Electronic Research Archive of Blekinge Institute of Technology
<http://www.bth.se/fou/>

This is an author produced version of a journal paper. The paper has been peer-reviewed but may not include the final publisher proof-corrections or journal pagination.

Citation for the published Journal paper:

Title:

Author:

Journal:

Year:

Vol.

Issue:

Pagination:

URL/DOI to the paper:

Access to the published version may require subscription.

Published with permission from:

Mechanical Properties and Life-Cycle Sustainability Aspects of Natural Fibre

Sharon Kao-Walter^{1, a}, Etienne Mfoumou^{1, 2, b}, Maurice Ndikontar^{3, c}

¹Dept. of Mechanical Engineering, School of Engineering, Blekinge Institute of Technology, Sweden

²Research Center, University of Montreal Hospital, Montreal QC, Canada

³Laboratory for the Physico-Chemistry of Wood, University of Yaoundé I, Cameroon

^asharon.kao-walter@bth.se , ^bmfoumou@gmail.com, ^cmdikontar@yahoo.com

Keywords: natural fibre, coconut, mechanical properties, tensile test, sustainability

Abstract

In order to understand the basic definition of the natural material, references of recently published articles were studied. From these articles, the definition of different terms like renewable material, recyclable material, biodegradable material, sustainable material and finally natural material were collected. Furthermore, a classification of natural fibre was drawn. One of these natural fibres - the coconut was chosen for a more detail analysis in mechanical point of view. An integrated method to analyse the sustainability of the coconut fibre as one of the blend components in building construction will be suggested. Finally, several uses of the fibre are reviewed.

Introduction

The application of the natural fibre can be dated back to the primitive age where humans used the agricultural resources to make shelter, cook food and construct tools. With the advent of plastics, high performance metals, ceramics and other synthetics, the use of biodegradable materials lost its place. Only recently, the sustainability of the society started to be discussed worldwide, and the application of the natural material in different fields has become more and more important [1].

Work focused on coconut (*Cocos nucifera*) fibre as a biodegradable and eco-friendly material, in order to investigate the possibility of using coconut fibre as a component in building construction. The properties needed to be studied, not only from the mechanical point of view but also from that of sustainability. Traditionally, the inner and outer fibres were investigated using a tensile testing machine. The mechanical properties such as the modulus of elasticity, yield stress, stresses at rupture and strain at rupture were measured and calculated [1]. Furthermore, methods like “The Natural Step Framework”, “Life cycle assessments” and “Strategic life cycle management” were studied and the process for analysis the coconut as part of building components were discussed and a process described in a earlier master thesis work [2] was recommended.

The Definition of some Useful Terms

1. Renewable material: the recovery and reuse of a material after its initial function has expired [3].
2. Recyclable material: a very broad term referring to the conversion of waste (as discarded materials with no worth) into a useful material [4].
3. Biodegradable material: the materials that do not have adverse effects on our eco-system; these can grow in different zones [5].
4. Sustainable material: those materials which are usable for the life-cycle of the product that will not cause any harm to the environment [6].
5. Natural material: in a broad sense, this is material that is either of plant or animal origin or plant crops that are fundamental to human existence [7-8].

Classification of the Natural Fibre Material

Natural materials are basically classified as lignocelluloses in nature and contain cellulose, hemicelluloses, lignin, pectin, waxes and water. Natural fibres are the stem, leaves, roots and fruits of the plant. They can be categorised into two distinct groups namely: wood fibre and non-wood fibre, on which can also be divided by plant fibre (for example: leaves of sisal, banana or pineapple) and stalk fibre (such as elephant grass, bamboo, cotton and fruits of coconut) [9-10].

The Constituents and Fibre structure of Coconut

Coconut palm is mainly cultivated in the tropical regions of the world. Coconut comprises of a white meat which constitutes 28% by weight of the fruit. It is surrounded by a protective shell and husk which are 12 and 35% by weight respectively. It is also known that the husk from the coconut palm is comprised of 30% by weight of fibre and 70% by weight of pith material. The fibres are extracted from the husk by several methods such as the traditional retting, decortications, using bacteria and fungi, and also mechanical and chemical processes. Fibres are typically 10 to 30 centimetres (4 to 12 inches) long and are used for the production of building and packaging materials such as ropes and yarns, brushes and padding of mattresses, etc [6, 11].

