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Effect of NaOH Treatment on the Tesile Properties of Coconut Fibre for Polyester Resin Transtibial Prosthetic Socket Reinforcement

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ABSTRACT: Recently, there is increase in the use of natural fiber in the reinforcement of polymer composites due to its low production cost, ease of fabrication and enhanced strength. In this study, the effect of NaOH treatment on the tensile properties of coconut fibre for polyester resin transtibial prosthetic socket reinforcement was investigated. The coconut fibres were extracted using hand pulling and water retting method; NaOH treatment was used to mercerize the fibres was carried out 5% to 25% at time interval of between 30Min. to 150Min. The result indicated that the effect of NaOH treatment on the Coconut fibre vary, depending on the concentration of NaOH and the treatment time. It is concluded that treatment of Coconut fibre in 15% NaOH for 150minutes is the best treatment protocol of Coconut fibre for polyester resin reinforcement.

KEYWORDS: NaOH treatment, prosthesis, coconut fibre, Tensile strength, polyester resin.

INTRODUCTION

Amputation is a last resort surgical procedure that involved the removal of an external part of the body, such as a limb or part of it as a treatment plan, about 285million people globally are living with limb amputation. Although, loss of a limb create additional health burden and affects the quality of life of the amputee, amputation, however, is deployed to save the patient's life (Paudel *et al*., 2005 and Udosen *et al*., 2009). Prosthesis is a device designed to substitute the function or the appearance of a missing limb or body part (Sixtus *et al*., 2022), to restore mobility and degree of normal functions to amputees (Arvela *et al* 2010 and Bierbaum *et al* 2002).

Prosthesis for transtibial amputation comprises of a socket assembled to the foot with a pylon. The socket is the most important component of artificial limb and it is the part in contact with the stump (Carrol and Binder, 2006). Most prosthesis is designed to be comfortable to wear, light weight, durable, cosmetically acceptable, functional and easy to maintain. They are usually made of reinforced polymer matrix (Bledzki and Gassan, 1999 and Ferguson and Smith, 1999). Although, synthetic reinforcement materials are available, they are derived from non-sustainable source (Okafor *et al*., 2021), produce dangerous gas emissions and are non biodegradable.

However, natural reinforcement composite materials which include natural fibres and biopolymers such as rattan, food gum, and coconut fibre, have been confirmed to be a good reinforcement material in thermoset and thermoplastic matrices. (Azeez and Onukwuli, 2017; Azeez *et al*., 2017 and Giuliania *et al*., 2020) and are abundantly available (Okafor *et al*., 2022). Coconut fibre, however, is reported to be a great competitor to fiberglass and carbon fibre in terms of performance (Baiardo *et al* 2004; Brahmakumar *et al* 2005 and Ray *et al.*, 2001). There is a need to develop readily available, cheap and eco-friendly reinforcement composite materials from natural sources.

Figure 1.1: Transtibial prosthetic socket made from natural fibre

MATERIALS AND METHODS

Plant fibre material

Matured coconut fruit were obtained from a coconut plantation in Ahiazu Mbaise LGA, Imo state Nigeria.

Chemicals and reagents

Polyester resin and sodium hydroxide (NaOH) were sourced from a chemical company located at Douglas road in Owerri, Imo state.

Extraction and Preparation of Coconut fibers

Coconut fibers were extracted from the husk of coconut fruits using hand pulling and water retting techniques. The fibers were prepared according the methods described by Azeez and Onukwuli, (2017) and modified by Ogbonna *et al*., (2023).

Tensile analysis

Tensile properties were determined using Instron Universal Tester model-3369. Each strand of the fibre was gripped at both ends of 50mm length by the grip of Instron Universal Tester model-3369, which slowly pulls apart until fractures. The pulling force is called load, which is plotted against the fibre length change or displacement. The load is converted to stress and the displacement to a strain. With this procedure, the tensile strength, tensile strain, and young’s modulus, extension, and energy at break were evaluated.

Optimization of Coconut fibres modifications

The response surface methodology (RSM) of 3 – LFD with second order polynomial equation (3.1) was used to optimize the modification conditions of coconut and p fibres based on tensile responses.

$$T_i = \beta_0 + \beta_a C + \beta_b t_w + \beta_c C^2 + \beta_d t_w^2 + \beta_e Ct \qquad (3.1)$$

Where T_i is the tensile property of coconut fibre as dependent variables; C and t are the concentration of chemical used and treatment time respectively; is the random error; β_0 is intercept term, β_a and β_b, β_c and β_d, and β_e are the coefficients of linear, quadratics and interaction terms, respectively. The experimental results were modeled and empirical models were developed as shown in equation and (3.2) for the tensile responses of mercerized fibers, respectively. These optimally mercerized fibres were used for preparation of polyester composites.

