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Mechanical Properties of Renewable Materials: A Study on Alpaca Fibre

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ABSTRACT:*In recent years, efforts are being made to develop alternative and renewable sources of materials for engineering and industrial applications. Alpaca fibre is a renewable biobased material that is mainly produced in South and North America. The purpose of this study was to evaluate the stress and strain behaviour of alpaca fibre under continuous and cyclic loading conditions with the aim of determining the feasibility of its use as an alternative material for a number of industrial applications. A set of alpaca fibre were prepared by securing each strand of fibre to paper at both ends with cellophane tape. Each sample was then clamped on an in-house designed highly sensitive fibre testing jig that was specifically designed to measure load and elongation of fibres. Under continuous loadings, the fibre exhibits continuous plastic behaviour as the loading increases until either the sample breaks or the end of the testing machine capability is reached. Under cyclic loading, the samples did not break and an anelastic recovery in the stress-strain behaviour of the fibre was observed. This behaviour makes products manufactured with this material to be durable. It can also make the product to warp in service. Consequently its composite with other materials that enable the manipulation of this property would be more suitable for industrial applications than products made purely from this material.*

Keywords -*Alpaca fibre, bio-based materials, mechanical properties, natural fibres, strain properties, tensile properties*

I. INTRODUCTION

The twenty first century offers an enormous sustainability challenges and opportunities. This is consequent upon the increasing world population and the human desire for better standard of living. This desire is expressed in terms of healthy foods, decent clothing, adequate housing, affordable healthcare, and other necessities for comfortable living. Various resources, means and approaches are being used by governments and other stakeholders at all levels of the society to achieve these goals. However, many of the resources such as synthetic fibres being employed to achieve these goals are causing huge problems for the environment. These problems are evident in environmental pollution, reduction in biodiversity, and resource depletion seen in various places all over the world. There is therefore a need to consider and employ environmentally friendly resources and approaches to meet the increasing need of the populace. Natural fibres as renewable and biodegradable material resources are considered as potential substitutes for synthetic fibres. The growing interest in the use of natural fibres has been attributed to increasing sustainability consciousness, desire for biodegradability of materials at their end-of-life, and increasing stringency in environmental regulations in many parts of the world. There is however a need to evaluate the stiffness and strength characteristics of these natural fibres in comparison with the synthetic fibres, as an example, fibreglass [1 - 10].

A number of scholars have attempted testing the mechanical properties of some natural fibres and their composites as well as their industrial applications [11-14]. For example, Wambua, Ivens and Vrpoest [11] tested the mechanical properties of the different natural fibre composites made from sisal, kenaf, hemp, jute and coir and compared them with the corresponding properties of glass mat reinforced polypropylene composites from the open literature. Kenaf, hemp and sisal composites were found to have comparable tensile strength and modulus results but in impact properties hemp out-performed kenaf. They also reported that the tensile modulus, impact strength and the ultimate tensile stress of kenaf reinforced polypropylene composites were found to increase with increasing fibre weight fraction. Moreover, Coir fibre composites were found to have the lowest mechanical properties, but their impact strength was higher than that of jute and kenaf composites. They concluded that the specific properties of the tested natural fibre composites were found to compare favourably with those of glass. However, there are a number of natural fibres, especially those from non-plant sources. One of those fibres whose mechanical properties and industrial applications are yet to be researched is alpaca fibres.

The purpose of this study was to evaluate the stress and strain behaviour of alpaca fibre under continuous and cyclic loading conditions with the aim of determining the feasibility of its use as an alternative material for a number of industrial applications. Alpaca fibre is a natural fibre harvested from Alpaca, an animal that is traditionally raised as fibre producing livestock. Alpacas come in 22 basic colors, including white, black, brown, grey, tan, and cream. However, white is predominant as a result of selective breeding: The white fibre can be dyed in a large ranges of colors. There are two distinct breeds of alpacas: The Huacaya, Figure 1, constitute 95 percent of all alpacas while the rarer Suri, Figure 2, constitute the remainder. Virtually all the alpaca yarn used by knitters comes from the Huacaya, whose fibre is organized into uniform degrees of waviness. The Huacaya have their fluffy hair sticks straight out from their bodies. Their fibre is also dense and wooly. The Suri have long, separate locks with a high lustre. Their hair hangs down from their bodies in dreadlock-like ringlets, much like the fur of afghan hounds. The finest part of alpaca fleece is found on their back and sides. They are sheared much like sheep and the fibre is combed, carded, and after a basic cleaning process is ready to spin. Shorn every year, an alpaca will produce a fleece that weighs between two and four kilogram; the staple length—the length of the sheared locks without stretching or disturbing the crimp—is between ten and twenty centimeters [15 - 18].

