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Influence of Polyester Resin Treatment on Jute Fabrics for Geotextile Applications

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Abstract

In this study, jute woven fabrics (1 × 1 plain, twill, zigzag and diamond weave) were manufactured from 100% raw jute yarn. The fabric specimens were treated by 5%, 10%, 15%, 20% and 25% unsaturated polyester resin where styrene monomer used as a solvent and 1% methyl ethyl ketone peroxide (MEKP) was used as initiator. Two bar pressure was applied for complete wetting of the fabric by a Padder and curing was done at 130˚C for 10 minutes. The physico-mechanical characteristics of untreated and treated samples were examined and evaluated. It was revealed that moisture content (MC) and water absorbency of the treated specimens were decreased with the increase of resin percentage (%) in the fabrics. MC and water absorbency were maximum decreased up to 50.23% and 60.14% respectively by 25% resin treatment. On the other hand, bending length (BL), flexural rigidity (FR), flexural modulus (FM) and tensile strength (TS) were enhanced with the increase of resin percentage in the fabrics which resulted higher fabric stiffness. The maximum improvement of BL, FR, FM and TS were found to be 6.67%, 56.04%, 10.57% and 18.75% respectively in comparison to untreated sample. Soil degradation tests exhibited that 33.59% TS loss occurred for untreated specimens where only 8.04% loss of TS found for 25% resin treated one. Furthermore, jute based twill, zigzag and diamond fabrics were also treated by 10%, 15%, 20% and 25% resin, then measured their TS and compared with plain fabrics. It was revealed that plain fabrics have superior TS over other fabrics. It was also evident that TS enhanced for all the fabrics after resin treatment and maximum increase found for all the fabrics up to 25% resin treatment.

Keywords

Jute Fiber, Woven Fabrics, Polyester Resin, Tensile Strength, Geotextiles

1. Introduction

Natural fibers have gained tremendous attention all over the globe in the recent decades due to the environmental concern. Natural fibers have some unique advantageous properties like low density, better specific strength, high toughness, good thermal properties, biodegradability, low cost, availability and easy to process [1]. In comparison to all natural fiber, jute is abundant as well as high staple length fiber and has excellent characteristics for textile applications with high cellulose content. Jute is basically composed of α-cellulose, hemicelluloses, and lignin. There are also some ingredients like fats, waxes, inorganic and nitrogenous matters, and traces of pigments like β-carotene and xanthophyls [2] [3] [4]. Generally, jute fiber has versatile applications in our modern life. Jute geotextiles are going popular worldwide as technical applications. Geotextiles are permeable fabrics which have the capability to separate, filter, reinforce, or drain when used in association with soil [5]. The prime functions of jute geotextiles are separation, filtration and drainage, initial reinforcement, surface soil detachment control, improving vegetation growth or biotechnical support [6].

Usually, jute is a hydrophilic fiber *i.e.* strong affinity towards water and also biodegradable. Under moist condition or bacterial, mildew, fungal and insect attack, the degradation is accelerated. It can be basically swelled and degraded within six months in water and not so viable in acidic, alkaline and other chemical solutions. Quick biodegradability and high hydrophilic character of jute fiber are the main disadvantages for using as raw material for jute geotextiles. It can be possible to improve the biodegradation and hydrophobic character of jute fiber by various chemical treatments [7]-[14] without altering its environmental friendly nature. Chemical treatment such as NaOH [15] [16] [17] [18] [19] is a widely used method to eliminate noncellulosic materials from the natural fibers and the improvement of interfacial bonding [20] [21] [22] and mechanical characteristics of composite materials [23] [24] have been unlocked. Interfacial bonding also raised by anhydride modification [25], organosilane treatment [26] and different coupling agents [27] [28], where treatment experienced better result [29] [30]. The improvement of TS and TM of tossa jute yarn has been reported approximately 120% and 150% respectively for 25% (by weight) NaOH by Gassan & Bledzki [15]. Increased weather resistance and hydrophobicity has been found by treating various concentration of NaOH and acetylated with or without an acid catalyst to graft acetyl groups onto the cellulose structure [31]. The effects of de-waxing with hot benzene, bleaching with NaOCl and H_2O_2 and delignification by NaOH or KOH treatments on the reflectance, fluorescence and tensile properties were examined and bleaching with H_2O_2 gives better result [32]. Sodium hydroxide and carboxylated styrene-butadiene copolymer based polymer latex were used for jute fiber surface modification. Alkali and polymer modifications of jute fiber improved TS and elongation at break about 41% and 34% respectively. Water absorption of jute was reduced to 108% from 210% after alkali and polymer treatment [33]. After the experimentation of various parameters such as alkali concentration, time, temperature, sodium silicate concentration, fiber-to-liquor ratio, auxiliaries and degumming agent, the impurities were removed as well as cellulosic materials remarkably enhanced from 65.44% to 84.78% [34].

