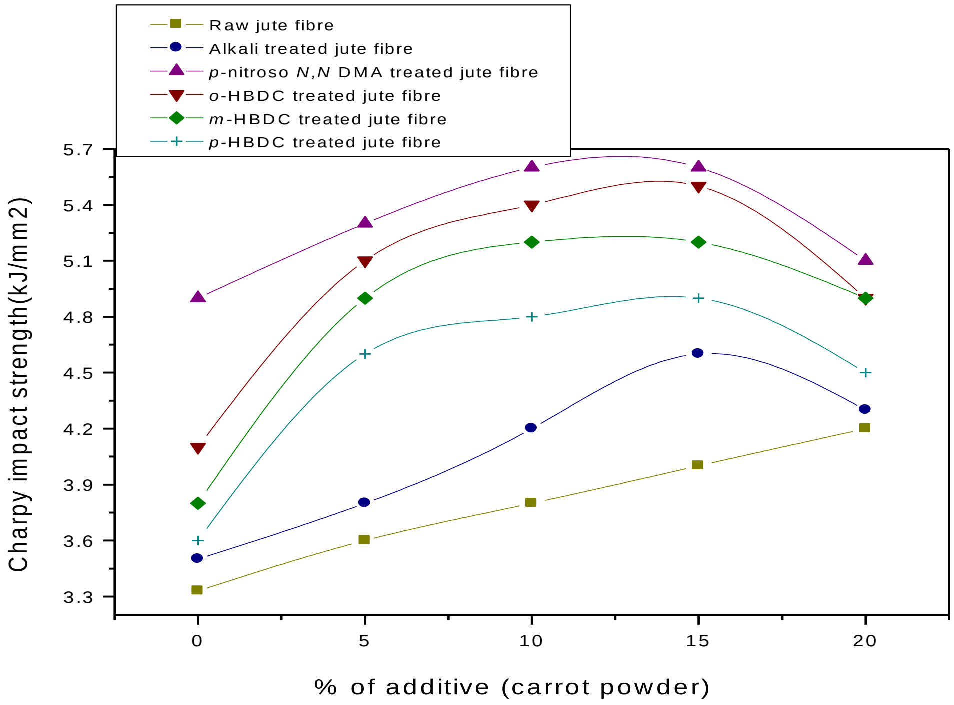


Fig. 4.45: Effect of additive carrot powder on Charpy impact strength of 30% raw, alkali, *p*- nitroso *N, N*- DMA, *o*-HBDC, *m*-HBDC and *p*-HBDC treated jute fibre-PP composites

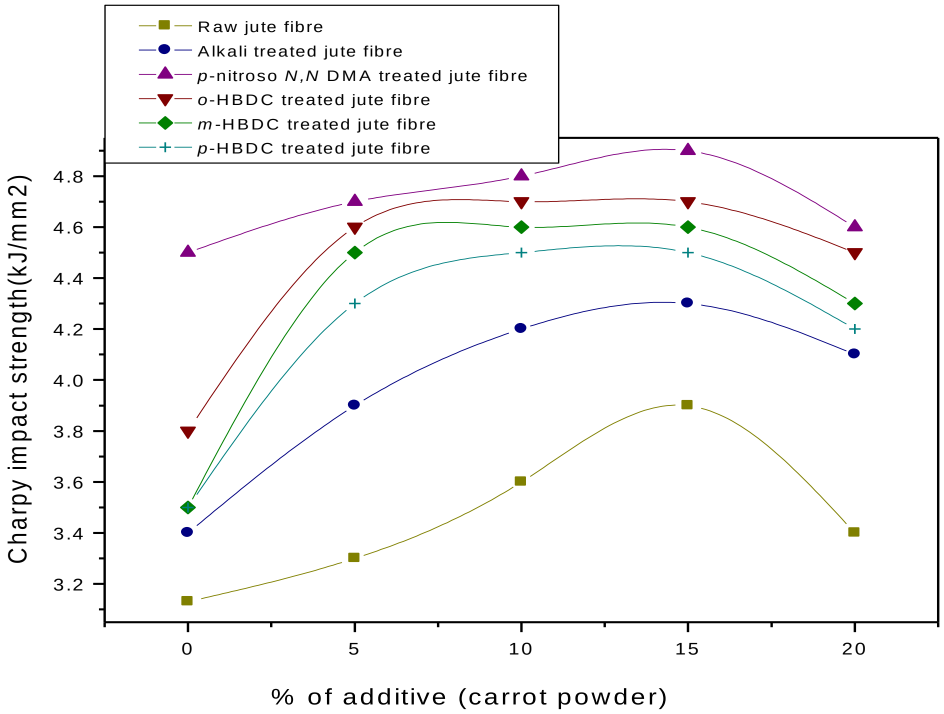


Fig. 4.46: Effect of additive carrot powder on Charpy impact strength of 35% raw, alkali, *p*- nitroso *N, N*- DMA, *o*-HBDC, *m*-HBDC and *p*-HBDC treated jute fibre-PP composites

Table 4.9: Results on physico-mechanical properties of raw jute fibre along with carrot powder -PP composites

Composite materials	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation at break (%)	Flexural strength (MPa)	Flexural modulus (MPa)	Charpy impact strength (kJ/mm^2)
20% raw jute-PP	26	975	3.5	58	1087	3.6
5% carrot powder +20% raw jute+75% PP	28	1013	3.6	59	1118	3.6
10% carrot powder +20% raw jute+70% PP	29	1065	3.7	62	1148	3.8
15% carrot powder +20% raw jute+65% PP	32	1098	3.8	64	1197	4.0
20% carrot powder +20% raw jute+60% PP	28	1023	3.4	50	1049	3.5

Table 4.10: Results on physico-mechanical properties of alkali treated jute fibre along with carrot powder -PP composites

Composite materials	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation at break (%)	Flexural strength (MPa)	Flexural modulus (MPa)	Charpy impact strength (kJ/mm^2)
20% alkali treated jute-PP	28.8	1080	3.8	61	1134	3.8
5% carrot powder +20% treated jute+ 75% PP	30.0	1127	3.9	63	1209	3.8
10% carrot powder +20% treated jute+ 70% PP	31.0	1157	4.0	65	1237	4.1
15% carrot powder +20% treated jute+ 65% PP	33.0	1187	4.2	66	1297	4.2
20% carrot powder +20% treated jute+ 60% PP	29.5	1135	3.7	57	1137	3.9

Table 4.11: Results on physico-mechanical properties of *p*- nitroso *N, N*- DMA treated jute fibre along with carrot powder -PP composites

