# Chapter 10
# Manufacturing of Long Puchika Grass Fibre Reinforced Polyester Composites: Assessment Under Mechanical and Dielectric Loading

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**Abstract** The introduction of the 'sustainable development' concept changed the mindset of environmental concerned people to introduce the new materials reinforced with natural renewable substances. An attempt is made in this work to introduce a new natural fibre extracted from the puchika grass, and its physical and mechanical performance is evaluated. Variation of chemicals, concentration and soaking time on this natural fibre resulted in the diversified characteristics of the fibre surface and are observed using scanning electron microscope. Fibre in its raw form and chemically treated is reinforced into the polyester matrix at various contents to assess their mechanical performance under tensile, flexural and impact loadings. Puchika grass CT-7 FRP composites have exhibited the highest tensile strength (58.09) and modulus (1.313 GPa) at maximum fibre content. The composites reinforced with puchika grass CT-3 and CT-7 at maximum fibre volume fraction resulted in maximum flexural strength of 74.93 MPa and 7.51 GPa, respectively. The Charpy impact strength of the material is 65.01 kJ/m$^2$ at 45.95 % fibre volume fraction. The insulation ability of the composites is also assessed after dielectric strength test, and the highest value achieved is 9.67 kV/mm at very low fibre content.

**Keywords** Puchika grass fibre • Polyester resin • Mechanical properties • Dielectric strength • Scanning electron micrograph

## 10.1 Introduction

The substances originated from the nature are called natural materials which are available in renewable and non-renewable forms. Some potential natural renewable resource/biomaterials that are grown extensively in the tropical regions of India like

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Kerala are fruits, plants and trees that exist in diversified forms. In the ancient times, Indians had very intact relationship with the natural world, be it for gathering of food, clothing and shelter to protect them from the surrounding weathering conditions. So, for their house (huts) construction, various stems of the plants and grasses were utilized along with the black sand which are evidenced from the history and are seen in some of the villages in and around the state of Andhra Pradesh and the other parts of India. For instance, coconut one-seeded drupe (dry) fire was utilized from a long time for the making of ropes used for the various household and agricultural applications; leaves of the Palmyra palm were used for house cover; the young grown plants of various varieties were used for nutrition of the sand. Another important area of utilization of natural fibres is in the textile industry to make shirts, bags and other degradable items which are of the present interest to the public. Several researchers have struggled a lot to exploit various natural fibres in chopped, short and long forms to reinforce them into a variety of matrices like polyester, vinyl ester, epoxy and thermoplastic materials for the making of the composite materials. The use of natural fibres dates as far back as 3,000 years ago to ancient Egypt, where the straw was reinforced into clay (composite). The composites were reinforced with natural fibres either in as is or in modified form (physical, chemical, etc.) to attain the target properties. The green reinforcements are of low price, abundantly available, renewable in nature and of high specific properties.

The role of fibres and their applications as reinforcement in composites were neatly exploited (Thomas and Pothan 2009). The German auto manufacturers Mercedes, BMW, Audi and Volkswagen have taken the initiative to make interior and exterior parts using natural fibres as reinforcement in the composites made by injection moulding. Using 35 % Baypreg F semi-rigid elastomer from Bayer and a 65 % blend of flax, hemp and sisal, an inner door panel for the 1999 S-Class Mercedes-Benz was made in Germany.

These situations have given the author an opportunity to do review on nearly 1,500 natural fibre reinforced polymer composites articles. Based on the article survey, the author understood that almost all the natural fibres were extracted by ‘retting and manual extraction method’, so he introduced various new methods (Srinivasababu et al. 2010, 2012, 2014) of extraction of various new natural fibres, and the gist is given in Table 10.1, and the procedures were published elsewhere.

A specific review is conducted on various grass fibre reinforced polymer composites along with the regular study, and the key points are given in the order of grass composites that possess polyester matrix, thermoplastic material, epoxy and

**Table 10.1** Novel methods of extraction of natural fibres (Srinivasababu et al. 2010, 2012, 2014)

| Rolling and splitting (R and S) | Pure splitting (PS) | Hot water immersion (HWI) |
|---|---|---|
| Turmeric stem (TS) | Palm tree sprout leaf (PTSL) | Palmyra palm empty fruit bunch (EFB) |
| Turmeric petiole (TP) | Indian date leaf (IDL) | |
| | Broom grass (BG) | |
| | Sacred grass | |
| | Palm petiole | |

rubber. Indian grass fibre reinforced soy protein composites were analysed for their mechanical properties when the fibre was chemically treated (Liu et al. 2004a, b). The influence of chemically extracted elephant grass fibre on tensile strength and modulus was determined and is 58 and 41 % more than the untreated fibre (Murali Mohan Rao et al. 2007). Flexural strength and modulus of the polyester composites reinforced with chemically extracted wild cane grass fibre had shown 7 and 17 % more than the composites reinforced with untreated fibre (Ratna Prasad et al. 2011). The influence of hybridization effect was studied and reported that snake grass/banana and snake grass/coir fibre reinforced polyester composites have better performance than snake grass FRP composites (Satish Kumar et al. 2013). Waste broom grass fibre has a tensile strength of 297.58 MPa, 18.28 GPa (Ramanaiah et al. 2012). The increase in snake grass fibre content resulted in an increase in tensile and flexural properties (Satish Kumar and Navaneethakrishnan 2012).