Unsaturated polyesters resins are very popular thermoset polymer which has diverse applications in the field of plastic materials. Polyester resin has many advantageous properties such as curing at room temperature, decent mechanical characteristics and clearness. Curing has been performed by polymerization reaction which imparts crosslinking among individual linear polymer chains and by-product is not produced in comparison to other thermosetting resins, as a result, it can be easily moulded, cast and laminated at low pressures and temperatures. The reinforcement of polyester resin with cellulosic fibers has been vastly experimented such as polyester-jute [35] [36] [37], polyester-sisal [38], polyester-coir [39] [40], polyester-banana [41], polyester-pineapple leaf [42], polyester-hemp [43] and polyester-cotton-kapok [44].

The present study deals with the treatment of jute fabrics with unsaturated polyester resin mixing with styrene monomer as a solvent. MEKP is used as an initiator. The major purpose of this work was to study the effect of polyester resin on the physico-mechanical properties of jute plain fabrics so that it can be used as geotextile. After that, to study the effect of fabric structures, a comparative study of TS and soil degradation test was studied with plain, twill, zigzag and diamond fabrics.

2. Materials and Methods

2.1. Materials

Jute yarn (6 lbs/spindle, 100% raw jute) was collected from Jute Diversified Promotion Center (JDPC), Dhaka, Bangladesh. Jute woven fabric (1 × 1 weave) such as plain, twill, diamond and zigzag was manufactured in the local loom, all weaves were produced by 12 ends per inch and 13 picks per inch. Unsaturated polyester resin, styrene monomer and methyl ethyl ketone peroxide (MEKP) were collected from Dhaka, Bangladesh, made in Polymer Company Limited, Singapore.

2.2. Methods

2.2.1. Polyester Resin Treatment on Jute Samples

The solution was prepared by 5%, 10%, 15%, 20% and 25% polyester resin and added styrene monomer as a solvent. 1% MEKP was added in the solution as initiator. Then Jute fabric was soaked in the solution and then the fabric was being padding at two bar pressure by a padder. After that, the samples were dried at 80˚C for 10 minutes by a mini-stenter and curing at 130˚C for 10 minutes.

2.2.2. Measurement of Moisture Content

The amount of moisture in a fibre sample can be expressed as either regain or moisture content. Regain is the weight of water in a material expressed as a percentage of the oven dry weight.

$$\text{Moisture Regain}\left(\text{MR}\right)=\frac{W}{D}\times 100\%$$

Moisture content is the weight of water expressed as a percentage of the total weight.

$$\text{Moisture Content}\left(\text{MC}\right)=\frac{W}{W+D}\times 100\%$$

where, W = Weight of water ($A - D$), A = Weight of the sample before, D = Weight of the sample after drying. Moisture regain and content based on the oven dry mass, which for most fibres is the constant mass obtained by drying at a temperature of 105˚C ± 2˚C. Constant mass is achieved by drying and weightting repeatedly until successive weighting differ by less than 0.05% [45].

2.2.3. Water Absorbency Test

Fabric samples (5 cm × 5 cm) were immersed in a static water bath at 25˚C for 10 minutes. Before immersion in water, the specimens were dried in an oven at 105˚C, cooled and weighed. After certain periods of time, samples were taken out from the bath and wiped using tissue paper, then weighed. The water absorption study of jute fibers was done in accordance with British standard 3449 [46]. The water absorption was calculated as

$\text{Water absorption}\left(\%\right)=\left[\left(w_2-w_1\right)/w_1\right]\times 100$.

