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Effect of Soil Burial on Durability of Alkali Activated Binder Treated Jute Geotextile

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Abstract. Jute geotextile is a widely used natural geotextile for reinforcing soil. However, jute fibers have the tendency to biodegrade when exposed to natural conditions. Treatment of jute with antimicrobial chemicals to improve its durability may lead to leaching. The present paper focuses on developing an economic and environment friendly alkali activated binder (AAB) treatment for improving the strength and durability characteristics of jute geotextile. AAB is produced by reacting an aluminosilicate precursor (fly ash/ slag) and an alkaline activator solution consisting of sodium silicate and sodium hydroxide. The water-to-solids (w/s) ratio is varied from 0.35 to 0.45 in this study. Laboratory scale soil burial test is carried out to examine the biodegradability of AAB treated jute at time intervals of 1, 3 and 6 months. Untreated and treated jute specimens are buried in soil at a depth of 10 cm from the surface and thus subjected to the action of microorganisms normally present in the soil. A series of microstructural (stereomicroscopy, Fourier-transform infrared (FTIR) spectroscopy and scanning electron microscope (SEM)) and mechanical (mass density, aperture opening size, tensile strength) characterization tests are conducted for both untreated and treated jute after soil burial tests at different periods. The microstructural studies indicate that the lignocellulose present in jute is not altered significantly by AAB treatment. The tensile strength of AAB treated jute shows a significant improvement compared to untreated jute, the highest strength being that of 0.40 w/s ratio. However, the tensile strength decreases with the progress of soil burial period. Thus, the technique proposed in this study has the potential for implementation in practical applications.

Keywords: Jute Geotextile, Alkali Activated Binder, Soil Burial Test, Durability, Tensile Strength.

1 Introduction

Since the genesis of civilization, ground improvement is found to be a major problem that has been troubling mankind. The consumption of geosynthetics has been increased from 10 million sq. meters to more than 2000 million sq. meters during the past three decades. Naturally available geotextiles are comparable to synthetic geotextiles in terms of mechanical performance [1-3]. Similar ranges of tensile strength and Young's modulus can be found in both natural fibers and synthetic fibers [4]. However, in the present scenario, only 5-6% of total geotextile consumption is contributed from natural geotextiles like jute, coir, hemp etc. [5]. This limited usage of natural geotextiles can be attributed to irregular properties among same type of geotextiles, and low resistance to biological, physical and weathering degradation. Past research resources report performance of coir, banana, jute, hemp, flax etc. for improving strength of soft soil. However, biodegradability of the jute geotextile within a span of 1 year causes problem [5-8]. Hence, improving the serviceability of natural fibers and resistance to degradation of fiber by chemical treatment has grasped the attention of researchers. Several methods are available to improve the tensile strength of natural fibers are alkali treatment, bleaching and acetylating [9]. Reduction in the hemicellulose and lignin content of jute was observed when it is chemically treated with sodium hydroxide and hydrogen peroxide, which enhanced moisture absorption capacity and breaking tenacity [10, 11]. Plant oils along with sodium hydroxide and formaldehyde improved the resistance to biodegradation of natural fibers. Transesterification reaction replaced the hydroxyl group by oleic and stearic acid after the treatment [12]. Treating jute with 0.5% isothiazolinone and 1.0% fluorocarbon lead to higher water repellency and rot resistance [13]. The uniaxial tensile strength of jute increased by 65% because of alkali steam treatment containing NaOH solution, which also led to removal of cellulosic matters like lignin, pectin and hemi cellulose [11]. Bitumen coating reduced biological degradation of jute geotextile. Bitumen treated jute was found to possess significant tensile strength even after a span of 1.5 years which was used for river-bank protection [14]. Leaching occurred because of bitumen coating on jute geotextile [15]. Chemicals like N-vinyl pyrrolidone and ethyl hexyl acrylate in presence of plasticizers increased the tensile strength of jute upto 80% along with improvement in durability [16].