The degradation of Bermuda grass and orchard grass was evaluated gravimetrically and by SEM and TEM (Danny Akin and Luanne Rigsby 1985). An analysis was made to use switch grass as a potential bioenergy feedstock (McLaughlin et al. 1996). The effect of morphology, structure and properties of Indian grass/native grass of the USA was reported (Liu et al. 2004a, b). Alkali treatment resulted in the improvement of thermal stability, tensile properties and crystallinity of the Napier grass fibres (Obi Reddy et al. 2009). Napier grass fibre (native African) strands treated with 10 % NaOH showed optimum tensile strength, modulus and percentage elongation with an improvement of 51.9, 47.3 and 12.1 %, respectively (Kommula et al. 2013a, b).

Natural rubber composites reinforced with 400 mesh grass (*Cyperus tegetum* Roxb) fibre had shown superior mechanical properties (De et al. 2004). Further rubber and grass fibre interface was modified, and improved bonding was achieved by the addition of resorcinol formaldehyde latex as bonding agent for the formulation (De et al. 2006). Big bluestem grass fibre reinforced high-density polyethylene composites were analysed for their mechanical properties (Liu et al. 2007). The composites reinforced with 1 % alkali-treated grass fibre and 55 % phenol formaldehyde resin had shown high tensile strength, whereas the composites prepared from 5 % alkali-treated grass fibre and 55 % resin had exhibited maximum flexural properties (De et al. 2007). Untreated and alkali-treated long Napier grass fibre reinforced epoxy composites (Kommula et al. 2013a, b).

Hence an attempt is made in this work to introduce a new natural fibre extracted from the puchika grass which is used in as is condition and treated in the matrix for making composites. The composites are analysed for mechanical and dielectric properties.

## 10.2 Materials, Methods of Manufacturing and Testing

In this section the focus is made on describing the materials used, method of manufacturing employed to extract the fibre and to make the composites and testing procedures followed.

**Fig. 10.1** Dried puchika grass

## *10.2.1 Materials*

The materials considered in the present work are puchika grass fibre in as is condition and modified chemically and polyester resin as reinforcement and matrix, respectively.

### 10.2.1.1 Puchika Grass Fibre

Puchika grass available in Eluru, Andhra Pradesh, is collected from the field, and the crop is of 5–6.2 ft. in height. Initially the grass is exposed to the sunlight for the first-stage removal of moisture, and the dried grass is shown in Fig. 10.1. Then the fibre is extracted by PS method and the extracted fibre is visible as shown in Fig. 10.2, and the procedure of extraction is described in the subsequent section.

### 10.2.1.2 Ecmalon 4413 Matrix

The matrix used in the present work is Ecmalon 4413, which is purchased from Ecmas Resins Pvt. Ltd., Hyderabad, Telangana, India. The resin is a general purpose unsaturated polyester resin of medium reactivity and has medium viscosity, and the mouldings are rigid. This kind of matrix is ideally suited for mouldings using wet lay-up technique. The appearance of the liquid is clear to light yellow. As per the specifications given by the manufacturer, the properties of the liquid resin are given in Table 10.2.

**Fig. 10.2** Extracted puchika grass by pure splitting method

**Table 10.2** Properties of Ecmalon 4413 liquid resin

| Property | Value |
|---|---|
| Viscosity at 25 °C (cps) | 500 (Brookfield viscometer) |
| Specific gravity (25/25 °C) | 1.13 |
| Acid value (mgKOH/g) | 25 |
| Volatiles at 150 °C (%) | 35 |
| Gel time at 25 °C (minutes) | 20 |

## *10.2.2 Methods of Manufacturing*

The methods of extraction of fibre and fabrication of the composites are discussed in the forthcoming sections.

### 10.2.2.1 Pure Splitting Method of Puchika Grass Fibre

Initially one end of the grass is positioned under the needle of 0.25 mm diameter and is moved along its length to split into two. Care must be taken during the passage and straight path is to be maintained during its travel, so that the grass is exactly separated into fibres. The procedure is repeated for entire grass is converted to fibres. Palm tree sprout leaf fibres were extracted by the same method and were firstly introduced.

### 10.2.2.2 Chemical Processing of Puchika Grass Fibre

The role of alkali, permanganate treatments is given as follows. In 1919 Beckmann proposed the first method of NaOH treatment which consists of straw that was treated with 1.5 % NaOH solution and washed with huge quantity of water.