2.2.4. Measurement of Flexural Properties

This test measures the bending stiffness of a fabric by allowing a strip of the fabric to bend to a fixed angle to its own weight. Stiffness was measured with the help of fabric bending length by Shirley Fabric Stiffness Tester. The dimension of the test specimens were 25 mm × 200 mm. The flexural rigidity (G) which is a measure of stiffness associated with handle of fabric was determined from the following relationship [47].

$$G=WC^3\times 10^3\ \text{mg/cm}$$

where, C = Bending length, W = Cloth weight in grams per square cm. The flexural modulus or bending modulus is determined by the following formula:

$$\text{Flexural or Bending modulus: } q=\left(12\times G\times 10^{-6}\right)/g^3\ \text{kg/cm}^2$$

where, q = Bending modulus, G = Flexural rigidity, g = fabric thickness (mm).

2.2.5. Measurement of Tensile Strength

TS of the test specimens were measured by Titan Universal Strength Tester. The specimen of TS was prepared according to grab test method [48]. The sample used was 4 inch (100 mm) wide by 6 inch (150 mm) long but the jaws which were used have one of their faces only 1 inch (25 mm) wide. This means that only the central 25 mm of the fabric was stressed. A line was drawn on the fabric sample 1.5 inch (37 mm) from the edge to assist in clamping it so that the same set of threads were clamped in both jaws. The gauge length used was 3 inch (75 mm) and the speed was adjusted so that the sample was broken in 20 ± 3 seconds. In this test there was a certain amount of assistance from yarns adjacent to the central stressed area so that the strength measured was higher than for a 25 mm raveled strip test.

2.2.6. Soil Degradation Tests

All the fabric specimens were buried in soil (having at least 25% moisture) for 6 weeks (42 days). After 6 weeks, specimens were withdrawn carefully, washed with distilled water and dried under sunlight and kept at room temperature for 24 hours and then measured the tensile strength [49].

3. Result and Discussion

3.1. Mechanical Properties

Figure 1 demonstrated that MC for 0% (untreated sample), 5%, 10%, 15%, 20% and 25% polyester resin treated jute fabrics was 13.20%, 12.60%, 10.73%, 10.22%, 8.95% and 6.57% respectively. MC reduced up to 50.23% for 25% resin treated specimen as compared to untreated one. It was revealed that MC decreased for jute fabrics with increased in polyester resin content.

Figure 2 showed that water absorbency for 0%, 5%, 10%, 15%, 20% and 25% polyester resin treated jute fabrics were found to be 414%, 345%, 301%, 251%,

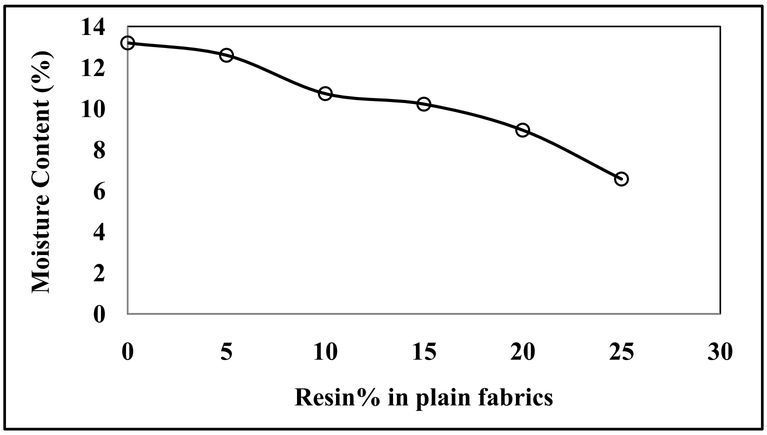

Figure 1. Moisture content (%) of polyester resin treated jute plain fabrics.

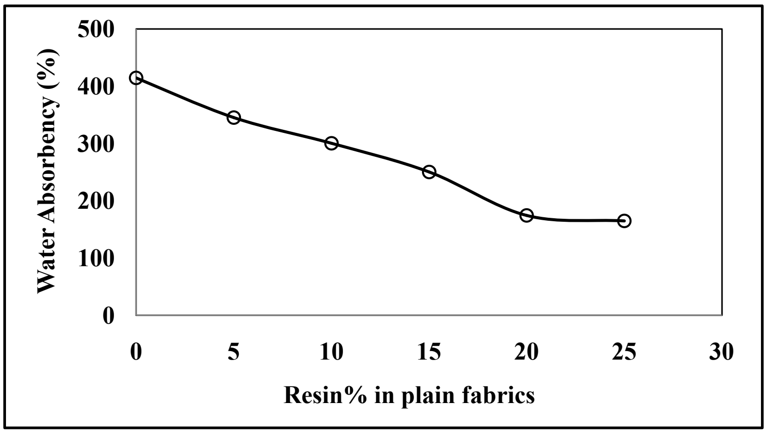

Figure 2. Water absorbency (%) of polyester resin treated jute plain fabrics.