Preparation of coconut fibre polyester composites

The mould was designed and fabricated at the MME workshop of Federal University of Technology, Owerri. It has five different dumpbell cavities of dimensions of 100mm (length) x 5mm (width) and 3mm (thickness). The coconut fibres were weighed using a weighing balance SF-400 model of 3dp. The composites were prepared using rule of mixture model for fibre and polyester resin as presented in equation (3.2).

$$X_f + X_m = 1 \qquad (3.2)$$

X_f and X_m represent fiber and polyester weight fractions, respectively.

The fibre were interwoven and laid into the cavity of the mould as labelled in Table 2.1. Polyster resin was mixed with cobalt nephthenate, methyl ethyl ketone peroxide in accordance with manufacturer guidelines in a ratio of 10:1:1 and poured into the chambers. The mould were closed for 12 hours to allow curing process to take place, then the coconut fibre polyester composites were removed from the mould.

Table 1: Weight fraction of fiber – polyester composites preparation

S/N	Weight of the fibre (%) (X_f)	Weight of the matrix (%) (X_m)
1	0.025	0.975
2	0.050	0.950
3	0.075	0.925
4	0.100	0.900
5	0.125	0.875

Mechanical properties of coconut and plantain fiber-composites

Tensile properties were determined on 100 mm x 5 mm x 3 mm sample dimensions using Instron Universal Tester model-3369. Sample was gripped at both ends of 100mm length by the grip of Instron Universal Tester model-3369.

The impact strength was determined from tensile analysis using equation (3.3) as described by Azeez and Onukwuli (2017) and modified by Uchenna *et al*., (2022).

$$I = \frac{E}{A} \qquad (3.3)$$

Where E is the energy absorbed (J) which is equivalent to energy to break and A is the area of cross section of the specimen below the notch (mm2). Impact strength I is measured in J/mm^2.

Flexural properties of dump bell shape of coconut, plantain and glass fibre composites with a dimension of 100 mm x 25 mm x 3 mm were determined using three-point flexural test on a using Monsanto Tensometer–TK/2/1140 UK at a crosshead moving speed of 40 mm/min.

A Rockwell Hardness Tester- RBHT/S-39 model UK used with steel indenter for the hardness test in accordance with ASTM E – 18 on sample dimensions of 30mm x 30mmx 3mm. A minor load of 30 kgf to lower the steel ball on composites sample surface and a major load of 60 kgf were applied for 15 seconds at zero scale, Rockwell hardness measurement was recorded.

Based on the ultimate performance of the mechanical properties of these composites, the water absorption was carried out and prosthetic socket was designed.

Preparation of Mould and Production of Transtibial Prosthetic Socket

The production of prosthetic socket requires the following steps: Anthropometric data measurements, negative mold (cast) and positive mold, preparation process of lamination, lamination process and testing of prosthetic sockets. The transtibial socket was produced using the method described by Brahmakumar *et al* 2005