Geosynthetics are exposed to atmosphere and microbial attacks which leads to decrease in its tensile strength [17, 18]. Natural fibers are limitedly used in the market because of its low durability nature than the artificial fibers. Different methods like accelerated weathering tests, soil burial test, resistance to acid and alkalis and hydrolysis of water, microbial attacks are used to assess the biodegradability of natural fibers [19]. By observing the behavior of fibers upto 1-2 years their long-term performance can be evaluated when they are exposed to different environmental conditions [20]. It is observed that jute exposed to natural weathering for 2 years showed polymer cracking, black spots, bulging, twitching of fibers, leading to reduction in tensile strength [21]. Bamboo reinforced epoxy hybrid composites degraded more when subjected to soil burial test compared to accelerated weathering [22]. Coir fibers coated with cashew nut shell liquid (CNSL) showed an increase in tensile strength by 22%.

The degradation rate is more for unmodified coir fibers. 76% of tensile strength is retained for modified coir fibers which decreased by 19% for unmodified coir fibers at the end of 240 days [23]. 65% loss in tensile strength in water and 75% in soil was observed for untreated jute, while 5-15% loss was observed for treated jute [16]. Exposing jute–polyester amide composite specimens to weathering for a period of 21 days led to a loss of 30% of its original weight [24]. Treating jute jute geotextile with bitumen emulsion and polyster resin solution increased its tensile strength considerably. Different environmental conditions lead to higher rate of biodegradability of coir geotextiles [25].

Past research works indicate that the existing treatment methods are quite expensive and involve complex work procedure. A new treatment method with alkali activated binder (AAB) is considered in the present study for improving the strength and durability properties of jute. AAB can be prepared by mixing an aluminosilicate precursor of Class F flyash and an alkali activator solution consisting of a mixture of sodium silicate and sodium hydroxide. Different water to solid ratios (w/s) varied in AAB are 0.35, 0.40 and 0.45 and the optimum mix is obtained. A series of microstructural and material characterization tests are carried out on untreated and AAB treated jute. Soil burial tests are also conducted to assess the durability of untreated and treated jute after exposure to environment for 1, 3 and 6 months.

2 Materials

2.1 Alkali activated binder (AAB)

Chemical reaction between aluminosilicate precursor containing Class F fly ash and an alkali activator solution of sodium silicate and sodium hydroxide can produce Alkali Activated Binder (AAB). The main components of sodium silicate solution are 55.9% water, 29.4% silica, 14.7% sodium oxide and 99% of pure sodium hydroxide pellets. The ratio of fly ash, sodium hydroxide and sodium silicate used in AAB solution is 74.07:1.96:2.97 by mass [26]. The chemicals used in the experimental study are supplied from Hychem Chemicals Ltd., Hyderabad. Class F fly ash is obtained from National Thermal Power Corporation, Ramagundam. The water to solids (w/s) ratios used to prepare AAB solution as additional water content are considered as 0.35, 0.40 and 0.45. The activator mix is blended thorughly to obtain a clear solution. The activator solution is kept for rest for 24 hours at 40°C in a humidity-controlled chamber before mixing with fly ash, as the reaction between sodium hydroxide and sodium silicate generates lot of heat. The entire surface area of jute sheet is uniformly coated with a brush by maintaining suitable consistency of AAB. Table 1 shows the quantities of raw materials required for treating 1m^2 of jute geotextile.

Table 1. Amount of raw materials for treating 1m^2 of Raw Jute.

Water to Solid ratio	AAB paste (kg/m^2)	Class F Fly Ash (kg/m^2)	Sodium Hydroxide (kg/m^2)	Sodium Silicate (kg/m^2)	Water (kg/m^2)
0.35	3.45	2.20	0.060	0.71	0.50
0.40	3.10	1.90	0.050	0.61	0.54
0.45	2.75	1.70	0.045	0.53	0.56

2.2 Jute

A roll of 0.91m wide and 30m long woven type jute obtained from Secunderabad in India is used for the experimental study. The basic properties of raw jute are provided in Table 2. Fig 1 shows the images of untreated and jute treated with AAB containing 0.40 w/s ratio.

Table 2. Basic properties of Untreated Jute.

Parameters	Values
Aperture opening size (μm^2)	4.7x10^7
Thickness (μm)	0.64
Mass per unit area (gm/cm^2)	0.0225
Cellulose (%)	58
Hemicellulose (%)	22
Lignin (%)	14
Elongation at Break (%)	66.38
Tensile Strength (MPa)	10.44
Young's Modulus (GPa)	22.8

Fig. 1. Images of (a) untreated jute and (b) jute treated with AAB containing 0.40 w/s ratio.