Figure 1: Fibres (left) and the cross-sectional view (right) of the coconut fruit [6]

Coconut has numerous good characteristics. It is a renewable resource and CO₂-neutral material. The fibre is abundant, non-toxic in nature, biodegradable, low density and very cheap. The fibre has a high retention of water and also rich in micronutrients. The fibres, instead of going to waste are explored for new uses, which in turn provide gainful employment to improve the standard living condition of individuals [4, 11-13].

The main constituents of coconut fibre are: cellulose, hemicelluloses, lignin and other vital substances. These materials are the building block of the cell structure. The coconut fibre is naturally multi cellular and its diameter and length ranges between several dimensions and it is usually very thick at the middle of the fibre length.

Coconut fibre has the highest percentage by volume of lignin, which makes the fibre very tough and stiffer compared to other natural fibre. This can be attributed to the fact that the lignin helps provide the plant tissue and the individual cells with compressive strength and also stiffens the cell wall of the fibre where it protects the carbohydrate from chemical and physical damage. The lignin content also influences the structure; properties, flexibility and rate of hydrolysis. At high lignin content, it appears to be finer and also more flexible [14].

The fibre structure is determined by the dimension and arrangement of various unit cells which also influence the fibre properties. Fibres are elongated cells with tapering ends and very thick lignified cell wall [5]. Fibre dimensions of the various individual cells are found to be dependent on the type of species, location and maturity of the plant. The flexibility and rupture of the fibre is affected by the length to diameter ratio (l/d) of the fibre and this also determines the nature of the product that can be made from it. The transverse sections of the unit cell in a fibre have a central hollow cavity known as the lumen and its shape and size depends on two factors such as the thickness of the cell wall and the source of the fibre (see Figure below). The hollow cavity serves as an acoustic and thermal insulator.

Figure 2: Section of a fibre cell [15]

The structure and properties in a fibre are determined by the quantity of cellulose and non cellulosic constituents. They are also influenced by the crystalline and moisture regain. The mechanical properties such as tensile strength, density and Young's modulus are related to the composition by the internal structure of the fibre. Fibres that have high cellulose content, a high degree of polymerisation and a low micro fibril angle give better mechanical properties. Meanwhile, those with higher contents of lignin, lower length to diameter ratios and high micro fibril angle give lower mechanical strengths and Young's modulus but with better and higher extensibility. Mechanical properties are also influenced by the composition, structure and number of defects in a fibre. When tensile failure occurs under stress by intercellular or intracellular modes, the fibres with high cellulose will content crack. It will cause intercellular fracture without the removal of micro fibrils. Those with low cellulose contents crack, causing intracellular fracture with the removal of micro fibrils. The factors that affect elongation of a fibre can be attributed to the orientation, high degree of crystallisation and the angle of the micro fibrils with respect to the axis of the fibre [5].

Mechanical Testing

The material (coconut) used for this experiment was obtained from the southern region of Nigeria. To prepare the specimen, these coconut husks were retted carefully to obtain the fibre for analysis for its mechanical properties. The fibres were sorted in two categories: inner and outer fibres. The diameters of each specimen of the inner and outer fibre were measured carefully. For each case, five specimens were prepared.

Mechanical tests have been carried out using MTS Q-TEST 100 machine (see figure 3). This machine has a crosshead – a horizontal bar – that can be accurately traversed up and down under digital control by means of two large jack screws. Specimens were tested by attaching them between the crosshead and the stationary base of the machine and then traversing the crosshead up, thereby increasing the tensile load on the specimen. The data (load vs. displacement or stress vs. strain) were stored and displayed by the software package MTS Test Work 4 [16]. The 100N load cell with pneumatic grippers was used, a pre-length of 30mm was considered on the fibre specimen, and the test speed (crosshead speed) was set to 1.2mm/min. The experiments were conducted at room temperature and 40% relative humidity.