**Table 10.3** Puchika grass chemical treatment procedures

| Fibre | Chemical used for treatment | Soaking time (h) | Concentration (M) | Fibre name after chemical treatment |
|---|---|---|---|---|
| Puchika grass | NaOH | 7 | 0.275 | Puchika grass CT-1 |
| Puchika grass | NaOH | 14 | 0.275 | Puchika grass CT-2 |
| Puchika grass | NaOH | 28 | 0.275 | Puchika grass CT-3 |
| Puchika grass | $KMnO_4$ | 7 | 0.03164 | Puchika grass CT-4 |
| Puchika grass | $KMnO_4$ | 7 | 0.03164 | Puchika grass CT-5[a] |
| Puchika grass | $KMnO_4$ | 14 | 0.03164 | Puchika grass CT-6[a] |
| Puchika grass | $KMnO_4$ | 28 | 0.03164 | Puchika grass CT-7[a] |

[a]Puchika grass fibre is pretreated with NaOH

Subsequently in 1964 Wilson and Pigden developed new methods of treatment with aqueous solutions of NaOH (Galletti 1991). The consumption and conversion of crystalline cellulose through mercerization leads to the formation of amorphous cellulose. In the network structure, the hydrogen bond removal is the key step. Alkali cellulose is formed as a result of NaOH penetration into the crystalline region of cellulose I. In the next phase non-reacted cellulose is percolated which results in the formation of cellulose II. The elementary cells are modified during the transformation of cellulose I to II which is an irreversible exothermic reaction. The effect of alkali treatment depends on concentration, time, temperature, etc. Permanganate treatment results in the formation of cellulose radicals, through the formation of $MnO_3^-$ ion. This radical will enhance the interlocking at the fibre matrix interface (Frederick Wallenberger 2004).

Hence the fibre is subjected to various chemical treatments under different conditions and is described in Table 10.3. Chemical treatment procedures are adopted from the knowledge of literature review and the experience of the author in previous works.

Then the fibre in as is condition and treated condition is dried in NSW-143 Oven Universal, supplied by Narang Scientific Works Pvt. Ltd., New Delhi, to make the fibre free from moisture.

#### 10.2.2.3 Rolled Hand Lay-Up Method of Manufacturing Composites

The entire composites are fabricated by hand lay-up technique for various kinds of mechanical and electric tests, viz., tensile, flexural, impact and dielectric, at different volume fractions of the fibre as per the procedure of regular hand lay-up with slight modifications (Srinivasababu et al. 2010). The extracted puchika grass fibres are very stiff and look like a stick. The chemically processed fibres are trying to mingle with each other which is quite undesirable, since the present work concentrates on understanding complete ability of the reinforcement in its longitudinal direction. Hence with the help of a 25 mm diameter mild steel roller, the entire mould surface is rolled slowly and manually from one end to the other end.

This resulted in proper settlement of the fibre in the mould with correct alignment. Then the rest of the procedure is followed according to the regular procedure of hand lay-up technique, and the composites are fabricated.

### *10.2.3 Testing Procedures*

Initially the fibres were examined for its properties, and then the composites were evaluated under various loading conditions.

#### 10.2.3.1 Fibre Density and Tensile Test

Density of the fibre is determined by ASTM D3800-99 Procedure A-Buoyancy (Archimedes) method. In order to assess the capabilities of the reinforcement, the tensile properties of the fibre are determined by single fibre tensile test (SFTT) according to ASTM C 1557-03$^{\epsilon 1}$. Ecmalon 4413 unsaturated polyester resin is procured from Ecmas Resins Pvt. Ltd., Hyderabad.

#### 10.2.3.2 Composite Test

Then the manufactured composites are taken out from the mould, ground using a belt-type grinding machine and conditioned as per ASTM procedure in NSW-178 Environmental Chamber, procured from Narang Scientific Works Pvt. Ltd., New Delhi.

Using PC 2000 Electronic Tensometer, supplied by Kudale Instruments Pvt. Ltd., Pune, tensile and flexural tests are conducted, whereas the impact test is conducted on Computerized Izod/Charpy Impact Tester, which can be bought from International Equipments, Bombay. The notch for impact test is cut using a notch cutter precisely. The dielectric test is performed on a dielectric strength tester.

## 10.3 Results and Discussion

Initially using the JEOL JSM-5350A, the morphological study of the puchika grass fibres is examined with the kind permission of the Department of Physics, University of Pune, Pune. The study concentrates only to understand the surface of the fibre before and after treatments. From Fig. 10.3 it is understandable that the structure resembles a honeycomb, and the treatment resulted in the suppression of the structure which is visible as shown in Figs. 10.4, 10.5, 10.6, 10.7, 10.8, 10.9 and 10.10.