3 Experimental Methodology and Results

3.1 Microstructural characterization

Stereomicroscopy. Olympus SXZ7 setup is used to conduct stereo microscopy to identify the surface texture and physical features of the outer surface of untreated and treated jute sheets. Images are captured at different magnifications having least dimension of 20 µm. Stereomicroscopic images of untreated and treated jute sheets are shown in Figs. 2(a-d). The formation of voids due to evaporation of water from hardened AAB paste can be observed through black colored patches in Figs.7(b-d).

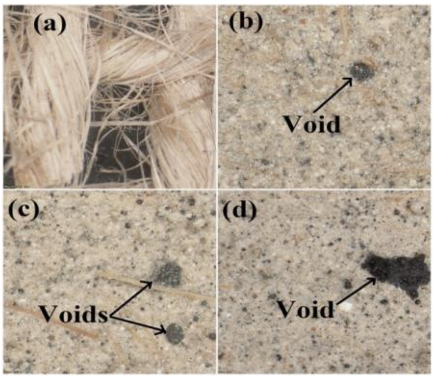

Fig. 2. Stereo microscopic images a) Untreated Jute b) 0.35 AAB jute c) 0.40 AAB jute d) 0.45 AAB jute.

Fourier-transform infrared spectroscopy (FTIR). JASCO FTIR 4200 set-up is used to carry out FTIR to find out changes in the chemical bonds of untreated and treated jute fibers. A transmittance spectral range of 4000 to 400 cm^{-1} is maintained to perform the test on powdered sample. The powdered samples are kept for removal of excess moisture for 24 hours at 105 °C. KBr powder is used in order to prepare the pellets. Fig. 3 explains the bonds present in untreated and AAB treated jute. Transmittance peaks of 3427cm^{-1}, 3476 cm^{-1}, 3465 cm-1, and 3474 cm-1 are observed for untreated, 0.35 w/s AAB, 0.40 w/s AAB and 0.45 w/s AAB treated jute, respectively. These represent the O-H stretching absorption. The transmittance peaks of 1700 cm^{-1} and 1644 cm^{-1} correspond to the acetyl groups and the C=O bonds represents hemicellulose [27]. The disappearance of the transmittance peaks from 2820 cm^{-1} to 1784 cm^{-1} and 1490 cm^{-1} to 1214 cm^{-1} indicates that the cellulose and the hemicellulose are removed after treatment with AAB solution.

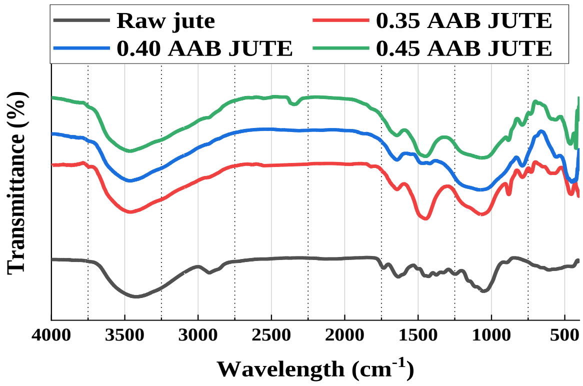

Fig. 3. FTIR Values for treated and untreated jute.

Scanning Electron Microscope (SEM). Scanning Electron Microscope (SEM) is conducted to identify the changes in surface morphology and elemental composition for untreated and treated jute sheets using thermal Field Emission Scanning Electron Microscope (FE-SEMJSM-7600F), supplied by JEOL Ltd. The excitation voltage for AAB is 5kV–15 kV [28]. In the experimental study an average of 10kV is maintained as the excitation voltage. Jute fibers are dried enough to remove excess moisture by keeping them 105°C for 24 hours. SEM images of untreated jute, 0.35 w/s, 0.40 w/s and 0.45 w/s ratio AAB treated jute for X1200, X2000 and X5000 magnification shown in Figs. 4(a-d). Impurities like hemicellulose, lignin, pectin are observed from the SEM images [10]. Formation of spherical shape morphology particles of different sizes unreacted fly ash particles can also be observed after application of AAB (Fig. 4c). Fig. 4d explains that as the w/s ratio increases, a reduction in formation of unreacted fly ash particles occur [29].