Composite materials	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation at break (%)	Flexural strength (MPa)	Flexural modulus (MPa)	Charpy impact strength (kJ/mm^2)
20% *N, N*-DMA treated jute-PP	34	1275	4.4	66	1407	5.3
5% carrot powder +20% treated jute+ 75% PP	37	1388	5.0	68	1428	5.3
10% carrot powder +20% treated jute+ 70% PP	38	1425	5.2	71	1491	5.3
15% carrot powder +20% treated jute+ 65% PP	39	1463	5.4	73	1533	5.4
20% carrot powder +20% treated jute+ 60% PP	35	1313	4.2	63	1323	4.9

Table 4.12: Results on physico-mechanical properties of *o*- HBDC treated jute fibre along with carrot powder -PP composites

Composite materials	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation at break (%)	Flexural strength (MPa)	Flexural modulus (MPa)	Charpy impact strength (kJ/mm^2)
20% *o*-HBDS treated jute -PP	32	1200	4.2	64	1344	4.4
5% carrot powder +20% treated jute+ 75% PP	36	1350	4.7	66	1386	4.5
10% carrot powder +20% treated jute+ 70% PP	37	1388	4.8	68	1428	4.5
15% carrot powder +20% treated jute+ 65% PP	38	1425	4.9	70	1470	4.8
20% carrot powder +20% treated jute+ 60% PP	32	1224	3.9	62	1302	4.6

Table 4.13: Results on physico-mechanical properties of *m*- HBDC treated jute fibre along with carrot powder –PP composites

Composite materials	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation at break (%)	Flexural strength (MPa)	Flexural modulus (MPa)	Charpy impact strength (kJ/mm^2)
20% *m*-HBDC treated jute –PP	31	1163	3.9	62	1218	4.2
5% carrot powder +20% treated jute+ 75% PP	35	1313	4.5	64	1344	4.3
10% carrot powder +20% treated jute+ 70% PP	36	1350	4.6	66	1386	4.4
15% carrot powder +20% treated jute+ 65% PP	37	1388	4.7	68	1428	4.5
20% carrot powder +20% treated jute+ 60% PP	32	1200	3.8	60	1260	4.1

Table 4.14: Results on physico-mechanical properties of *p*- HBDC treated jute fibre along with carrot powder -PP composites

Composite materials	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation at break (%)	Flexural strength (MPa)	Flexural modulus (MPa)	Charpy impact strength (kJ/mm^2)
20% *p*-HBDC treated jute -PP	30	1125	3.8	61	1176	4.0
5% carrot powder +20% treated jute+ 75% PP	34	1275	4.1	64	1323	4.1
10% carrot powder +20% treated jute+ 70% PP	35	1313	4.2	65	1365	4.2
15% carrot powder +20% treated jute+ 65% PP	35	1313	4.3	67	1407	4.3
20% carrot powder +20% treated jute+ 60% PP	31	1163	3.7	58	1218	4.0

Table 4.15: Results on physico-mechanical properties of raw jute fibre along with carrot powder -PP composites

Composite materials	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation at break (%)	Flexural strength (MPa)	Flexural modulus (MPa)	Charpy impact strength (kJ/mm^2)
25% raw jute-PP	25.5	958	3.4	56	1012	3.4
5% carrot powder +25% raw jute+70% PP	27.0	975	3.5	58	1058	3.8
10% carrot powder +25% raw jute+65% PP	29.0	958	3.5	60	1160	3.8
15% carrot powder +25% raw jute+60% PP	32.0	949	3.6	62	1210	4.0
20% carrot powder +25% raw jute+55% PP	28.0	938	3.2	59	1112	3.7

Table 4.16: Results on physico-mechanical properties of alkali treated jute fibre along with carrot powder -PP composites

Composite materials	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation at break (%)	Flexural strength (MPa)	Flexural modulus (MPa)	Charpy impact strength (kJ/mm^2)
25% alkali treated jute-PP	28	1023	3.7	59	1071	3.6
5% carrot powder +25% treated jute+ 70% PP	30	1080	3.9	63	1097	3.9
10% carrot powder +25% treated jute+ 65% PP	32	1073	4.1	65	1185	4.1
15% carrot powder +25% treated jute+ 60% PP	33	1035	4.2	66	1243	4.3
20% carrot powder +25% treated jute+ 55% PP	29	1028	3.8	60	1143	3.9

Table 4.17: Results on physico-mechanical properties of *p*- nitroso *N, N*-DMA treated jute fibre along with carrot powder -PP composites

Composite materials	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation at break (%)	Flexural strength (MPa)	Flexural modulus (MPa)	Charpy impact strength (kJ/mm^2)
25% *p*-nitroso *N,N* DMA treated jute-PP	32	1200	4.2	63	1273	5.1
5% carrot powder +25% treated jute+ 70% PP	36	1350	5.6	68	1407	5.2
10% carrot powder +25% treated jute+ 65% PP	37	1408	5.8	71	1470	5.4
15% carrot powder +25% treated jute+ 60% PP	38	1445	6.1	73	1491	5.5
20% carrot powder +25% treated jute+ 55% PP	34	1275	5.5	63	1281	4.7

Table 4.18: Results on physico-mechanical properties of *o*- HBDC treated jute fibre along with carrot powder jute fibre-PP composites

Composite materials	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation at break (%)	Flexural strength (MPa)	Flexural modulus (MPa)	Charpy impact strength (kJ/mm^2)
25%*o*-HBDC treated jute--PP	32	1128	4.1	62	1239	4.2
5% carrot powder +25% treated jute+ 70% PP	34	1275	4.9	66	1365	5.0
10% carrot powder +25% treated jute+ 65% PP	36	1378	5.3	69	1386	5.2
15% carrot powder +25% treated jute+ 60% PP	37	1415	5.8	70	1428	5.3
20% carrot powder +25% treated jute+ 55% PP	32	1163	4.6	62	1260	4.5

Table 4.19: Results on physico-mechanical properties of *m*- HBDC treated jute fibre along with carrot powder –PP composites

Composite materials	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation at break (%)	Flexural strength (MPa)	Flexural modulus (MPa)	Charpy impact strength (kJ/mm^2)
25% *m*-HBDC treated jute -PP	31	1088	3.8	61	1176	4.0
5% carrot powder +25% treated jute+ 70% PP	33	1238	4.6	65	1344	4.8
10% carrot powder +25% treated jute+ 65% PP	35	1350	4.9	68	1362	5.1
15% carrot powder +25% treated jute+ 60% PP	36	1388	5.6	68	1386	5.2
20% carrot powder +25% treated jute+ 55% PP	31	1125	4.5	61	1239	4.3