174% and 165% respectively. It was revealed that water absorbency decreased with the increase of resin% in the fabrics and maximum decreased of water absorbency found to be 60.14% for 25% resin treated specimen as compared to untreated one. Jute fiber is hydrophilic in nature due to the presence of polar −OH group in its structure. The polar group formed hydrogen bond by absorbing water molecules and this induces swelling in fibers. It was clear that treated specimen retained much of its hydrophobic nature than that of the untreated specimen in case of MC and water absorbency. Polyester is a hydrophobic resin which crosslinked with jute and created strong bonding with cellulose polymer chains and it imparted a coating on the fabric surface which leads to the hydrophobicity nature. Another reason for attenuated water absorbency by the treated specimen may be a polymer filling up the void space of the fiber. Besides, better fiber-resin adhesion might be responsible for the lower tendency of water absorption as compared to untreated one.

Figure 3 exhibited that the bending length (BL) of 0%, 5%, 10%, 15%, 20% and 25% polyester resin treated samples were found to be 5.25, 5.31, 5.39, 5.47, 5.53 and 5.60 cm respectively. Flexural rigidity (FR) and flexural modulus (FM) of the fabric found to be 77.05, 88.19, 99.56, 105.37, 112.21 and 120.23 mN-cm and 19.39, 20.99, 20.82, 20.70, 21.34 and 21.44 kg/cm^2 for 0%, 5%, 10%, 15%, 20% and 25% polyester resin treatment as shown in Figure 4 and Figure 5 respectively. Fabric BL, FR and FM gradually increased for 5% to 25% resin treated specimens. The highest improvement of BL, FR and FM were 6.67%, 56.04% and 10.57% respectively for 25% resin treated samples as compared to untreated one. The above observation showed that the unsaturated polyester resin affects the fabric stiffness mostly. BL increased means increases FR and FM of fabrics. The fabric appeared to increase FR or stiffness which indicated that the specimens became more hard, stiff and less flexible after polyester resin treatment. This was due to the surface coating of polyester resin around the jute fiber as well as crosslinking occurred between the fiber and resin. The mechanical properties which obtained can be suitable for polyester resin treated jute fabrics as geotextile applications.

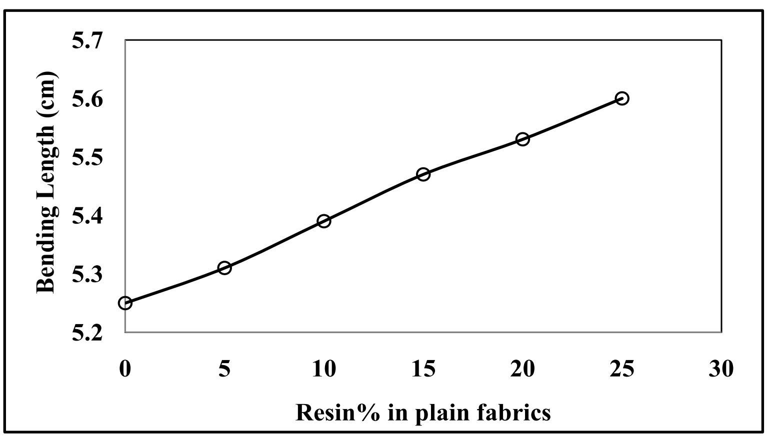

Figure 3. Bending length of polyester resin treated jute plain fabrics.