Figure 3: Specimen under investigation on MTS

The experimental stress versus strain curves of the five inner and five outer specimens of coconut fibres are plotted and shown in figure 4. From these curves, the modulus of elasticity, the stress at break and strain at break are calculated and the average values can be found in Table 1.

Figure 4: Stress vs. strain curve of (a) Inner fibre, (b) Outer fibre

Results show that, the coconut fibre is a material between metal and polymer. The elastic modulus is rather close to the polymer like PET. The inner fibres are bit thicker and stiffer and higher strength than the outer fibres by comparing the values of elastic modulus, yield stress and stress at break. On the other hand, the inner fibre is less ductile than the outer fibre by comparing the strain at break values. As can be seen from the curves, the properties of the outer fibres are more unstable than the inner fibre.

Table 1: Comparison of the mechanical properties of outer and inner fibres

Sample	Diameter $D(mm)$	Area $A(mm^2)$	Young's Modulus $E(Nmm^{-2})$	Yield stress $\sigma_y(Nmm^{-2})$	Stress at rupture $\sigma_b(Nmm^{-2})$	Strain at rupture $\epsilon_b(\%)$
The average value for outer fibre	0.494	0.19422	746.078	12.324	46.524	0.38972
The average value for inner fibre	0.538	0.22872	1229.006	21.986	66.95	0.18846

A suggested method for Sustainability Analysis

In this field, Life Cycle Assessment (LCA) [17], Strategic Life Cycle Management (SLCM) and The Natural Step Framework (TNSF) are some of the methods that have been developed and applied in the different fields.

LCA is a tool for the systematic evaluation of the environmental aspects of a product or service system through the entire cradle-to-grave “life cycle”. The entire life cycle starts when raw materials are extracted from the earth, followed by manufacturing, transport and use. It ends with waste management including recycling and final disposal. This method has been proven to be a valuable tool to document the environmental considerations that need to be part of decision-making towards sustainability [2].

SLCM is a further development method based on LCA. It provides a framework for sustainable management of materials, which helps to carry out continuous evaluation from social, ecological and economic perspectives. It also helps to identify strategic pathways towards sustainability rather than to simply choose lowest environmental impact products [2].

TNSF is a science and system-based methodology. The method describes core guiding principles for moving towards sustainability. It is intended to assist decision-makers by providing a practical set of planning and design criteria that can be used to direct social, environmental and economic action [18-19]. The model represented by TNSF provides a comprehensive and consistent approach for planning in complex systems and delineates five levels of understanding. A so called “backcasting” together with an “ABCD methodology” is a special tool for a systematic analysis from a sustainable future back to present [18]. In [2], an integrated method was applied to analyse the import and export flows of construction material. A similar process is therefore recommended for the sustainability analysis of coconut fibre as part of the construction material.

Uses of the coconut fibre

Coconut fiber, called “coir,” has historically been used for many purposes. Yarn and ropes can be made from the braided fibers of the coconut coir. Car seats cushions and seat covers, soundproofing for hollow doors, mattresses, door welcome mats and flower pots are commonly made from coconut fibers. Water filters for human use and for aquariums and fish tanks are often made from the stringy coconut fibers too [20]. Other uses of coconut fibres are being explored which include the creation of binderless particle board and as reinforcing polymer material for automotive interiors. The future of dashboard, centre consoles and armrests are not in plastics but in biodegradable plant-based fibres. The ability of coconut fibre to trap and hold solids make them an excellent top soil and erosion-control medium too. As a conservation tool, coconut coir matting (called geotextile or geotechnical netting) is commercially available to prevent erosion and in typhoon-prone regions; because it holds soil in place and thus prevents erosion. Coconut coir is also burned (charred) and steam-activated to make ‘activated charcoal’ for medicinal purposes. In one such study, Egwaikhide *et al* [21] found that coconut fibre charcoal, activated using ammonium chloride could remove kerosene and diesel from waste water at a rate of 45% following a pseudo-first order law. Activated charcoal is ingested in either tablet or aqueous form to absorb toxin and poisons in the body and often given in cases of accidental (or intentional) poisoning. Charcoal tablets are also commercially available for upset stomachs, indigestion and acute lower intestinal gas buildup.