Table 4.20: Results on physico-mechanical properties of *p*- HBDC treated jute fibre along with carrot powder -PP composites

Composite materials	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation at break (%)	Flexural strength (MPa)	Flexural modulus (MPa)	Charpy impact strength (kJ/mm^2)
25% *p*-HBDC treated jute—PP	30	1069	3.6	60	1113	3.8
5% carrot powder +25% treated jute+ 70% PP	32	1200	4.5	64	1302	4.6
10% carrot powder +25% treated jute+ 65% PP	34	1313	4.8	66	1321	4.9
15% carrot powder +25% treated jute+ 60% PP	35	1350	5.5	67	1352	5
20% carrot powder +25% treated jute+ 55% PP	30	1088	4.4	61	1218	4.2

Table 4.21: Results on physico-mechanical properties of raw jute fibre along with carrot powder -PP composites

Composite materials	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation at break (%)	Flexural strength (MPa)	Flexural modulus (MPa)	Charpy impact strength (kJ/mm^2)
30% raw jute-PP	25.3	949	3.3	52	978	3.33
5% carrot powder +30% raw jute+65% PP	27	1043	3.4	54	1033	3.6
10% carrot powder +30% raw jute+ 60% PP	29	1103	3.5	56	1086	3.8
15% carrot powder +30% raw jute+55% PP	30	1147	3.5	58	1107	4
20% carrot powder +30% raw jute+50% PP	28	1067	3.1	55	1043	4.2

Table 4.22: Results on physico-mechanical properties of alkali treated jute along with carrot powder -PP composites

Composite materials	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation at break (%)	Flexural strength (MPa)	Flexural modulus (MPa)	Charpy impact strength (kJ/mm^2)
30% alkali treated jute-PP	26.6	975	3.6	54	987	3.5
5% carrot powder +30% treated jute+ 65% PP	29	1068	3.6	58	1078	3.8
10% carrot powder +30% treated jute+ 60% PP	30	1148	3.8	60	1197	4.2
15% carrot powder +30% treated jute+ 55% PP	32	1164	4	63	1259	4.6
20% carrot powder +30% treated jute+ 50% PP	28.5	1089	3.7	57	1086	4.3

Table 4.23: Results on physico-mechanical properties of *p*- nitroso *N,N*- DMA treated jute fibre along with carrot powder –PP composites

Composite materials	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation at break (%)	Flexural strength (MPa)	Flexural modulus (MPa)	Charpy impact strength (kJ/mm^2)
30% *p*-nitroso *N,N* - DMA treated jute-PP	31	1163	4.1	59	1134	4.9
5% carrot powder +30% treated jute+65% PP	34	1275	5.0	63	1323	5.3
10% carrot powder +30% treated jute+60% PP	36	1350	5.6	68	1428	5.6
15% carrot powder +30% treated jute+55% PP	37	1388	5.8	69	1449	5.6
20% carrot powder +30% treated jute+50% PP	32	1200	4.7	60	1260	5.1

Table 4.24: Results on physico-mechanical properties of *o*- HBDC treated jute fibre along with carrot powder –PP composites

Composite materials	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation at break (%)	Flexural strength (MPa)	Flexural modulus (MPa)	Charpy impact strength (kJ/mm^2)
30% *o*-HBDC treated jute-PP	29.5	1069	4	56	1067	4.1
5% carrot powder +30% treated jute+ 65% PP	32	1200	4.6	62	1274	5.1
10% carrot powder +30% treated jute+ 60% PP	33	1238	5.4	67	1407	5.4
15% carrot powder +30% treated jute+ 55% PP	34	1275	5.5	68	1428	5.5
20% carrot powder +30% treated jute+ 50% PP	30	1163	4.1	60	1240	4.9

Table 4.25: Results on physico-mechanical properties of *m*- HBDC treated jute fibre along with carrot powder-PP composites

Composite materials	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation at break (%)	Flexural strength (MPa)	Flexural modulus (MPa)	Charpy impact strength (kJ/mm^2)
30% *m*-HBDC treated jute-PP	28	1050	3.7	55	1022	3.8
5% carrot powder +30% treated jute+ 65% PP	31	1125	4.3	61	1163	4.9
10% carrot powder +30% treated jute+ 60% PP	32	1200	5.2	66	1386	5.2
15% carrot powder +30% treated jute+ 55% PP	33	1248	5.3	67	1407	5.2
20% carrot powder +30% treated jute+50% PP	29.5	1138	4.0	58	1218	4.9

Table 4.26: Results on physico-mechanical properties of *p*- HBDC treated jute fibre along with carrot powder -PP composites

Composite materials	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation at break (%)	Flexural strength (MPa)	Flexural modulus (MPa)	Charpy impact strength (kJ/mm^2)
30% *p*-HBDC treated jute-PP	27.5	1013	3.5	54.5	1012	3.6
5% carrot powder +30% treated jute+65% PP	30.0	1108	4.0	59	1092	4.6
10% carrot powder +30% treated jute+60% PP	31.6	1163	4.5	65	1207	4.8
15% carrot powder +30% treated jute+55% PP	32.5	1183	4.8	66	1286	4.9
20% carrot powder +30% treated jute+50% PP	28.5	1123	3.9	57.5	1176	4.5

Table 4.27: Results on physico-mechanical properties of raw jute fibre along with carrot powder -PP composites

Composite materials	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation at break (%)	Flexural strength (MPa)	Flexural modulus (MPa)	Charpy impact strength (kJ/mm^2)
35% raw jute-PP	24	938	3.2	50	935	3.13
5% carrot powder +35% raw jute+60% PP	27	957	3.3	52	985	3.30
10% carrot powder +35% raw jute+55% PP	29	1024	3.4	54	1027	3.60
15% carrot powder +35% raw jute+50% PP	30	1059	3.5	56	1089	3.90
20% carrot powder +35% raw jute+45% PP	27	967	3.1	48	997	3.40

Table 4.28: Results on physico-mechanical properties of alkali treated jute fibre along with carrot powder -PP composites

Composite materials	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation at break (%)	Flexural strength (MPa)	Flexural modulus (MPa)	Charpy impact strength (kJ/mm^2)
35% alkali treated jute-PP	26	958	3.4	51	957	3.4
5% carrot powder +35% treated jute+ 60% PP	29	1028	3.4	53	1035	3.9
10% carrot powder +35% treated jute+ 55% PP	31	1047	3.8	55	1089	4.2
15% carrot powder +35% treated jute+ 50% PP	32	1097	4.1	57	1123	4.3
20% carrot powder +35% treated jute+ 45% PP	28	993	3.5	49	1037	4.1