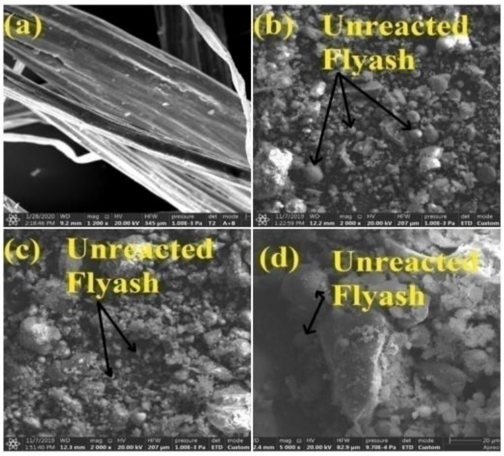

Fig. 4. SEM images of a) untreated jute b) 0.35 AAB Jute c) 0.40 AAB Jute d) 0.45 AAB jute.

3.2 Soil burial test

Soil burial test is used to assess the biodegradation of untreated and treated jute samples. 25cm x 5cm sized specimens are used for this experiment. Naturally available red soil from Medchal district of Telangana is placed in containers of 1 m x 1 m x 0.25 m size. Tiny holes are made for circulation of air and water purpose. Soil is kept at temperature of 27°C and a relative humidity of 75%. At depth of 10cm from surface the specimens are buried in the soil. The specimens are subjected to attack of microorganisms which generally present in soil. At a duration of 30, 90 and 180 days buried sample are taken out clean thoroughly and air dried to achieve constant weight. Using the following equation biodegradability is assessed by comparing weight loss before and after soil burial.

$$\text{Weight Loss } (\%) = \frac{W1 - W2}{W1} \times 100$$

where W1 and W2 are the weights of the jute samples before and after soil burial respectively.

Fig. 5 explains the percentage of weight loss of untreated and treated jute for different duration of exposure. The initial mass per unit area of untreated jute is 0.0225 gm/cm^2, which increased to 0.2697gm/cm^2, 0.22 gm/cm^2 and 0.2217 gm/cm^2 respectively after treatment for 0.35, 0.40 and 0.45 w/s AAB. From the graph, it is observed that treated jute losses less than 1% of weight with least in 0.35 AAB, while untreated losses more than 6.5% of its original weight. The untreated and treated jute sheets after 1, 3 and 6 months of exposure can be seen from Fig. 6. Complete degradation can be seen in untreated jute after 6 months, while treated jute retains its shape.

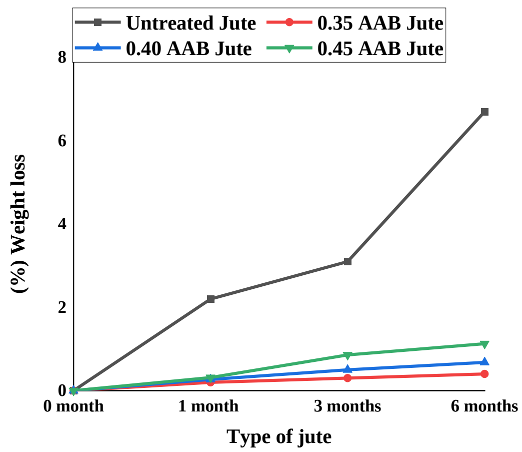

Fig. 5. % weight loss at different time periods for untreated and treated jute.

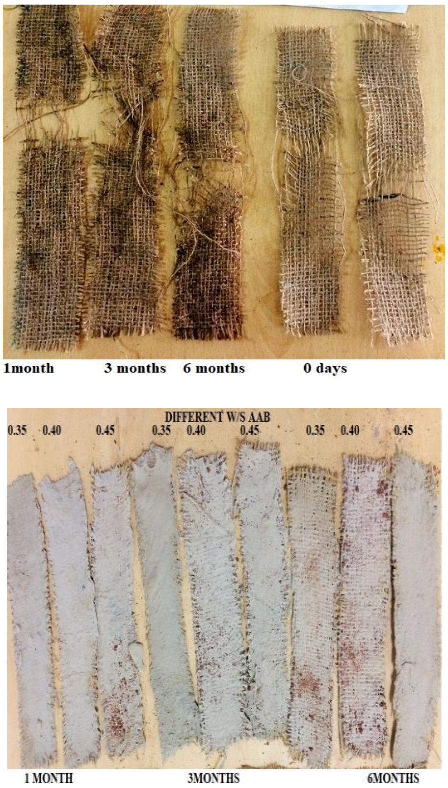

Fig. 6. Soil burial images of untreated and treated jute after 1, 3 and 6 months.