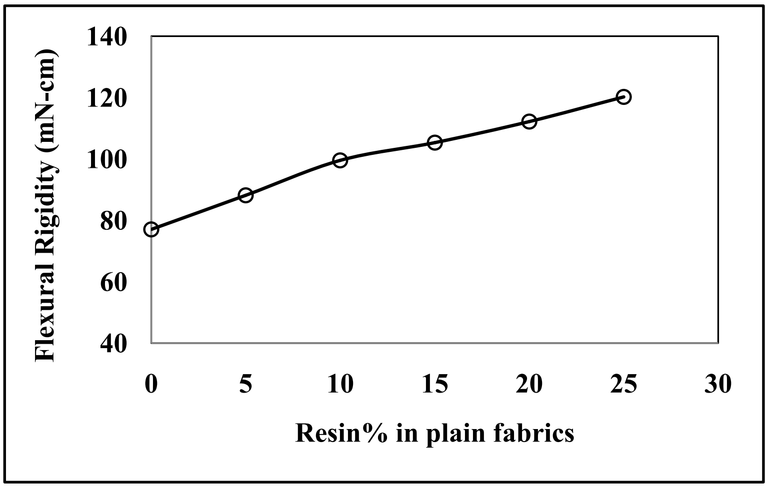

Figure 4. Flexural rigidity of polyester resin treated jute plain fabrics.

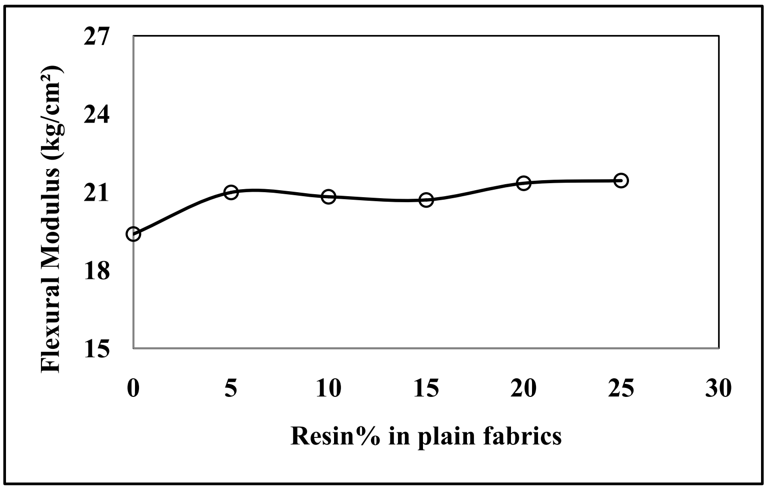

Figure 5. Flexural modulus of polyester resin treated jute plain fabrics.

3.2. Soil Degradation

From Figure 6, it was found that before buried in soil, the tensile strength (TS) of the test specimens were 1488.51, 1540.30, 1551.46, 1621.88, 1736.29 and 1767.66 N for 0%, 5%, 10%, 15%, 20% and 25% resin treatment respectively. TS increased from 3.48% to 18.75% when treated with 5% to 25% polyester resin respectively. Thus, resin treated specimens demonstrated an increasing trend of TS and maximum increased of TS found to be 18.75% for 25% resin treatment. A successful incorporation of jute fiber and polyester resin can be achieved by full and strong interfacial contact resulting from wetting and adhesion between jute fibers and resin. Nevertheless, these factors are practically physical and these contacts between fiber surface and resin can be basically obtained by the adequate adjustment of resin-to-jute ratios, calendaring, roller pressure, minimizing the voids and micro air pockets which yielding enhanced mechanical properties. In low resin% the TS is low, this is due to partial wetting of jute fibers where higher fiber ratio in the solution. During curing process, employing pressure or

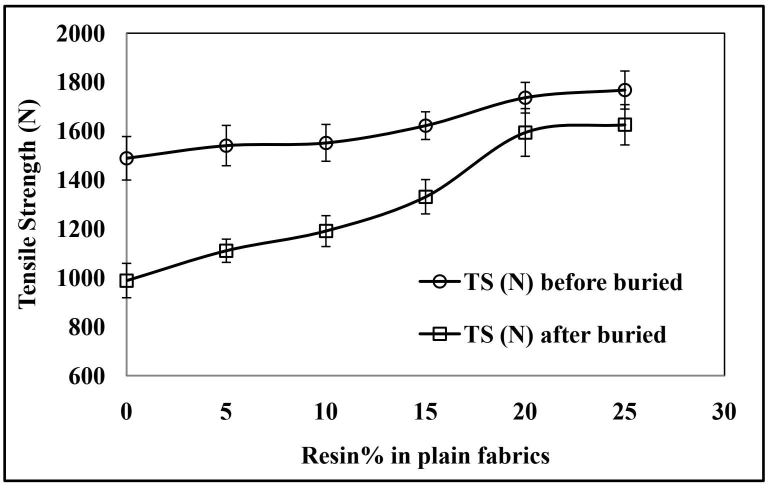

Figure 6. Tensile strength of polyester resin treated jute plain fabrics before and after buried into soil.