Puchika grass fibre in untreated and treated condition is used to determine their density, and the values range from 438.44 to 908.53 kg/m$^3$ and is graphically

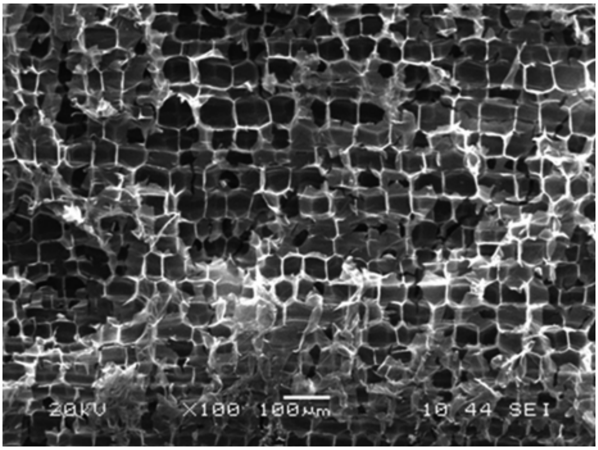



**Fig. 10.3** Scanning electron micrograph of puchika grass fibre

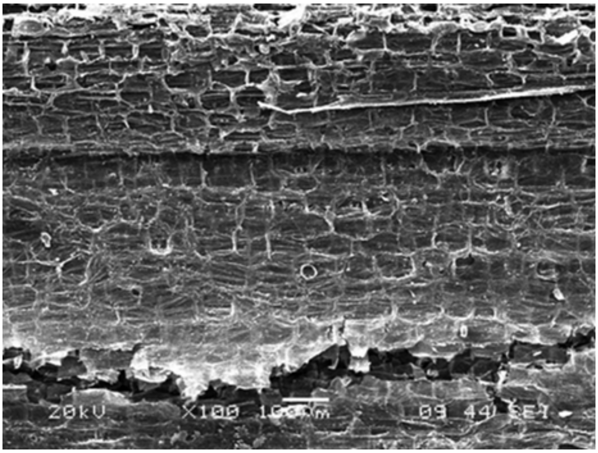



**Fig. 10.4** Scanning electron micrograph of puchika grass CT-1 fibre

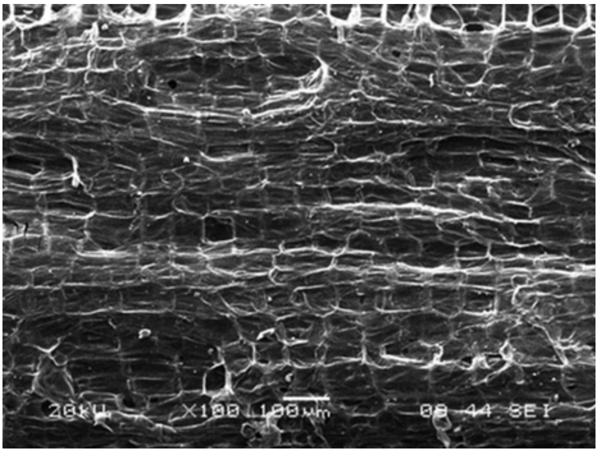



**Fig. 10.5** Scanning electron micrograph of puchika grass CT-2 fibre

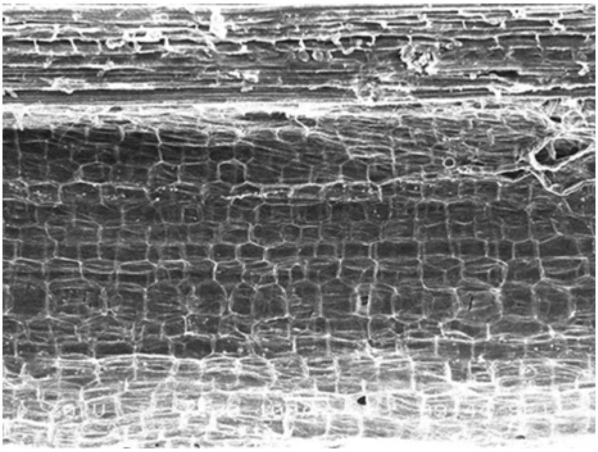


**Fig. 10.6** Scanning electron micrograph of puchika grass CT-3 fibre

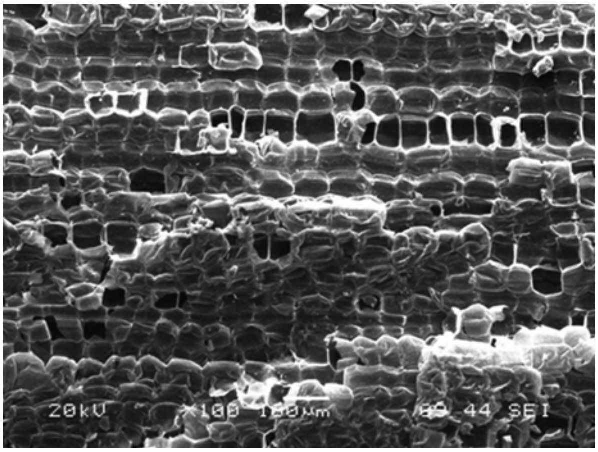



**Fig. 10.7** Scanning electron micrograph of puchika grass CT-4 fibre

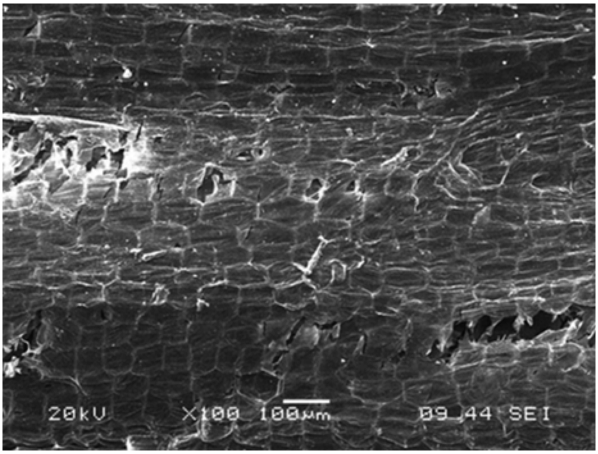



**Fig. 10.8** Scanning electron micrograph of puchika grass CT-5 fibre

**Fig. 10.9** Scanning electron micrograph of puchika grass CT-6 fibre

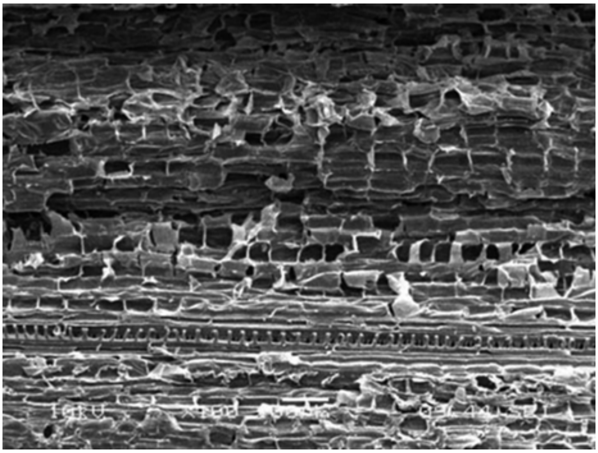