3.3 Mechanical Characterization

Tensile strength test. At duration of 30, 90 and 180 days of soil burial test, the tensile strength test of treated and untreated jute samples are conducted using UTM following ASTM D 5035 (Grab test). Samples of width 50mm, gauge 200mm and grab length 25 mm are used for testing purpose. In order to avoid slippage at jaws, the samples are thoroughly cleaned at top and bottom. A constant strain rate of 100 mm/min is used according to ISO 13934-1:1999. The average tensile strength of ten samples is reported for each sample.

Change is tensile strength of jute sheets for different durations are shown in Fig 7. From Fig 7, it is observed that for 0.35 AAB % decrement in tensile strength at 1 month, 3 and 6 months is observed to be low when compared with all other jute samples. It is also observed that the tensile strengths for 0.35, 0.40 and 0.45 AAB treated jute sheets are 59.73% ,57.78% and 41.32% more at 1 month, and 51.8%, 47.3% and 13.47 % more at 3 months when compared to untreated jute sheets at zero burial period. Hence it may be concluded that the treated samples retain their tensile strength for longer periods even after exposure to environment.

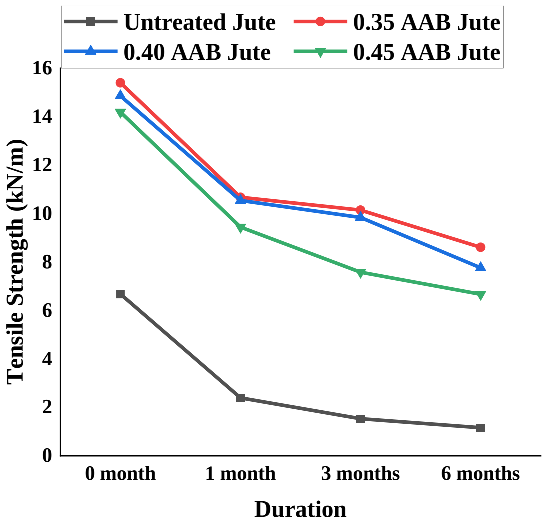

Fig. 7. Tensile strength of untreated and treated jutes after 1,3 and 6 months.

Elongation at Break. Increment in the length of specimen after application of load is termed as elongation at breakage point (Fig. 8). It is observed that the elongation at break is more for treated jute when compared to untreated jute. It decreases as w/s ratio increases.

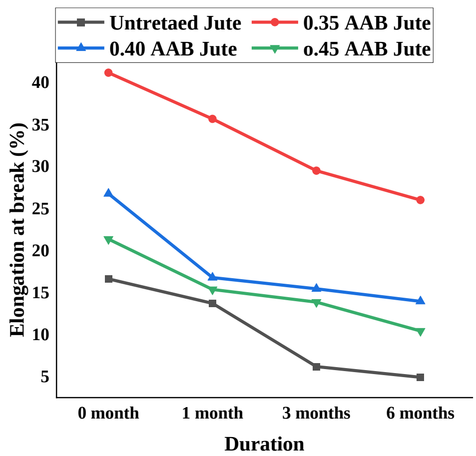

Fig. 8. Elongation at breakage point for untreated and treated jutes after 1,3 and 6 months.

4 Conclusions

This experimental study proposes a novel method of using alkali activated binder treatment to improve strength and durability properties of jute for ground improvement purpose. The following conclusions can be summarized from the present study:

1. The microstructural studies show that the chemical bonds present in raw jute are not altered by AAB treatment.
2. From SEM images it can be concluded that as w/s ratio increases, the reaction between fly ash and the alkali-activating solution also increases, thus leading to increment of sodium aluminosilicate hydrate matrix.
3. After 6 months exposure to soil burial, the untreated jute degraded completely, while treated jute is maintaining significant fraction of its original shape. Less than 1% of weight loss is observed in treated jute, while weight loss of 6.5% observed in untreated jute.
4. It is also observed that jute treated with AAB containing 0.35 w/s ratio gains highest tensile strength; however it may be noted that the workability of this ratio is much less compared to other w/s content and it tends to hardens fast. Also, voids increase on drying of jute treated with AAB containing 0.45 w/s ratio. Hence it is proposed to use an optimum w/s content of 0.40 to obtain an economic and sustainable solution. However, the tensile strength decreases with the progress of soil burial period.

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