Natural fibres are environment friendly materials and have proved to be a competitor for glass fibre/polyester in terms of strength performance and cost [22-24]. Combination of natural fibre reinforced polyester composites has been demonstrated to be an effective method to design materials suited for various requirement. Earlier studies by Brahmakumar *et al.* [25] proved that the coir fibres can be used as effective reinforcement and bonded in polyester matrix. The choice of polyester as a matrix is based on economic interest because it offers a very cheap resin, available with good

mechanical properties and used in many applications such as transport, marine and sport. In another study, Bujang et al. [26] found that the effects of reinforcing polyester matrix with the coconut fibres caused the composites to be more flexible and easily deform due to high strain values and reduction of high resonant amplitude. Moreover, chemical tests on composites made from poly(vinyl chloride) PVC and green coconut fibres [27] suggest that no physic-chemical interactions occur in these composites between the matrix and the fibres. Such a material would therefore easily degrade after its life span.

Conclusion

This is an initial work to apply solid mechanics principles and at the same time taking sustainability into account to analyse coconut fibre as one natural material. Coconut fibre is a biodegradable, recyclable and sustainable natural material. According to the tensile tests, the mechanical properties of coconut fibre are rather close to those of less ductile polymer. The inner fibres are bit thicker and stiffer and have higher strength than the outer fibres by comparing the values of elastic modulus, yield stress and stress at rupture. On the other hand, the inner fibre is less ductile than the outer fibre when comparing the strain at rupture values. Coconut fibre as one of the blend components in the building material needs to be further analysed by applying the technologies and test methods in the development of composite materials. An integrated method including Life Cycle Analysis (LCA), Strategic Life Cycle Management (SLCM) and The Natural Step Framework (TNSF) is recommended for detail sustainability analysis. Based on this work, the influences of climate, age and specimen size to determine the properties of natural fibre could be further investigated as a next “natural” step.

References

- [1] O. Bolarinwa and A. Waifielate: *Mechanical Property Evaluation of Coconut Fibre*, BTH-AMT-Ex--2008/D-05-SE, pp. 60. TEK/avd. för maskinteknik, 2008.
- [2] D. Dai and X. Tang, *Transitioning towards sustainable management of building materials in China*, pp. 66. TEK/avd. för maskinteknik, 2005
- [3] I.S Arvanitoyannis and L.A. Bosnea: *Recycling Of Polymeric Materials Used For Food Packaging: Current Status And Perspective,s* Food Reviews International, 17(3), 291-346 (2001).
- [4] AEEA & ICT Recycling. Wij Recyclen Graag Uw Ict En Elektrische Apparaten. <http://www.recydur.com>
- [5] P.A. Fowler, J.M. Hughes and R. Melias: *Review Bio Composites: Technology, Environmental Credentials and Market Forces*, Journal of the Science of Food and Agriculture 86: 1781- 1789, 2006.
- [6] J.E.G. Van Dam, Van Den Oever, M.J.A., Teunissen, W., Keijsers, E.R.P. and Peralta, A.G.: *Production of High Density/ High Performance Binderless Boards from Whole Coconut Husk. Part 1: Lignin as Intrinsic Thermosetting Binder Resin.*
- [7] M. Kern: *Food, Feed, Fibre, Fuel and Industrial Product of the Future: Challenges and Opportunities. Understanding the Strategic Potential of Plant Genetic Engineering.* J. Agronomy of Crop Science 188,291-305(2002).
- [8] A.K. Bledzik and J. Gassan: *Composite Reinforced with Cellulose Based fibres.* Progress in Polymer Science 24 (1999) 221-274.
- [9] C.K. Moshibudi: *The Processing Properties of Natural Fibre Reinforced Higher α - Olefin Based Thermoplastics*, 2005.