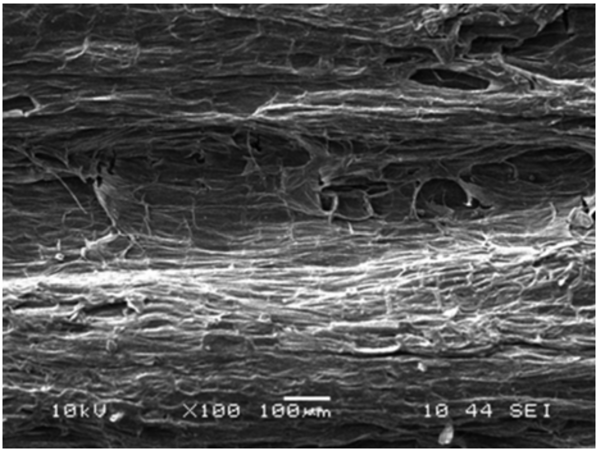


**Fig. 10.10** Scanning electron micrograph of puchika grass CT-7 fibre




represented in Fig. 10.11. The reinforcement ability is examined from SFTT, and the highest value of tensile strength and modulus achieved is 126.62 MPa and 2.11 GPa in the case of Puchika grass CT-7 and CT-1 fibre, respectively. Chemical treatment obviously enhanced the tensile properties and is varied with respect to the treatment which is shown in Figs. 10.12 and 10.13.

The properties of the fibre had given enough confidence to reinforce into the polyester matrix, and thereby the prepared composites are subjected to various types of tests. Out of which the tensile test of the puchika grass CT-7 FRP composites according to ASTM D5083-02 has exhibited the highest tensile strength of 58.04 MPa and modulus of 1.31 GPa at maximum fibre volume fraction, i.e. 22.84 %. Influence of chemical treatment is visible as shown in Figs. 10.14 and

