Effect of Surface Modification on the Performance of Natural Fibres – A Review

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Abstract. Ecological sustainability and environment has become one of the primary issues in the modern developmental strategy. The presence of non biodegradable residues of geotextiles as a pollutant has been recognised in the past few years. Geotextiles made of natural fibres has emerged as a strong alternative to synthetic geotextiles but with poor resistance against biodegradation. Due to the fast rate of degradation of natural geotextiles their application is limited to short term projects. Hence there is a need of converting natural geotextiles into durable material without changing its environment friendly properties. Natural fibres are easily susceptible to biodegradation due to its texture and it can be prevented by surface modification. Surface modification which can be done by several methods like alkali treatment, enzyme treatment, transesterification with vegetable oils, surface coating and chemical treatment. Alkalization on natural fibres resulted in the removal of surface impurities and thereby improved the fibre matrix adhesion, mechanical interlocking and bonding reaction with chemicals. Chemical treatments improve the strength of fibre, fibre rigidity and fibre matrix adhesion. The surface treatment of natural fibre does not adversely affect the flexibility, tensile strength and filtration characteristics of the fabrics. The surface modification improves the hydrophobicity and mechanical properties of fibres. The surface modification on natural geotextiles improves the performance of geotextile under adverse chemical, physical, and biological condition. This paper presents a review of the research works conducted on the durability enhancement of natural fibres by surface modification.

Keywords: natural fibre; surface modification; alkali treatment; chemical treatment; tensile strength

1 Introduction

Ecological sustainability and environmental protection are the biggest concerns of current development. Current developments focus on the utilization of natural geotextiles over their synthetic counterpart because of their environmental friendly and biodegradable nature (Chattopadhyay et al., 2010; Maity, 2016; Desai et al., 2016). Natural geotextiles produced from natural fibres like coir, jute, sisal, hemp etc. are non toxic materials with low cost and renewability (Baltazar et al., 2007; Carvalho et al., 2015). They are energy efficient and hence have less carbon foot print and are also easy to process. They help in the reduction of CO_2 emission and consumption of fuel. There are different sources such as plants, animals and minerals from which natural fibres can be extracted. Fibres originates from plants include coir, cotton, kapok, sisal, flax jute, kenaf and hemp. Wool and silk are natural fibres from animal sources. Natural fibres possess unique properties because of their growth in natural environment with the assistance of air, soil, sunlight and water. Mechanical and thermal properties of fibres vary with their geographical locations (Komuraiah et al., 2014). Natural fibres show fluctuating length, color, texture, drapability, flexibility, tensile strength and degradation resistance depending on their source of origin, age, environmental conditions and mode of extraction (Rajan et al., 2005).

Now a days, natural fibres and geotextiles are used in solving various engineering problems. Natural fibre based geotextiles play a vital role in addressing different engineering problems safely, efficiently and economically. Geotextiles from natural fibres are widely used in slope protection and erosion control (Lekha, 2004; Vishnudas et al., 2006, 2012) .The use of natural fibres like jute, coir and bamboo as a reinforcing material in soil is an accepted engineering practice. They were used as a reinforcing material in retaining walls, in embankments (Ranganathan, 1994; Vishnudas et al., 2006), in pavements (Subaida et al., 2009; Khan et al., 2014; Sudarsanan et al., 2018) and under foundations (Ghosh et al., 2005).

Natural fibres loses its strength over time and this loss of strength varies among fibres. The long term application of natural fibre based geotextiles is limited due to their higher rate of biodegradation (Ramesh et al., 2011). The fundamental mechanisms involved in degradation of natural fibre based geotextiles are hydrolysis and biological action. The numerous pores on the surface of natural fibres has tendency to absorb moisture and this weakens the cell wall and provides access to microbial attack under favourable conditions of nutrients, pH and temperature. Hence there is a need for improving the durability characteristics of natural geotextile. Durability of natural geotextiles can be enhanced by surface modification which cleans and alters the surface properties of fibres. This paper provides an overview of already existing surface modification methods and discusses the effect of surface modification on the performance of natural fibres.

2 Degradation Behaviour of Natural Fibres

Degradation of natural fibres is mainly due to the change in moisture content, microbial activity, temperature and ultraviolet radiation (Rowel, 1995; Miller et al., 1998; Sarsby, 2005; Carvalho et. al, 2015). The chemical composition of natural fibres also plays a vital role in their degradation behaviour. Natural fibers are mainly composed of cellulose, hemi cellulose and lignin (Rajan et al., 2007; Carvalho et. al, 2015; Prambauer et al., 2019). Hemi cellulose in natural fibres is responsible for moisture absorption which leads to the swelling of cell wall of fibre (Rowel, 1995). Microorganisms hydrolyze the cellulose in the cellwall and thereby enhance the degradation

(Rowel, 1995; Rajan, 2005). By thermal degradation, hemicellulose, cellulose and lignin in the natural fibres get decomposed (Adeniyi et al., 2019). The degradation resistance of natural fibres primarily depends on the lignin content. Lignin in natural fibres reduces the water uptake and microbial activity (Akin et al., 2010; Prambauer et al., 2019).

Durability of natural fibres exposed to natural soil are influenced by the soil type, organic content of soil, moisture content in soil, type of vegetation and climatic conditions (Balan, 1995; Lekha, 2004).Environmental exposure of natural fibres leads to the oxidation of lignin and formation of low mass lignin chains. The newly formed chains are chemically unstable and susceptible to thermal degradation (Marques et al., 2014). The degradation behaviour of an environmentally exposed fibre is a function of its depth of burial. Natural fibre, which is placed in the top layer of soil, is the most degradable (Joy et al., 2011). Due to the degradation of fibres, major strength loss of fibre based geotextiles takes place within one year of installation (Lekha, 2004; Vishnu et al., 2006; Marques et al., 2014; Carvalho et. al, 2015).