-
- [10] M.K. Mohan Rao and K. Mohan Rao: *Extraction and Tensile Properties of Natural Fibres: Vakka, Date and Bamboo*. Department of Mechanical Engineering, V.R. Siddhartha Engineering College, Vijayawada 520 007, AP, India.
- [11] R. Narendra and Y. Yigi: Biofibres from Agricultural Byproducts for Industrial Applications.
- [12] T. Fabio, H.D.S. Thais and G.S. Kestur: *Studies on Lignocellulosic Fibres of Brazil part 2: Morphology and Properties of Brazilian Coconut Fibre*.
- [13] C.S. Vavrina, K. Armbruster, A. Mireia and M. Pena: *Coconut Coir as an Alternative to Peat Media for Vegetable Transplant Production*. University of Florida, Southwest Florida Research and Education Centre P.O. Drawer 5127, Immokalee, FL 33934.
- [14] A. Rajan, C.R. Senan, C. Pavithran and T.A. Emilia: *Biosoftening Of Coir Fibre Using Selected Microorganisms*. Bioprocess Biosyst Eng (2005) 28: 165-173.
- [15] Fibres, For Paper, Cordage & Textiles. <http://waynesword.palomar.edu/traug99b.htm>
- [16] MTS Systems Corporation, www.mts.com, c 2002
- [17] Atlantic Consulting and IPU. 1998. "LCA Study of the Product Group Personal Computers in the EU Ecolabel Scheme," http://www.europa.eu.int/comm/environment/ecolabel/pdf/personal_computers/lcastudy_pc_1998.pdf (accessed March 12, 2006).
- [18] K.-H. Robèrt and others, eds. 2002. "Strategic sustainable development: Selection, design and synergies of applied tools". Journal of Cleaner Production, 10:197-214.
- [19] H. Ny, J.P. MacDonald, G. Broman, R. Yamamoto and K.-H. Robèrt: *Sustainability constraints as system boundaries: an approach to making life-cycle management strategic*. Journal of Industrial Ecology, 10:61-77, 2006.
- [20] B.J. Russo: The many different uses of coconut fiber in *Food*. <http://www.bo-jack-russo.quazen.com/>
- [21] P.A. Egwaikhede, E.E. Akporhonor and F.E. Okieimen: Utilization of coconut fibre carbon in the removal of soluble petroleum fraction polluted water, International Journal of Physical Sciences, 2(2), pp. 047-049, 2007.
- [22] M. Baiardo, E. Zini and M. Scandola: Flax fibre-Polyester Composites, *Composites: Part A*, 35. 703-710. 2004.
- [23] S.B. Brahim and R.B. Cheikh: Influence of Fibre Orientation and Volume Fraction on the Tensile Properties of Unidirectional Alfa-Polyester Composite. *Composites Science and Technology*, 2006.
- [24] M. Idicula, A. Boudenne, L. Umadevi, L. Ibos, Y. Candau, and S. Thomas. Thermophysical Properties of Natural Fibre Reinforced Polyester Composite. *Composites Science and Technology*, 66. 2719-2725, 2006.
- [25] M. Brahmakumar, C. Pavithran and R.M. Pillai: Coconut fibre reinforced polyethylene composites: effect of natural waxy surface layer of the fibre on fibre/matrix interfacial bonding and strength of composites. *Composites Science and Technology* 65: 563-569, 2005.
- [26] I.Z. Bujang, M.K. Awang and A.E. Ismail: Study on the dynamic characteristic of coconut fibre reinforced composites, *Regional Conference on Engineering Mathematics, Mechanics, Manufacturing & Architecture (EM*ARC) 2007*, Noise, Vibration and Comfort Research Group.
- [27] R.L. Ferreira, C.R.G. Furtado, L.L.Y. Visconte and J.L. Leblanc: Optimized preparation techniques for PVC-green coconut fiber composites, International Journal of Polymeric Materials, 2006, 55 (10-12), 10 pp.

Renewable and Sustainable Energy

10.4028/www.scientific.net/AMR.347-353

Mechanical Properties and Life-Cycle Sustainability Aspects of Natural Fibre

10.4028/www.scientific.net/AMR.347-353.1887