RESULTS

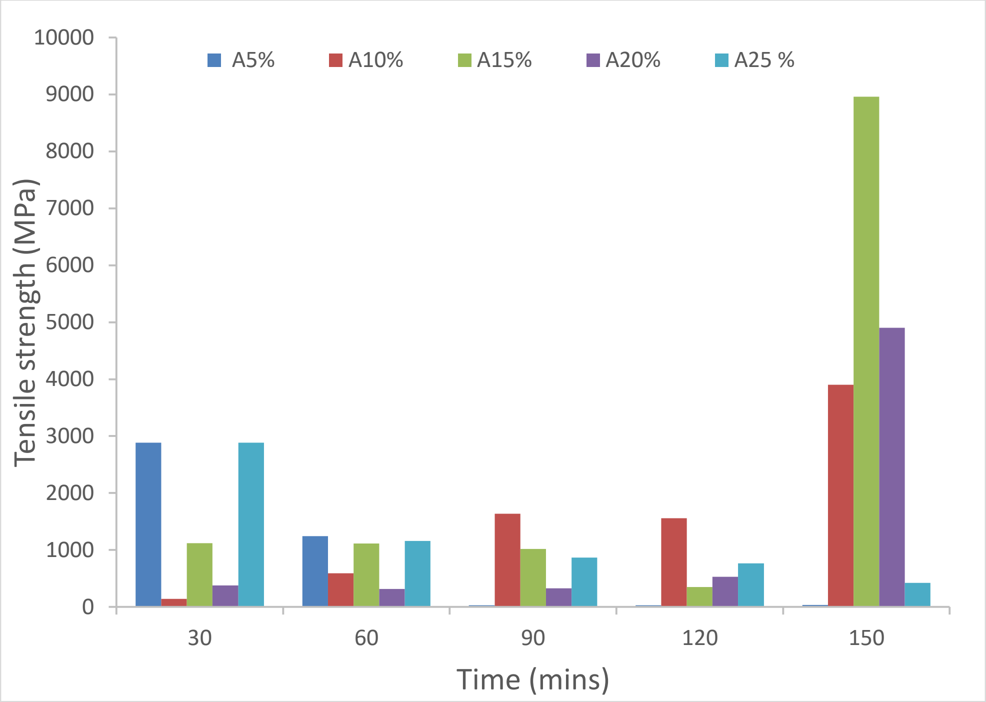

Figure 1: Tensile strength of coconut fibres

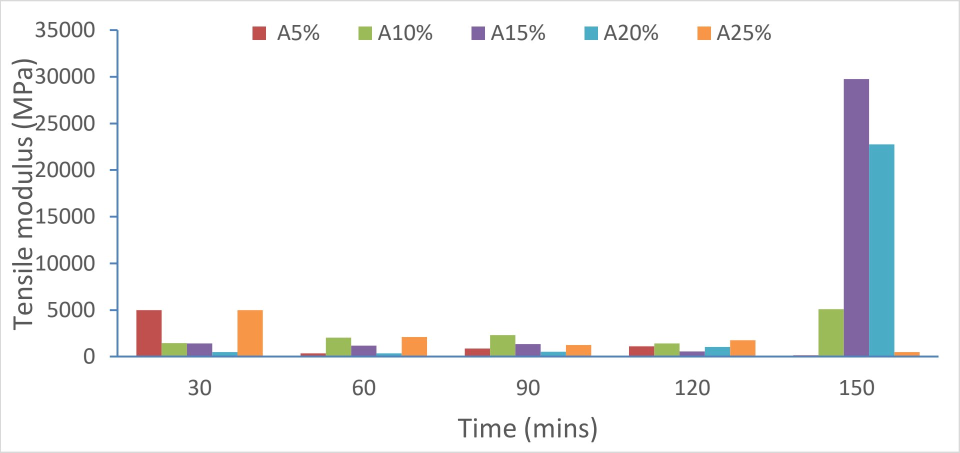

Figure 2: Tensile modulus of treated coconut fibres

DISCUSSION

The effects of the NaOH treatment on the ultimate tensile strength of the coconut fibres showed that the tensile strength of fibres treated with 5 and 25% of NaOH decreased from 3000MPa to <1000MPa with increased in time from 30 to 150 minutes (See figure 1). This decrease in tensile strength may be as a result of exposure of crystalline cellulose of the first layer in the secondary wall (S1) of the coconut fibres as reported by Sawpan *et al*., (2011) and Azeez *et al*., (2017). Although an increase from 100MPa to 1500MPa in fibre strength of coconut fibres treated with 10% NaOH was observed at 90 minutes (See figure 1), this behaviour may be attributed to the removal of the amorphous constituents of the first layers in the secondary wall of the coconut treated with 10% NaOH which may have replaced the hydrogen bond of the hydroxyl group of the crystalline cellulose (Wang *et al*, 2007 and Azeez and Onukwuli, 2017).

The treatment of coconut fibre with 25% NaOH indicated a constant decrease in tensile strength of the treated coconut fibre with increase in time (See figure 1).The best ultimate tensile strength of 8960.251MPa was obtained for coconut fibre treated with 15% NaOH at treatment time of 150minutes (See figure 1). The increased in the tensile strength of the coconut fibre may be caused by the removal of the amorphous constituents of the second layers (S2) in the secondary wall of the coconut fibre at 15% NaOH concentration, which may have replaced the hydrogen bond of the hydroxyl group of the crystalline cellulose, therefore increasing the strength of the fibre (Arsyad *et al*, 2015).

The effects of NaOH treatment on the tensile modulus of coconut fibres were also noted. It was observed that the tensile modulus of coconut fibre treated with 5% and 25% NaOH decreased with the time increase from 30 to 150 minutes (See figure 2). This decrease may be attributed to exposure of crystalline cellulose of the of the coconut fibres (See Azeez and Onukwuli 2017). At 15% and 20% NaOH treatment, we noted similar behavior in the tensile modulus decreas with increase in time from 30 minutes to 120 minutes (See figure 2); this may be due to degradation of the cellulose of the coconut fibre.

However, at 150 minutes treatment time, there was remarkable increase in the tensile modulus of the fibre treated with 15% NaOH (See figure 2) this may be as a result of the removal of the amorphous constituent of second layer in the secondary wall of coconut fibre, occasioned by the substitution of the hydrogen bond of the hydroxyl group of the crystalline cellulose and the reduction in diameter of the fibre due to the alkaline treatment.

CONCLUSION

Coconut fibre was treated with NaOH at various concentrations; the result showed that the tensile properties of the fibre are affected by the NaOH concentration and the treatment time. It is concluded that the treatment of Coconut fibre in 15% NaOH for 150minutes is the best treatment protocol of the Coconut fibre for polyester resin reinforcement.

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