Figure 1: A pair of Huacaya alpacas
Source: Wikipedia [15]

Alpacas are environmentally friendly. They have padded feet without hooves, doing little damage to their terrain. They also digest their diet of grasses and hay efficiently. Their camel ancestry means that they drink little water. While still small in numbers in United States and Canada, alpacas are a growing agricultural business and one that is uncommonly earth friendly [15, 18]. The world alpaca fibre production is around 5,000 tonnes per year. Peru is the largest producer of alpaca with 90% share of the world market [19].

1.1 Characteristics of Alpaca Fibre

Alpaca fibre is a soft, durable, luxurious and silky natural fibre. In physical structure, the fibre is very glossy and durable. Although it is similar to sheep's wool but it is warmer and not as prickly as sheep's wool. The fibre can be produced as light weight or heavy weight, depending on how it is spun [15-16]. The most valued attribute of alpaca fibre is its handle, or how it feels to the touch—creamy, silky and soft. While many factors affect the handle, the diameter of the fibre (fineness) is most important and is measured in microns (µm). The fibre used to make most alpaca yarn available to knitters ranges from the ultra-luxurious royal baby, which is never more than 18 microns, to super-fine, which averages 25.5 microns. Alpaca is also valued because it is lustrous, extremely strong, very warm (because of the microscopic pockets within the fibres that trap air), drapes beautifully, takes dye extremely well, and is not prone to pilling [15 - 21].

Alpaca fibre is valued by the textile industry and high fashion houses for its desirable luxurious softness, warmth without weight, range of natural colour and strength. Alpaca wool is a renewable biomass resource and it is easily obtainable [19]. Besides the reported use of Alpaca wool in the textile industry, there is no record of its utilization for other industrial applications. But it may have strong potential applications as a renewable biobased material. However to date, there are no reported studies of its mechanical properties that may warrant its utilization as a material for industrial applications like in electronics, furniture or automotives. The current upsurge in the wave of studies on natural materials and the growing interest in bio-based materials necessitate a study of this material to explore its potential use. In this study, alpaca wool fibre mechanical properties including its tensile strength, strain properties and young's modulus were investigated.

II. MATERIALS AND METHOD

2.1. Materials Characteristics

The fibres used in this study were obtained from the Natural Fibre Centre of Olds College School of Innovation. They were sheared from various parts of the body of Huacaya breeds of Alpaca. The fibres were collected in small plastic bags. They were neither treated with any chemical nor coloured. They were free of dirt and any physical impurity.

2.2. Preparation, Clamping and Testing of Alpaca Fibre

2.2.1 Stress-strain Testing

Test samples were prepared by mounting a strand of alpaca fibre on a paper carrier with a 5mm by 15mm cut out section. The fibre was secured to the paper, at both ends, with cellophane tape as shown in Figure 3. The sample was then clamped on an in-house designed fibre testing jig shown in Figure 4. The highly sensitive testing jig was designed specifically for this purpose, to measure load and elongation of fibres. The machine can travel at a rate from 0.008µm/s to 13.0µm/s [22]. The displacement is measured using a linear differential voltage transducer, LVDT. The displacement has a range of up to 40 mm, and an accuracy of ±0.1 mm. The load is measured through the use of a instrumented cantilever beam load cell. The load cell uses a full bridge strain gage arrangement, giving full temperature compensation and high amplification. The test results are measured and recorded through a computer coupled with a strain gauge conditioner and amplifier as shown in **Figure 5.**