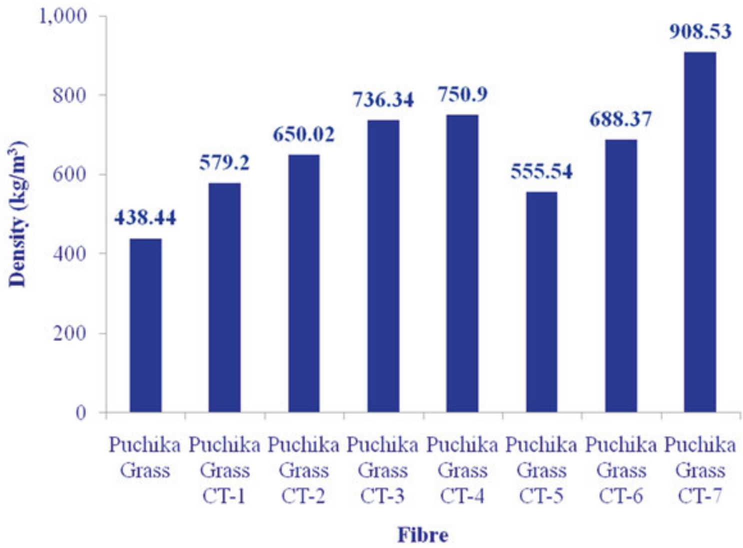



**Fig. 10.11** Density of puchika grass fibre

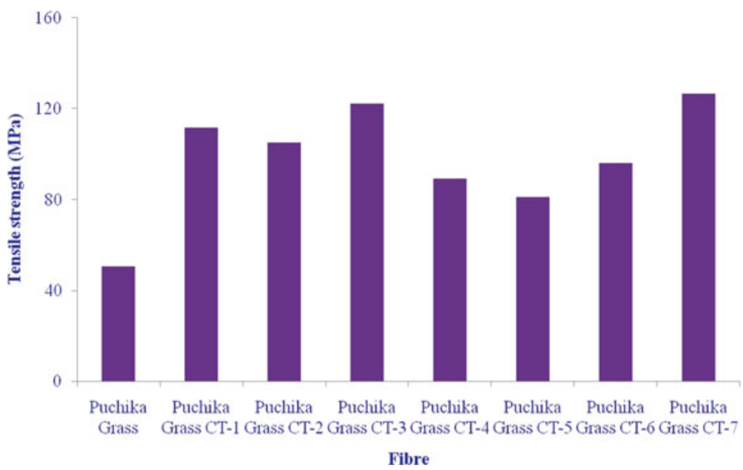



**Fig. 10.12** Tensile strength of SFTT puchika grass fibre

10.15, where the tensile strength of all the treated fibre composites is increased with increase in fibre content which has not happened in the case of the untreated fibre composites due to lack of bonding. Tensile modulus of puchika grass CT-2 and CT-7 FRP composites is increased with increase in fibre volume fraction, whereas the composites reinforced with other treated fibres like CT-1, CT-3, CT-4, CT-5 and CT-6 had shown variation due to more elongation exhibited by the composites than the load.

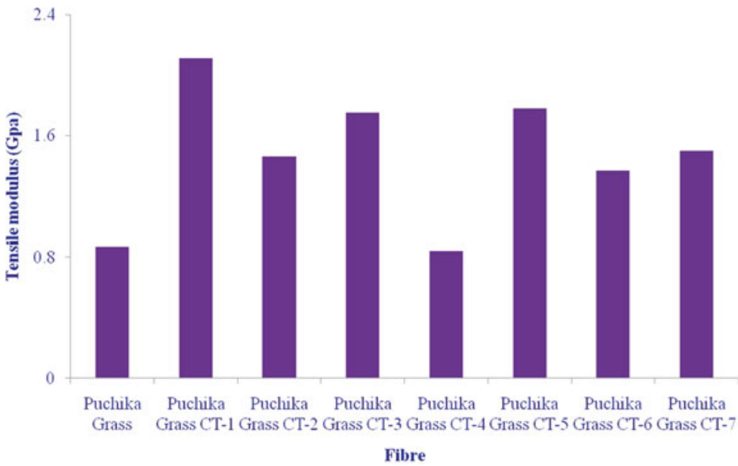



**Fig. 10.13** Tensile modulus of SFTT puchika grass fibre

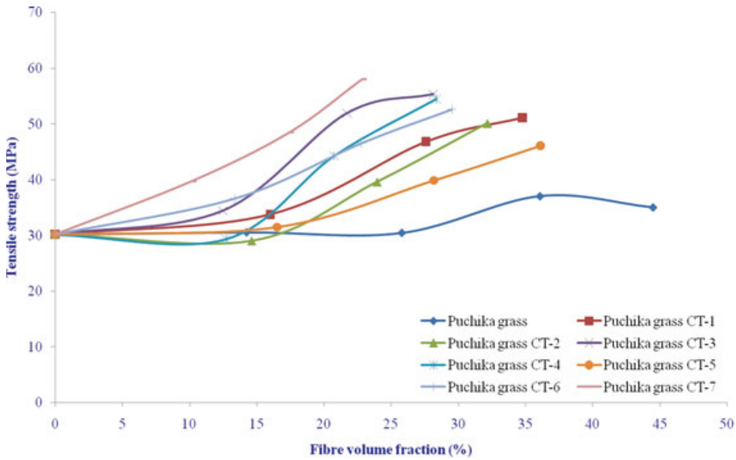



**Fig. 10.14** Tensile strength of puchika grass fibre reinforced polyester composites

The alkali-treated puchika grass at 0.275 M concentration and 28 h soaking time, i.e. CT-3 FRP composites at 21.69 % fibre volume fraction, resulted in the tensile modulus of 1.314 GPa. All the composites failed due to tensile load only and there is no pull-out of the fibre visualized.

The composites under the bending load are examined using a three-point bend test, and their flexural properties are determined as per the procedures of ASTM D790-07$\varepsilon^1$. Because of the non-stick nature between the fibre and matrix, it is not allowed to test the puchika grass fibre beyond 39.87 % fibre volume fraction.