3 Surface Modification of Natural Fibres

Natural fibres possess certain drawbacks such as degradability and higher moisture absorption which limits its application in long term engineering problems. Hence there is requirement of modification of natural fibres for their long lasting performance. Surface modification is an effective way of enhancing the durability of natural fibres (Prasad et al., 1983; Sanyal et al., 1994; Saha et al., 2012a; Sumi et al., 2018). There are two methods of surface modification - physical and chemical methods. Physical methods of surface modification are cold plasma, UV bombardment, corona discharge and γ ray. Mercerization, silanization, acrylation and grafting are the commonly used chemical surface modification methods (Obi et al., 2013; Santos et al., 2019).Alkali treatment (Prasad et al., 1983; Saha et al., 2010; Kabir et al., 2012), Enzyme treatment (George et al., 2014), Transesterification with vegetable oils (Dankovich et al., 2007; Saha et al., 2012b), UV grafting with monomers (Rahman et al., 2007), surface coating (Sanyal et al., 1994; Saha et al., 2012a; Sumi et al, 2016; 2018; Tiwari et al., 2020)and treatment with specific chemicals (Mwaikambo et al., 2002; Vivek et al., 2018) are the usually adopted surface modification techniques. Enzyme treatment is an effective method for improving the thermal properties, by removing cellulose and pectin from fibre surface (George et al., 2014). Vegetable oils help to remove the water soluble components and lignin in natural fibres, which leads to the reduction of swelling behaviour (Saha et al., 2012b). In UV grafting method, monomers form a mechanically stable coating around the fibres by penetrating into the pores on the surface of the fibres. This is the reason for the improved strength of fibres after surface modification by monomers (Rahman et al., 2007). Surface coating of natural fibres reduces the moisture absorption and improves the tensile strength and degradation period (Sanyal et al., 1994; Saha et al., 2012a). The surface coating is effective in controlling the penetration of aqueous chemicals through the micro pores and thereby inhibits the development of fungal growth on fiber surface by 95% (Sumi et al, 2016; 2018).

4 Alkaline Treatment

Alkaline treatment using sodium hydroxide is one of the commonly used surface modification method (Kabir et al., 2012). Modifications of surface of coir fibres with sodium hydroxide lead to increase in wettability and prevent the flotation and segregation of coir fibres. Alkali treatment on coir fibre improves the tensile strength, modulus and debonding strength from polyester (Prasad et al., 1983). Sodium hydroxide treated kenaf fibre based geotextile shows an improvement in tensile strength about 45.5 % and 51% compared to untreated geotextiles for wet and dry condition respectively (Shirazi et al., 2019). Sodium hydroxide treatment on natural fibres forms an amorphous region in which cellulose molecules are separated by large spaces. The sensible OH groups in fibre reacts with the water molecules occupied in the large paces in the amorphous region and cause a reduction in hydrophilic groups (Kabir et al., 2012). The alkaline treatment removes the hemicelluloses, pectin, lignin, oil and wax from the surface of fibre and makes the fibre surface become more rough uniform (Saha et al., 2010; Kabir et al., 2012). Surface modification by alkali treatment makes the fibre more stiff and strong by changing the structure of cellulose I to cellulose II (Liu et al., 2009). It also causes a reduction in fibre diameter and weight of fibres by the removal of surface impurities (Liu et al., 2009; Saha et al., 2010).

5 Chemical Treatments

Alkali, acetylation, silane, acrylation, benzoylation, maleated coupling agents, isocynates and permanganate treatments are commonly used chemical treatment on natural fibres. Chemical treatments are found to be effective in enhancing the strength of fibre, fibre rigidity and fibre matrix adhesion (Li et al., 2007).Chemical modification on natural fibres like jute, sisal, hemp and kapok fibres was effective in changing the surface characteristics of the fibre. Chemical modification on natural fibres results in the removal of surface impurities and thereby improved the matrix- fibre adhesion, mechanical interlocking and bonding with chemicals (Mwaikambo et al., 2002). Structural properties of coir geotextile depend on the cellulose retention capacity and lignin degradation. Coir geotextile treated with lime was effective in conserving the cellulose content during the early stages of degradation (Marques et al., 2014). Anggraini et al. (2016) investigated the effect of surface modification of coir fibre with nano particle on the mechanical properties of lime treated marine clay. Nano particles of Ca(OH)2 and Mg(OH)2 occupies both internal spaces and external surface of the fibre. Nano particle in the internal spaces causes an improvement in mechanical properties where as particle in external surface causes an increased interaction between soil and fibre. The load carrying capacity and peak strength of lime treated marine clay increases with in cooperation of nano particle modified coir fibre. Sodium bicarbonate treatment on sisal fibres remove large amount of hemicelluloses which leads to the close packing of fibres and formation of hydrogen bonds between chains of cellulose (Fiore et al., 2016). Chemical treatment using chemicals like sodium periodate, p aminophenol and sodium hydroxide enhance the tensile strength of both non woven and woven coir geotextiles (Vivek et al., 2018).

6 Summary and Conclusions

1. Surface modification of natural fibres significantly improves the performance of natural fibres.
2. The degradation behaviour of natural fibres mainly depends on its chemical composition. Natural fibres with high cellulose content are susceptible to more degradation. Lignin in fibres is responsible for degradation resistance and reduces microbial activity.
3. Alkaline treatment of natural fibres removes the surface impurities and makes the surface more rough and strong. Sodium hydroxide treatment improves the hydrophobicity and tensile strength of fibres.
4. Chemical treatment on natural fibres enhances the surface characteristics of fibres. Such fibres provide better tensile strength, bonding reaction with chemicals and fibre matrix adhesion.

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