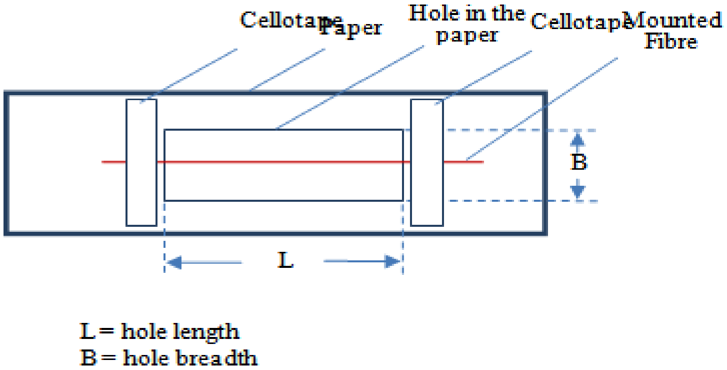

Figure 3: Test sample preparation

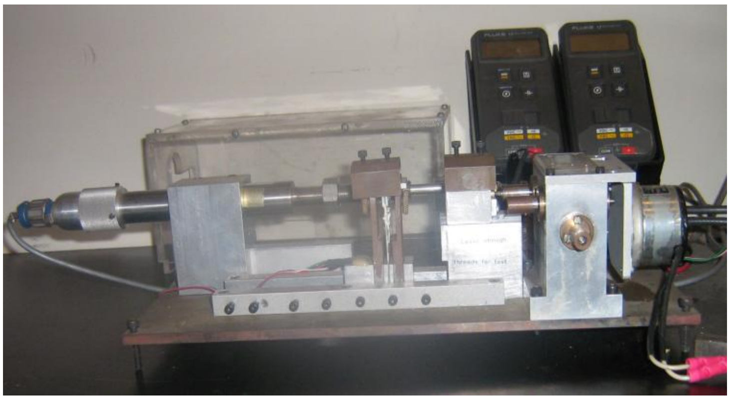

Figure 4 Fibre testing jig

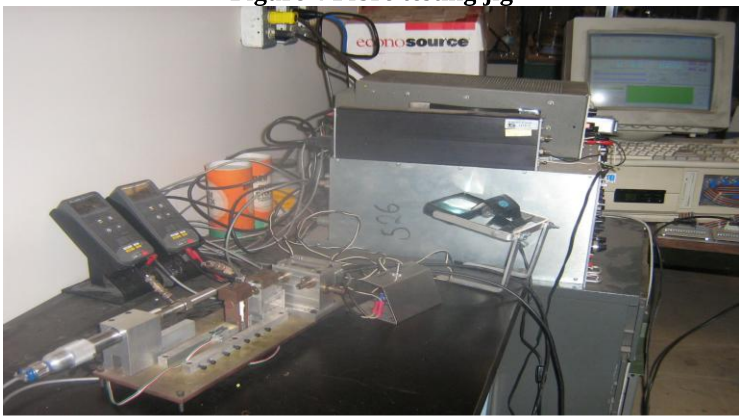

Figure 5 Fibre testing jig setup with computer for data recording

III. MECHANICAL PROPERTIES

The tensile strength and elongation of the fibre samples were measured with the fibre testing machine (shown in Figure 4) at various speeds and for various time periods. All testing was conducted at ambient temperature (22^0C) and a relative humidity of approximately 50%. The grip distance was set at 15 mm, which becomes the gage length of the fibre for the test condition. The initial and final lengths of each fibre were measured with a vernier calliper while the original and final diameters were measured by using a scanning electron microscope, SEM. The tensile strength, strain and young's modulus were calculated from the following equations [23]:

Stress

$$\sigma = \frac{F}{A} \qquad \text{………………………………………………………………..………………………….. 1}$$

σ …. Stress (Nm^{-2} or Pa)
F …. Force applied to the material N
A … cross section of the material m^2
Strain

$$\varepsilon = \frac{\Delta l}{l} \qquad \text{…………………………………………………………………………………………… 2}$$

l_0 … original length
$\triangle l$ … change in length

Young's modulus or elastic modulus $E = \frac{\sigma}{\varepsilon}$ ………………………………………………………. 3

E is a measure of stiffness i.e. resistance to strain by the fibre in the linear or elastic region.

IV. RESULTS AND DISCUSSION

A total of 4 fibres were randomly chosen from a given batch and tested using a 15mm gauge length. Young's modulus was calculated in the elastic portion of the stress–strain curve and then corrected for compliance by measuring force versus displacement of the testing machine. These results are shown in Table 1.

3.1 Stress-strain behaviour under cyclic loading

The fibre samples were tested under cyclic loading by stopping the stretching electric motor every minute and at different motor speed. We observedanelastic behaviourby alpaca fibre as shown in figure 10 below. The rebound in the fibre strength could be advantageous or disadvantageous. The merit and demerit of this property of alpaca depends on the area of its applications, time duration of each cycle, time interval between each cycle, and the intensity of stress induced each time. In dynamic applications, this would prevent the failure of the part. However, anelasticity could make the product to warp after a long time of cyclic loading due to thinning.