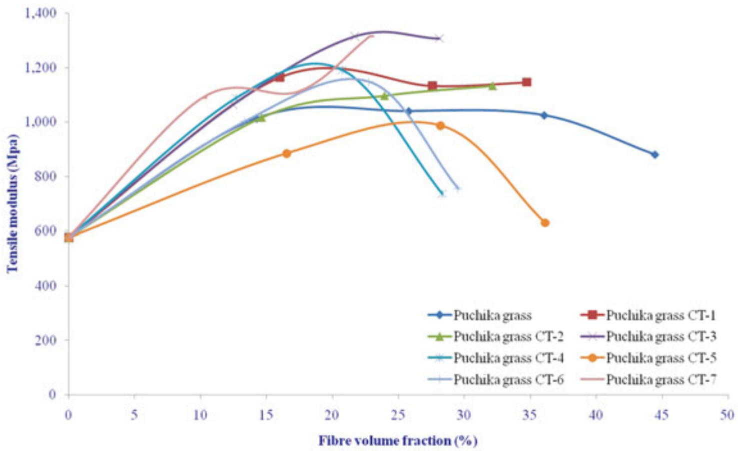



**Fig. 10.15** Tensile modulus of puchika grass fibre reinforced polyester composites

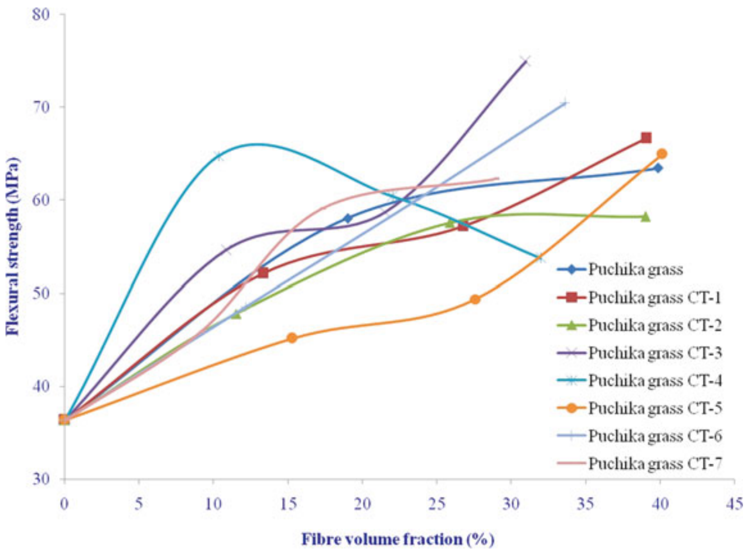



**Fig. 10.16** Flexural strength of puchika grass fibre reinforced polyester composites

Except CT-4 all the puchika grass FRP composites have showed increase in flexural strength with increase in fibre volume fraction. During the bend test it is interesting to note that all the chemically treated puchika grass FRP composites failed in its outer layer which is quite desirable. The flexural modulus of all the puchika grass FRP composites is increased with increase in fibre volume fraction. The graphs drawn between the flexural strength and modulus against fibre volume fraction are represented in Figs. 10.16 and 10.17, respectively.

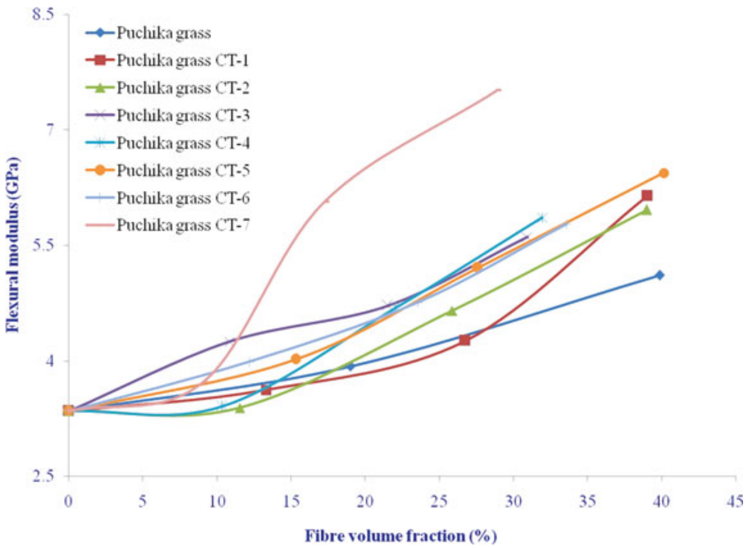



**Fig. 10.17** Flexural modulus of puchika grass fibre reinforced polyester composites

The relative susceptibility of the component to failure due to the stress applied at higher resistance is called impact resistance, whereas the ability of the material to withstand the application of a sudden load which results in fracture is defined as an impact strength of the material. Hence Charpy impact test is conducted as per the standards of ASTM D6110-08 on puchika grass FRP composites, and its impact resistance and strength are determined which are graphically shown in Figs. 10.18 and 10.19, respectively. The impact resistance and strength of the composite material range from 18.44 to 744.37 J/m and 1.66 to 65.01 kJ/$m^2$, respectively.