load improves the wetting and enhances the bonding between fiber and resin. If calendaring or load is not used, the hairy surfaces of the fiber hampered the reinforcement possibility by withstanding the contacts and leaving micro voids which resulting poor mechanical properties. The calendaring operation of jute fabric facilitates the orientation of fibers which imparted more effective packing with few micro voids that can lead to water absorption in the fiber-resin matrix interface. Albeit, intensive calendaring may cause the damage and breakage of jute fiber.

After buried in soil for 6 weeks of the test specimens, the TS were 988.56, 1110.50, 1191.02, 1331.26, 1594.16 and 1625.61 N for 0%, 5%, 10%, 15%, 20% and 25% resin treatment respectively as shown in Figure 6. Maximum loss of TS was observed 33.59% for untreated specimen and minimum loss of TS observed 8.04% for 25% resin treated specimen. It was revealed that increasing resin% reduces the possibility of strength loss of the jute fabrics during soil degradation. Jute is cellulose based natural biodegradable fiber which can be able to absorb water within a couple of minutes, indicating its strong hydrophilic properties. Cellulose has a strong tendency to degrade when buried in soil. When buried, microbial degradation takes place and water may enter into the jute fiber, thus degrade the fiber slowly and, therefore, the mechanical features of jute fabrics reduced greatly. However, 25% resin treated specimen was highly hydrophobic and repelled water, hence keeping much of its integrity during soil degradation which extended the durability of geotextiles.

3.3. Effect of Fabric Structures

3.3.1. Tensile Strength

From Figure 7, it was observed that TS for untreated (0% resin) plain, twill, zigzag and diamond fabrics were 1488.51, 1386.68, 1062.99 and 1380.96 N respectively. It was revealed that plain fabric have superior TS over other fabrics and it were 7.34%, 40.03% and 7.79% higher TS than twill, zigzag and diamond

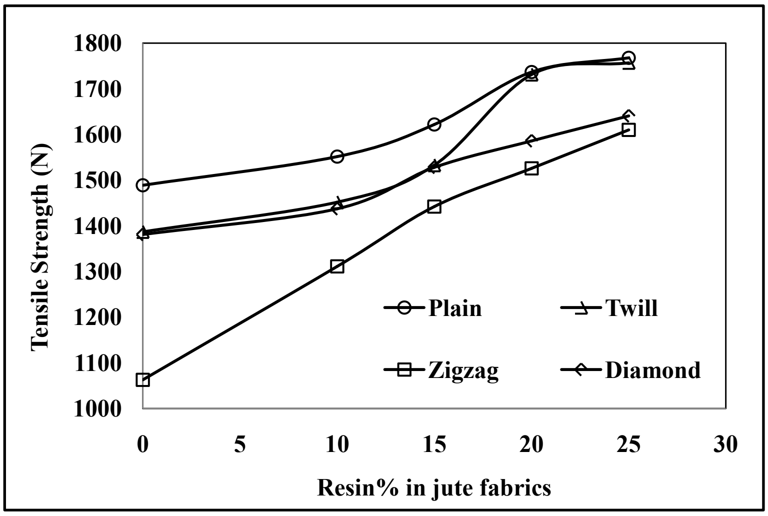

Figure 7. Effect of polyester resin treatment on the tensile strength of plain, twill, zigzag and diamond structure of jute fabrics.

fabrics respectively. Plain fabrics had uniform arrangement of warp and weft yarns and maximum interlacement points in it as a result exhibited better load bearing and stress transfer capacity than other fabrics. It was also found that after treating with 10%, 15%, 20% and 25% polyester resin, the TS of plain fabrics increased 4.23%, 8.96%, 16.67% and 18.75% respectively, and TS of twill fabrics increased 4.71%, 10.55%, 24.84% and 26.69% respectively. On the other hand, 10%, 15%, 20% and 25% resin treatment resulted in the increase of TS for zigzag fabrics were 23.33%, 35.69%, 43.56% and 51.48% respectively, and for diamond fabrics 4.08%, 10.65%, 14.84% and 18.78% respectively. The maximum increase found for all the fabrics up to 25% resin treatment which were 18.75%, 26.69%, 51.48% and 18.78% for plain, twill, zigzag and diamond fabrics respectively. So it was revealed that all the fabrics experienced improvement of its TS after the resin treatment. Hence, treated resin specimens demonstrated increasing trends of TS and maximum increased of TS found to be 51.48% for 25% resin treatment of zigzag fabrics as shown in **Figure 7**.