Table 4.29: Results on physico-mechanical properties of *p*- nitroso *N,N*-DMA treated jute fibre along with carrot powder -PP composites

Composite materials	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation at break (%)	Flexural strength (MPa)	Flexural modulus (MPa)	Charpy impact strength (kJ/mm^2)
35% *p*-nitroso *N,N* DMA treated jute-PP	30	1125	3.8	54	1017	4.5
5% carrot powder +35% treated jute+60% PP	33	1138	4.4	61	1181	4.7
10% carrot powder +35% treated jute+55% PP	35	1213	4.6	66	1286	4.8
15% carrot powder +35% treated jute+50% PP	36	1250	4.8	67	1307	4.9
20% carrot powder +35% treated jute+45% PP	30	1125	4.2	58	1178	4.6

Table 4.30: Results on physico-mechanical properties of *o*- HBDC treated jute fibre along with carrot powder -PP composites

Composite materials	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation at break (%)	Flexural strength (MPa)	Flexural modulus (MPa)	Charpy impact strength (kJ/mm^2)
35% *o*-HBDC treated jute -PP	28.5	1050	3.7	53	1004	3.8
5% carrot powder +35% treated jute+60% PP	31.0	1113	4.3	58	1160	4.6
10% carrot powder +35% treated jute+55% PP	33.0	1200	4.5	60	1197	4.7
15% carrot powder +35% treated jute+50% PP	34.0	1225	4.6	62	1218	4.7
20% carrot powder +35% treated jute+45% PP	29.5	1073	3.9	56	1176	4.5

Table 4.31: Results on physico-mechanical properties of *m*- HBDC treated jute fibre along with carrot powder -PP composites

Composite materials	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation at break (%)	Flexural strength (MPa)	Flexural modulus (MPa)	Charpy impact strength (kJ/mm^2)
35% *m*-HBDC treated jute -PP	28.0	1013	3.6	52	991	3.5
5% carrot powder +35% treated jute+60% PP	30.5	1073	4.1	57	1097	4.5
10% carrot powder +35% treated jute+55% PP	32.0	1185	4.2	58	1176	4.6
15% carrot powder +35% treated jute+50% PP	33.0	1197	4.4	59	1197	4.6
20% carrot powder +35% treated jute+45% PP	28.5	1058	3.7	54	1136	4.3

Table 4.32: Results on physico-mechanical properties of *p*- HBDC treated jute fibre along with carrot powder -PP composites

Composite Materials	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation at break (%)	Flexural strength (MPa)	Flexural modulus (MPa)	Charpy impact strength (kJ/mm^2)
35% *p*-HBDC treated jute -PP	27.5	975	3.4	51	977	3.5
5% carrot powder +35% treated jute+60% PP	30.0	1055	3.9	55	1055	4.3
10% carrot powder +35% treated jute+55% PP	31.5	1155	4.1	56	1097	4.5
15% carrot powder +35% treated jute+50% PP	32.5	1173	4.2	58	1136	4.5
20% carrot powder +35% treated jute+45% PP	28.5	1038	3.6	50	1050	4.2

4.11 Biodegradation

Biodegradation is an important factor for selecting materials for manufacturing articles for construction properties. This is non-biodegradable materials create lot of problems to the environment.

The biodegradability test of raw and treated jute fibre was carried out following the method described in section 3.3. The test results are presented in tables 4.33(a, b). From the result obtained in this study it may be said that jute fibre was fully degraded to the dust after two month. But the composites of jute fibre-PP were degraded to the dust after nine months..

The results presented in tables 4.33(a) show that in around two months the materials lost their strength into that extent for which no mechanical property could be measured.

It is also observed that the order of loss in tensile strength of treated jute fibre is as follows: raw jute fibre > alkali treated jute fibre > oxidized jute fibre> *p*-nitroso *N, N*-dimethyl aniline treated jute fibre >benzene diazonium chloride> *o*-hydroxy benzene diazonium chloride treated jute fibre > *m*-hydroxy benzene diazonium chloride treated jute fibre > *p*-hydroxy benzene diazonium chloride treated jute fibre.

This can be explained based on bacterial attack on raw jute fibre and treated jute fibre. Although the extent the attack is not clearly distinguishable however, it may be said in general that bacterial attack on raw and alkali treated jute fibre is higher than chemically treated jute fibre.

The results presented in tables 4.33(b) show that in around nine months the composite material lost their tensile strength almost completely for which no mechanical property could be measured.

It is also observed from the table that the order of loss in tensile strength of raw and chemically treated jute fibre reinforced composite - PP is as follows: *p*-nitroso *N, N* - dimethyl aniline treated jute fibre-PP composites > *o*-hydroxy benzene diazonium chloride treated jute fibre-PP composites > *m*-hydroxy benzene diazonium chloride treated jute fibre-PP composites > *p*-hydroxy benzene diazonium chloride treated jute fibre-PP composites > alkali treated jute fibre-PP composites >raw jute fibre-PP composites..

It is also observed that the order of loss in tensile strength of raw and treated jute fibre - PP composites along with 15% carrot powder is also in the same order. However, the incorporation of carrot powder increases the biodegradability of the composites i. e, enhances the bacterial attack.

In general, it has been found that with the increase of percentage of jute fibre and carrot powder the biodegradability increase in all kinds of composites investigated in this study.

Table 4.33 (a): Variation of tensile strength of raw jute fibre and treated jute fibre at different time duration

Name of jute fibre	Duration of biodegradation test (in days)				
	0 day	15 days	30days	45 days	60 days
	Tensile strength (MPa)	Tensile strength (MPa)	Tensile strength (MPa)	Tensile strength (MPa)	Tensile strength (MPa)
raw jute fibre	17.12	14.0	5.0	-	-
alkali treated fibre	14.50	12.0	5.0	-	-
Oxidized jute fibre	17.10	13.5	7.0	3.0	-
BDC treated jute fibre	17.50	13.0	9.5	4.0	-
p- nitroso *N,N* –DMA treated jute fibre	19.80	13.5	9.0	3.0	-
o- HBDC treated jute fibre	17.30	14.0	9.5	4.0	-
m- HBDC treated jute fibre	17.25	14.0	10.0	4.5	-
p- HBDC treated jute fibre	17.20	14.0	10.0	4.5	2.0

Table 4.33(b): Variation of tensile strength of jute fibre – PP composites along with carrot powder at different time duration