The maximum field that can be applied to an insulating material without causing dielectric breakdown is called dielectric strength. So the insulation property of the puchika grass FRP composites is determined, and its dielectric strength decreased with increase in fibre content. The maximum dielectric strength achieved at 12.67 % fibre volume fraction is 9.67 kV/mm and is shown in Fig. 10.20.

## 10.4 Conclusions and Applications

The puchika grass fibre is extracted successfully by pure splitting method and the wet lay-up technique adopted for neat manufacturing of the composites. The initial phase of success is visualized from the experimental results of the composites which are reinforced with alkali-treated puchika grass fibres. Thereafter alkali-pretreated

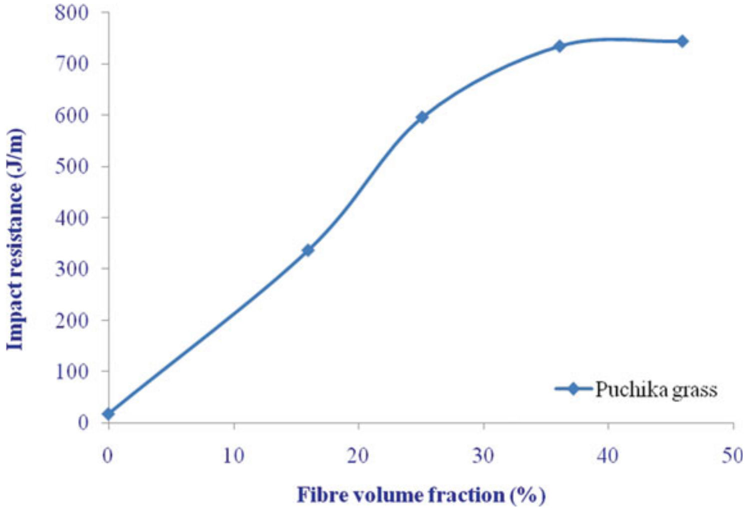



**Fig. 10.18** Impact resistance of puchika grass fibre reinforced polyester composites

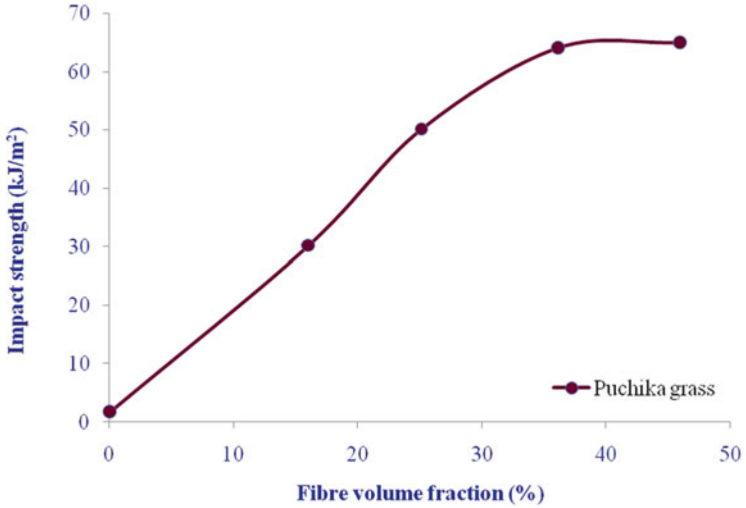



**Fig. 10.19** Impact strength of puchika grass fibre reinforced polyester composites

and permanganate-treated puchika grass, i.e. CT-7 FRP composites, resulted in the achievement of good tensile properties through good interface formation. This kind of grass is more suitable in making door panels and various automobile parts. Puchika grass fibre polyester composites may also find an application where it needs lightweight and reasonable dielectric strength.

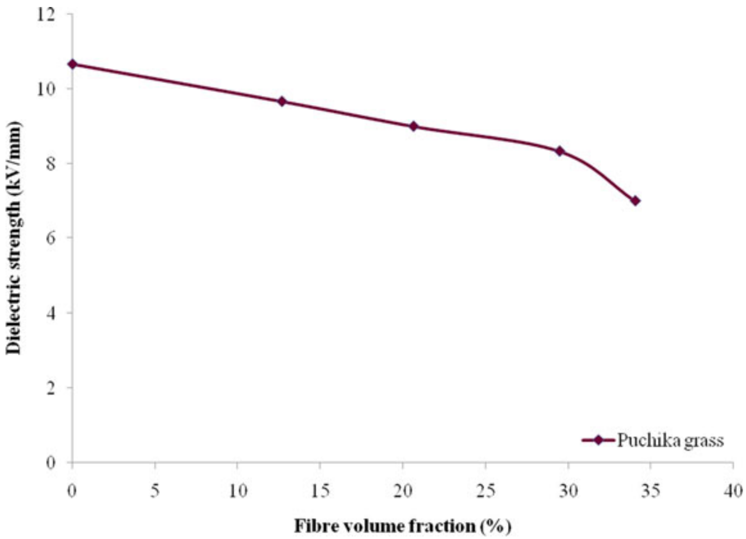



**Fig. 10.20** Dielectric strength of puchika grass fibre reinforced polyester composites

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