3.3.2. Soil Degradation

From **Figure 8**, it was observed that after buried in soil for 6 weeks of the test specimens, TS for untreated (0% resin) plain, twill, zigzag and diamond fabrics were 988.56, 870.20, 735.32 and 798.02 N respectively. The loss of TS were found to be 50.57%, 59.35%, 44.56% and 73.05% for plain, twill, zigzag and diamond fabrics respectively due to soil degradation of 6 weeks. It was revealed that diamond fabrics experienced maximum loss of its TS than other fabrics. The treated specimens demonstrated less degradation and retained its TS as shown in **Figure 8**. It was found that 10%, 15%, 20% and 25% resin treated samples showed 30.26%, 21.83%, 8.94% and 8.76% TS loss that of the untreated one for plain fabrics. Similarly, it was found to be 24.34%, 18.64%, 18.73% and 15.56% respectively for twill fabrics, 30.85%, 25.34%, 25.06% and 23.64% respectively for

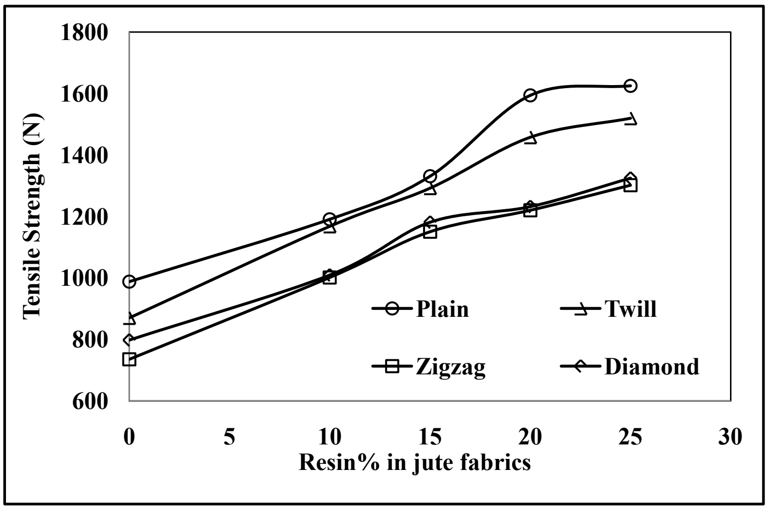

Figure 8. Effect of soil degradation on the tensile strength of polyester resin treated plain, twill, zigzag and diamond structure of jute fabrics.

zigzag fabrics, and 42.38%, 29.35%, 28.69% and 23.78% respectively for diamond fabrics. The maximum loss of TS found for untreated specimens and minimum loss of TS found for 25% resin treated specimens for all type of fabrics. In comparison to all the fabrics, plain fabrics showed the minimum loss of TS.

4. Conclusion

The usage of jute products is rapidly declining due to the availability of various synthetic materials which are harmful for our environment. Jute has some limitations such as extremely hydrophilic and easily biodegradable in nature. To avoid such drawbacks polyester resin treatment can be an excellent way to improve its physico-mechanical properties. Geotextile is related to soil which contains different types of fungi and other deteriorating organisms. As a result, untreated jute fabrics quickly destroyed and degraded into soil. Thus, the main purpose of using jute as a geotextile is not fulfilled. On the other hand, polyester resin treated jute fabric gives excellent performance against soil contact. In this experiment, tensile properties improved after resin treatment, and in six weeks soil degradation test, 25% resin treated samples showed approximately four times lesser degradation than that of untreated one. After the analysis of various fabric structures, it has been revealed that plain fabrics demonstrated the better tensile strength than other fabric structures. The use of these treated fabrics would ensure a better future of jute in geotextile as technical applications.

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