Name of Composites	Duration of biodegradation test (in months)			
	0 day	3 months	6 months	9 months
	Tensile strength MPa)	Tensile strength (MPa)	Tensile strength (MPa)	Tensile strength (MPa)
20% raw Jute fibre + 80% PP	26	23	18	8.0
20% alkali treated Jute fibre + 80% PP	28.8	23	18	9.0
20% *p*-nitroso *N,N* -DMA treated jute fibre + 80% PP	34	24	20	8.0
20% *o*-HBDC treated Jute fibre + 80% PP	32	27	19	8.0
20% *m*-HBDC treated Jute fibre + 80% PP	31	25	19	9.0
20% *p*-HBDC treated Jute fibre + 80% PP	30	25	18	9.0
15% carrot powder + 20% raw Jute + 65% PP	32	24	15	5.0
15% carrot powder + 20% alkali treated Jute + 65% PP	33	26	16	6.0
15% carrot powder + 20% *p*-nitroso *N,N* -DMA treated jute + 65% PP	39	24	14	-
15% carrot powder + 20% *o*-HBDC treated jute + 65% PP	38	28	15	4.0
15% carrot powder + 20% *m*-HBDC treated jute + 65% PP	37	29	15.	4.0
15% carrot powder + 20% *p*-HBDC treated jute + 65% PP	35	27.5	16	4.0

4.12 SEM morphology

To study the surface morphology of the prepared composites, Scanning Electron Micrograph (SEM) was taken using 20-wt % raw and treated jute fibre loaded PP composites. Scratched pieces from fractured sample of tensile test specimens were used to take SEM. The micrographs are shown in figures 4.18- 4.19 and 4.47- 4.48. The figure 4.18 has shown some void spaces on the surface texture of raw jute fibre –PP composites.

This may be due to lack of interfacial interaction between the raw jute fibre and PP matrix. This is perhaps because of hydrophilic nature jute fibre and hydrophobic nature PP matrix. Hydrophilic jute fibres tend to agglomerate into bundles and become unevenly distributed throughout the PP- matrix.

The images of raw (figure-4.18) and treated jute fibre-PP composite (figure -4.19) reveals that *p* - nitroso *N, N*-DMA and other coupling agents reduces the hydrophilic nature of jute fibre thereby increases the compatibility between treated jute fibre and PP. In addition to this the treatment with coupling agent formed a coating on the fibre surface, which enhances the morphological properties. Furthermore, chemical treatment partially filled the void spaces and aligns uneven fibres, which provide a smooth surface texture over raw jute fibre-PP composites. These results also suggest that the chemical treatment formed a strong interface with cell walls, accounting for the observed increase in mechanical and thermal properties. It is to be mentioned that the surface texture of alkali bleached *p*-nitroso *N, N*- dimethyl aniline treated jute (20%), PP(65%) along with 15% carrot powder composite has more smooth surface than that of alkali bleached HBDC treated jute-PP composites having similar composition as shown in figures 4.47-4.48.

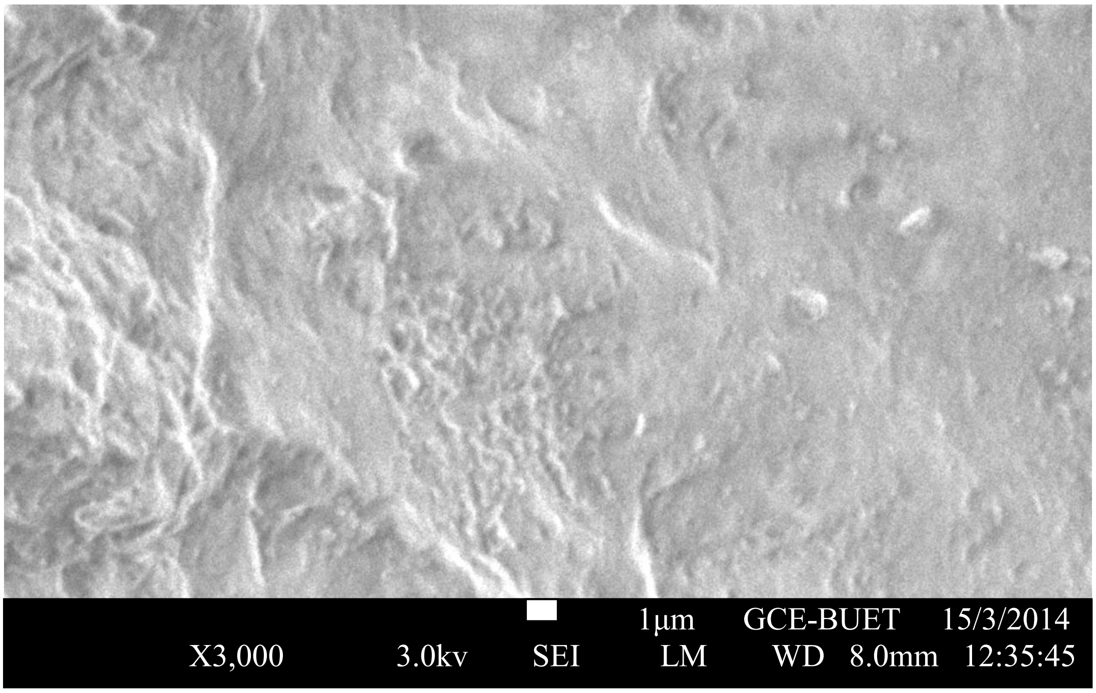


Fig 4.47: SEM of alkali bleached oxidized *p*- nitroso *N, N*-dimethyl aniline treated jute fibre (20%)-PP along with 15% carrot powder composites