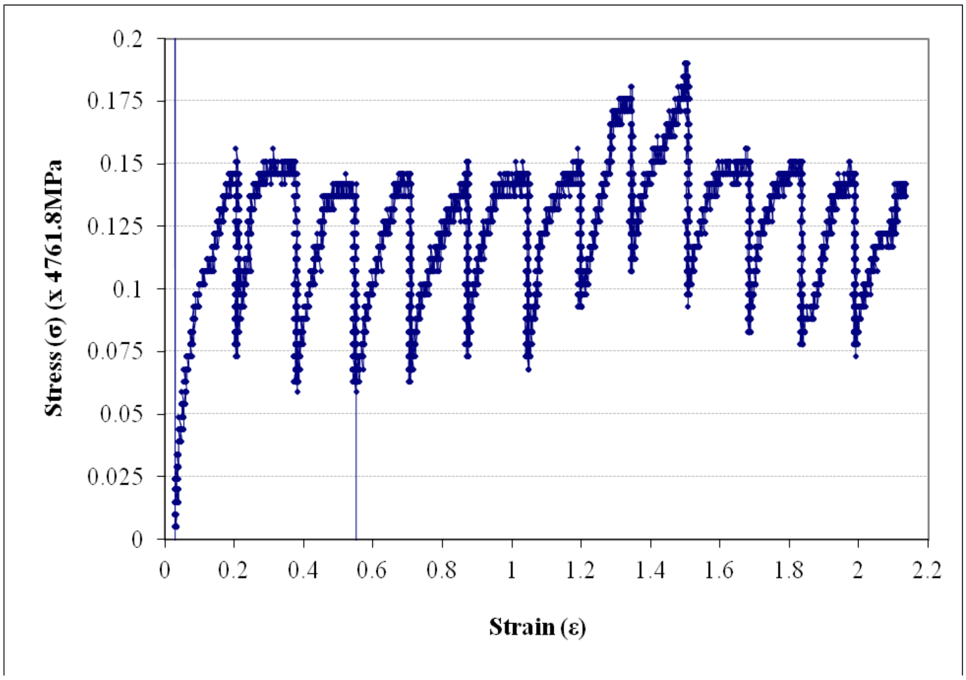

Figure 6 Alpaca fibre's behaviour under cyclic loading

3.2 Stress behaviour under cyclic loading

Alpaca fibre samples were tested under continuous loading by stretching the fibre at uniform speed until the stretchable limit permitted by the equipment was reached. We observed plastic behavior shown in Figure 7. This behaviour is similar to what is observed in many materials. It implies that the material will fail at a certain load value under continuous loading condition. It would be necessary to determine the load value by using a bigger capacity testing jig as the value could not be determine in this experiment due to the capacity limit of the jig used.

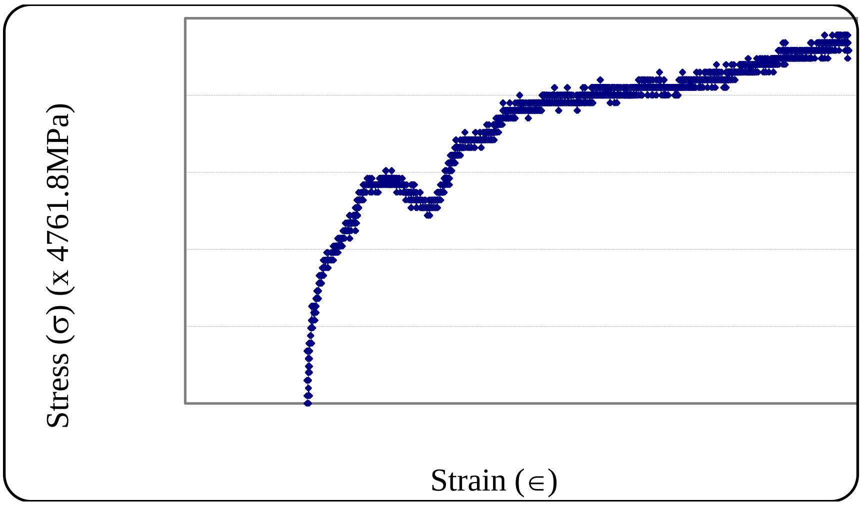

Figure 7 Alpaca fibre's behaviour under continuous loading

The variability in modulus and other mechanical properties is expected. The observation may likely be due to the variability in the microstructure and coarseness of the alpaca fibres obtained from different parts of its body and possible damage that may have occurred during the shearing process.

V. CONCLUSION

Initial mechanical properties of alpaca fibre have been determined. The knowledge of the fibre stress behaviour is essential to determining the potential utilization of the fibre for various industrial applications. The observed plastic behavior and rebounds in the fibre strength which are indications of its high ductility could significantly limit the fibre's utilization in many engineering applications. It would be necessary to carry out further studies to identify specific areas of possible applications. It would also be necessary to determine the relationship between alpaca age, the breeding conditions, and mechanical properties of the alpaca fibre. This would enable stakeholders to raise and manage alpaca herds for optimal fibre properties.

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