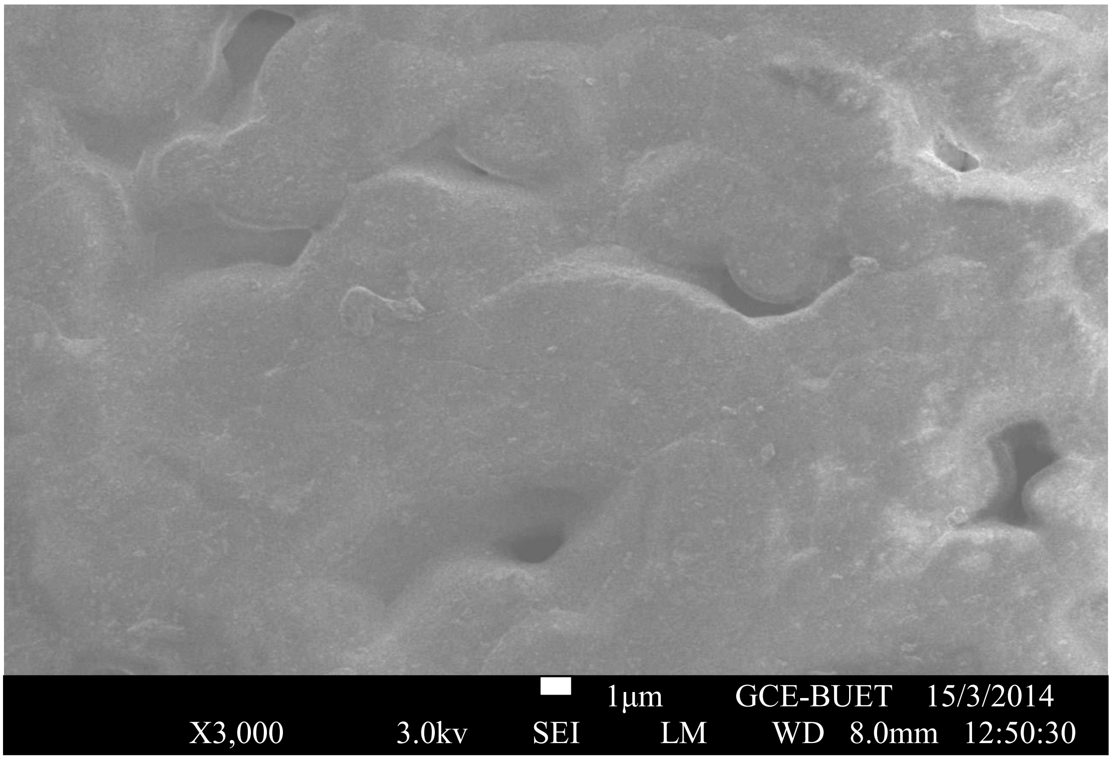


Fig 4.48: SEM of alkali bleached oxidized *o*- HBDC treated jute fibre (20%)-PP along with 15% carrot powder composites

4.13 Thermal properties

Figures 4.49-52 show the Thermo Gravimetry (TG), Differential Thermal Analysis (DTA) and Differential Thermo Gravimetry (DTG) curves of raw jute fibre -PP, alkali bleached oxidized benzene diazonium chloride treated jute fibre-PP, alkali bleached oxidized *p*-nitroso *N, N*-dimethyl aniline treated jute fibre along with carrot powder-PP and alkali bleached oxidized *o*-hydroxy benzene diazonium chloride treated jute fibre along with carrot powder-PP composites respectively. 20 % fibre loaded composites are taken in this purpose. The blue curve is for TG, bottom red one is for DTG and middle green one is for DTA in the figure.

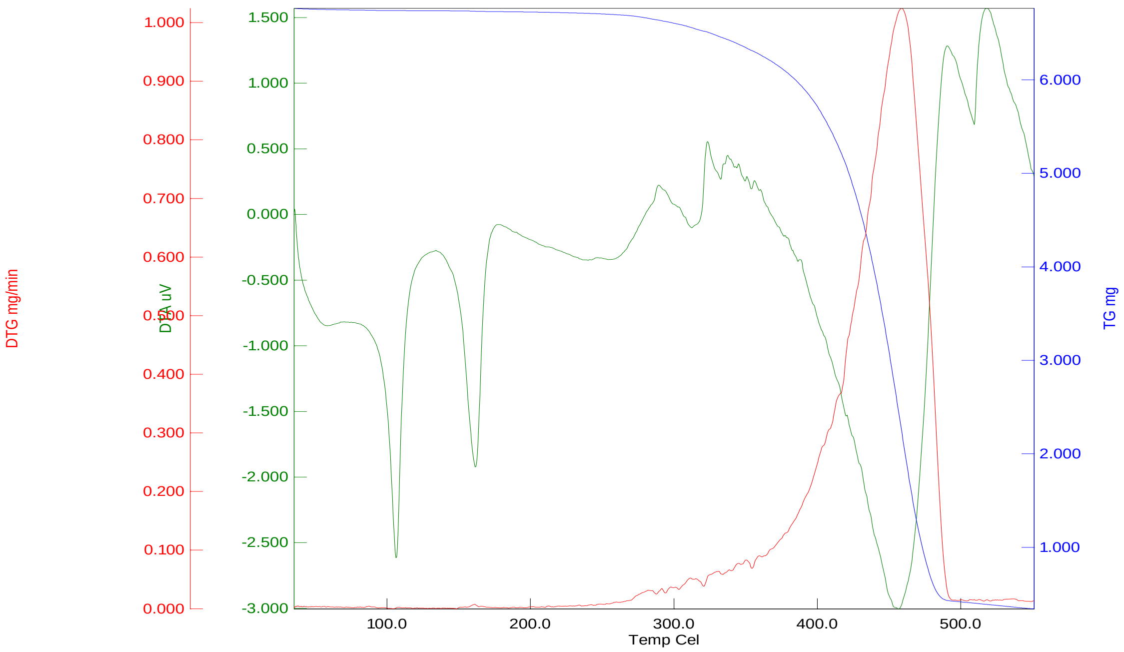


Fig. 4.49: **TGA, DTA, DTG curves for raw jute fibre (20%) -PP composites**

The TG curve in figure 4.49 shows degradations of composites starts at around 180^{0}C and completed at around 470^{0}C. The initial weight loss is related to fibre degradation and the final weight lose is related to polymer degradation. It is also observed from the figure that the rate of degradation of jute fibre becomes slow due to incorporation of PP matrix in the composites. However, final degradation at 450^0-470^{0}C occurred at a very high rate. This is because of degradation of polypropylene occurred alone at this temperature range. 90.8% mass loss was obtained remaining 9.1% residues. The maximum slope was obtained at 465.7^{0}C. The residue may be due to the presence of inorganic materials in jute fibre.

DTA curve the blue one of raw jute fibre shows endothermic peaks at 500^0, 470^0, 340^0, 330^0, 180^0, 110^{0}C which indicate that although the visible weight loss starts at 180^{0}C (according to TG curve). However the significant weight loss takes place at 110^{0}C due to evaporation of absorbed moisture as observed by the endothermic peak at 110^{0}C. The endothermic peaks 180^0, 330^0 & 340^{0}C may be due to the breakage of different bonds existed in different components of jute fibre and low molecular weight polypropylene. . The endothermic peaks at 470^0 and 500^{0}C may be due to the final decomposition of PP. i.e., breakage of C-C bonds existed in polypropylene molecules.

DTG curve of raw jute fibre depicts one predominant peak at 470^{0}C where the maximum degradation rate was 1.0mg/min. This may be due to breakage of different C-C bonds existed in jute polypropylene composites.

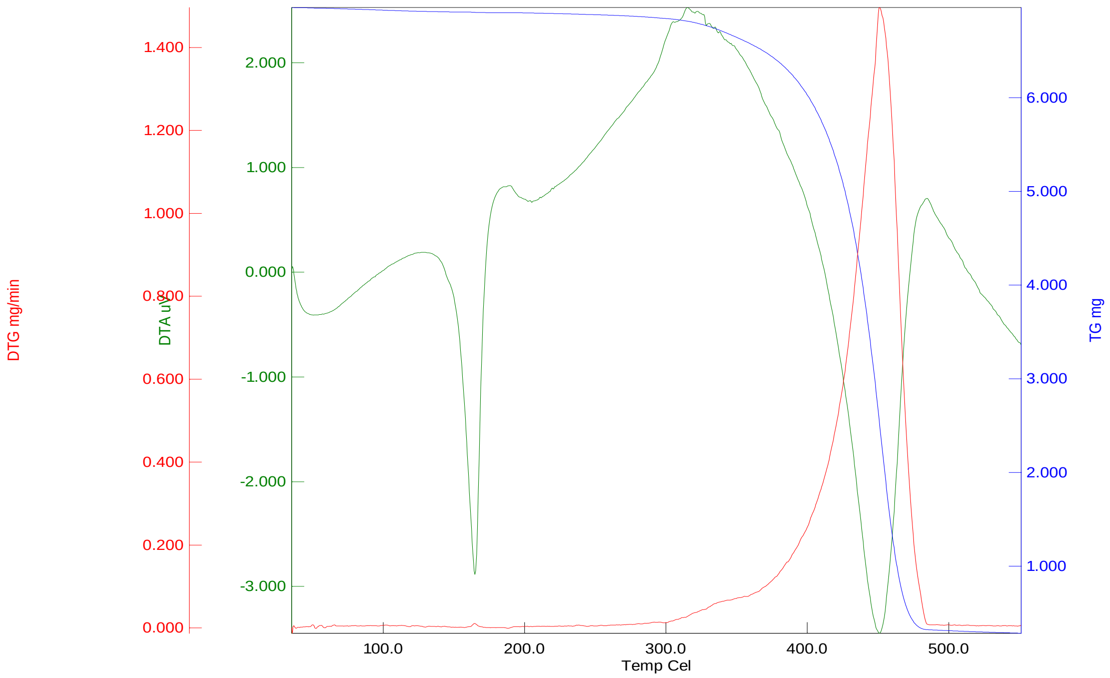


Fig. 4.50: TGA, DTA, DTG curves for alkali bleached oxidized *p*- nitroso *N, N*-dimethyl aniline treated jute fibre (20%) -PP composites

The TG curve in figure 4.50 bears the same nature as that of figure 4.49. The causes may be same. However, in this case the significant weight loss starts at around 280^{0}C instead of 180^{0}C which indicates that on bleaching with alkali followed by *p*- nitroso *N, N*-dimethyl aniline treatment enhances the inherent strength of the composite, which supports the enhanced tensile strength observed in this study.

DTA curve shows endothermic peaks at about 115^{0}C (relatively small), 170^0, 490^{0}C. The relatively small peak at 115^{0}C indicates that the amount of absorbed moisture is appreciable less in treated jute fibre that in raw jute fibre. The other characteristic of the degradation are similar to those of figure 4.49.

DTG curve of treted jute fibre depicts two predominant peak at about 170^{0}C, 470^{0}C where the maximum degradation rate was 1.3 mg/min and 1.25mg/min respectively.

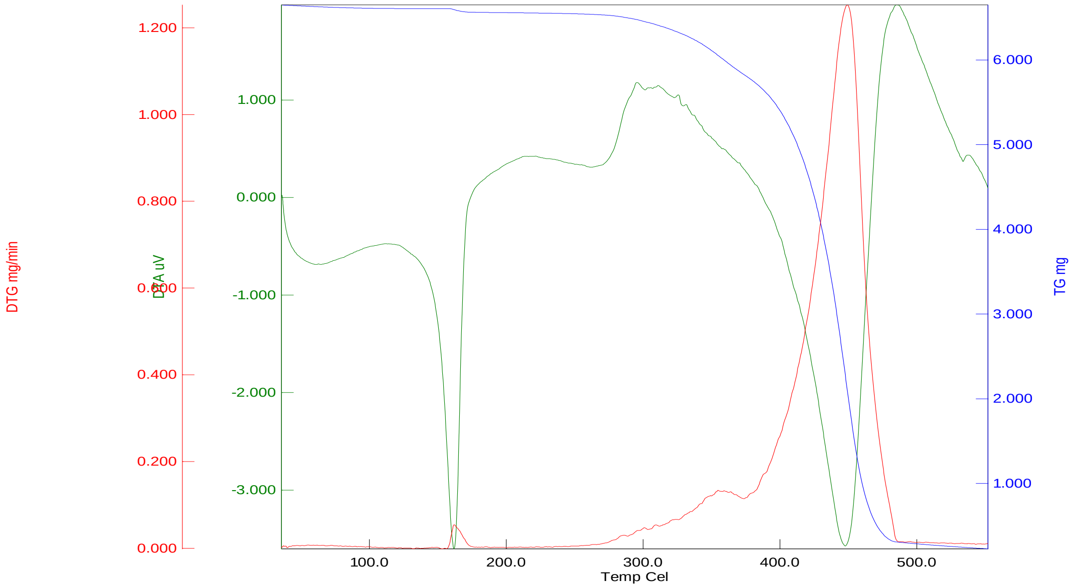
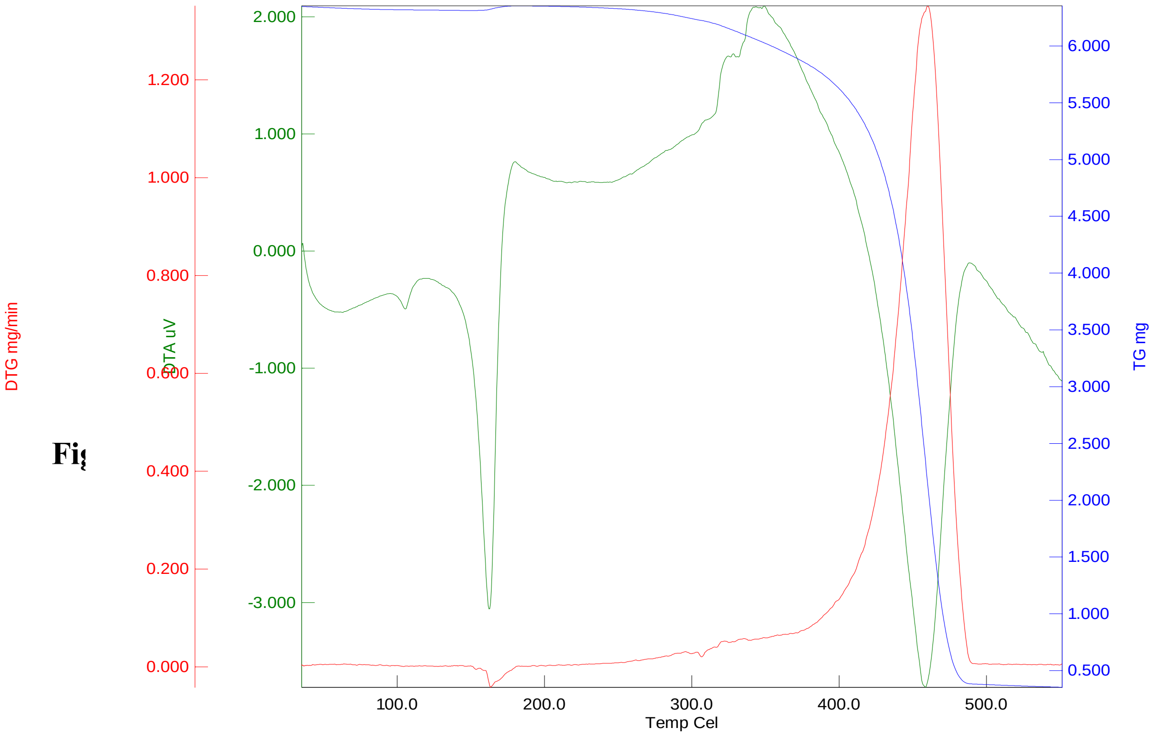


Fig. 4.51: TGA, DTA, DTG curves for alkali bleached oxidized *p*- nitroso *N, N*-dimethyl aniline treated jute fibre (20%) along with 15% carrot powder - PP composites

Figure 4.51 represents TGA, DTA and DTG curves for alkali bleached oxidized ***p***-nitroso *N, N*- dimethyl aniline treated jute fibre-PP composites. The TG curve in Figure 4.51 shows similar nature as those observed in figure 4.49 & 4.50. No significant differences are observed here.

DTA curve shows endothermic peaks at 170^0C, 460^0C, 530^0C respectively. These are also very similar to those observed in figure 4.49 & 4.50.

DTG curve depicts one predominant peak at 450^0C where the maximum degradation rate was 1.5 mg/min.



Fi **ute**

The TGA, DTA and DTG curves of figure 4.52 bear the similar characteristics as those observed in figures 4.49, 4.50 and 4.51.

From the above presented figures (Fig. 4.49-4.52) of thermal properties, it is found that chemically treated composites contain lower moisture than the raw one. It is also found that chemical treatment increase the thermal stability of the composite as compared to raw jute fibre-PP composite. The major source of thermal stability is the coupling reaction with cellulose and the new chemical bonding, which allows thermal energy to be distributed over many bonds.

CONCLUSIONS

From the results obtained in this study the following conclusions can be drawn:

1. The tensile strength and elongation at break of the alkali treated jute fibre were found lower in comparison to those of raw jute fibre and other chemically treated jute fibre.
2. The moisture regain properties of chemically (*p*-nitroso *N, N*-DMA, BDC, oxidized, *o*-, *m*-, and *p*-HBDC) treated jute fibre were found much lower than those of raw and alkali treated jute fibre.
3. Tensile strength and elongation at break of chemically (*p*-nitroso *N, N*,-DMA, BDC, $NaIO_4$, *o*-, *m-, p-* HBDC) treated jute fibre were found to change in the following order: *p*-nitroso *N, N* dimethyl aniline treated > benzene diazonium chloride treated > *o*-hydroxy benzene diazonium chloride treated > *m*- hydroxy benzene diazonium chloride treated > *p*- hydroxy benzene diazonium chloride treated jute fibre > oxidized treated jute fibre.
4. Tensile Strength, tensile modulus, elongation at break, flexural strength, flexural modulus and Charpy impact strength of raw jute and treated jute fibre –PP composites were found to change in the order: *p*-nitroso *N,N*- DMA> *o*-HBDC> *m*-HBDC> *p*-HBDC > alkali > raw jute fibre-PP composites
5. The incorporation of carrot powder in the jute-PP composites increases the mechanical properties in all cases.
6. The effect % of carrot powder on the mechanical properties of jute fibre-PP composite were found to be in the following order: 15%> 10%>5% ~20% carrot powder.
7. The biodegradation of raw jute fibre was found to be faster than that of treated jute fibre.
8. The incorporation of carrot powder increases the biodegradation of the composites.

9. With the increase of fibre loading in the composite the value of tensile strength, flexural strength and Charpy impact strength of composite materials were found to decrease.
10. The tensile modulus of treated (with alkali, *p*-nitroso *N, N* - DMA and HBDC) jute along with carrot powder -PP composites were found to be higher than the tensile modulus of treated (with alkali, *p*-nitroso *N, N* - DMA and HBDC) jute without carrot powder -PP composites.
11. The elongation at break of treated jute fibre (along with carrot powder)-PP composites was higher in comparison to those of raw jute fibre-PP composites.
12. Thermal analysis result revealed that the treated jute fibre-PP composites shows better thermal stability as it degrade at higher temperature than the untreated one.
13. SEM analysis indicated better interfacial interaction between treated jute fibre-PP composites than the untreated one.

Recommendation

The experimental results that have been presented in this thesis work show the physico-mechanical properties of jute and jute-PP composites have improved, but not to the full satisfactory level

By carrying out the similar research using different natural fibre, additives , coupling agents and also polymer matrix it may be possible to prepare better quality of composites.

So the authors of this research work suggest that further work (in light of this work) may be carried out for the future development of natural fibre-reinforced plastic composites.

Limitations

The only limitation of this work is instrumentation and availability of coupling agents. The instruments those are needed to be used in this type of research work are not available in a single institution or research organization of Bangladesh. The author of this work had to go different place and to request many people starting from higher authorities to machine operators several times. In some case the authors are asked to pay high amount fees which go beyond that provided by the funding authority of this work.

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