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Quantifying the uncertainty associated with the material properties of a natural fiber

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Abstract

Nowadays, natural fibers have earned a great deal of attention because they help produce eco-products. Since natural fibers grow naturally and their microscopic structures cannot be controlled, their material properties exhibit a great deal of variability. This variability or uncertainty must be known beforehand to ensure the reliability of a natural-fiber-based product. In this article, we use a widely used natural fiber collected from a plant called jute to perform the tensile tests, and, then, to determine the tensile strength and modulus of elasticity. We also quantify the uncertainty associated with abovementioned material properties using both statistical and logical approaches. Finally, we describe the design implications (while designing structure elements using jute fibers) of the quantified uncertainty.

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Keywords: Sustainability; Natural Fiber; Jute; Uncertainty; Material Property

1. Introduction

Nowadays, a concept called sustainability has earned a great deal of attention. It (sustainability) means fulfilling the present-day needs without jeopardizing the potential of fulfilling the future needs [1,2]. The salient point of sustainability is schematically illustrated in Fig. 1. As seen in Fig. 1, two worlds, artificial and natural worlds, simultaneously exist around us, and they must be synergistic to each other. In particular, the natural world consists of natural resources (water, air, land, ore, biomass, and hydrocarbon) whereas the artificial world consists of products (car, road, building, plane, train, pen, computer, paper, and many more). Using the natural resources, we produce primary energy and materials. Afterward, we use the primary energy and materials to produce products and support their lifecycles. A lifecycle means the chronological stages of a product, namely, conceptualization, design, manufacturing, use, recycle, and landfill. If a product (or its lifecycle) needs a large amount of energy and materials, it puts burden on the natural resources, and, thereby, on the natural world.

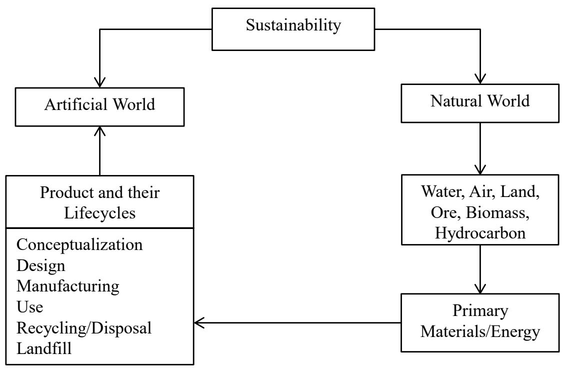

Fig. 1. Sustainability from the viewpoint of product lifecycle.

This means that the sustainability is jeopardized, if the demands of primary energy and materials are not kept within the stipulated limits. Numerous studies have shown that the types and usages of materials in the products (i.e., the constituents of the artificial world) heavily affect the sustainability [1,3]. Therefore, a great deal of attention is

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given on the materials that are sustainable. Needless to say, a sustainable material means its primary production requires less energy and resources. At the same time, its usages make the products less energy and recourse intensive. Natural fibers collected from various sources (e.g., coconut, coir, bamboo, sisal, and jute trees) are considered sustainable materials [4-7]. Since the natural fibers grow naturally, their microscopic structures cannot be controlled. As a result, the physical properties of natural fibers exhibit a great deal of variability. For example, see the works in [8-10] to realize how the strength and stiffness related properties of certain natural fibers vary. If the uncertainty associated with the material properties of natural fibers is not quantified in a systematic manner, a designer may face difficulties in designing a natural-fiber-based product. This means that the sustainable product development using natural fibers must be supported by an uncertainty quantification methodology/system.

In this study, we consider a widely used natural fiber collected from a plant called jute (hereinafter referred to as Jute fiber). We perform the tensile tests using the jute fiber specimens, and, then, determine the tensile strength and modulus of elasticity of each specimen. We also quantify the uncertainty associated with abovementioned material properties using both statistical and logical approaches. Finally, we describe the design implications (while designing structure elements using Jute fibers) of the quantified uncertainty. Finally, we show how the quantified uncertainty helps make an informed decision while designing such structural elements as tie, plate, column, beam, and alike, using the jute-fiber-based materials.

The remainder of the article is organized as follows. Section 2 describes the experimental procedure and results. Section 3 describes the uncertainty quantification process. Section 4 describes the implication of uncertainty based on some material indices. Section 5 provides the concluding remarks of this article.

2. Experimental Procedures and Results

Numerous authors have studied the material properties of various natural fibers by conducting experiments [11-24]. Some of the reported studies show that not only the length (short, medium, and long) of a fiber but also the segment (top, middle, or bottom) from where the fiber specimen has been collected may affect its material properties [11-14]. In particular, a fiber gradually becomes slender in the direction of bottom to medium to top [13-14,17]. This slenderness may cause a change in the material properties. Sometimes, the fibers are treated using chemicals (Copper Sulphate solutions) to protect them from the bacterial and fungal attacks. The chemical treatment may also affect the material properties of a natural fiber [15-17]. Therefore, it is customary to vary the length (long, medium, and short), chemical treatment procedure (raw and treated), and segment (top, middle, and bottom) while preparing the specimens for conducting material property related experiments.

Based on the above contemplation, the first half of this section describes the experimental procedure to perform the tensile tests using jute fiber specimens. The last half of this section reports the some of the experimental results showing the variability in the tensile strength and modulus of elasticity of jute fibers.

Figure 2 schematically illustrates the experimental procedure to know certain mechanical properties of the jute fibers. The procedure consists of the following six steps:

1) Collection of jute fiber and density measurement
2) Segmentation of fiber
3) Conditioning of fiber
4) Specimen preparation with required length
5) Tensile testing
6) Data analysis

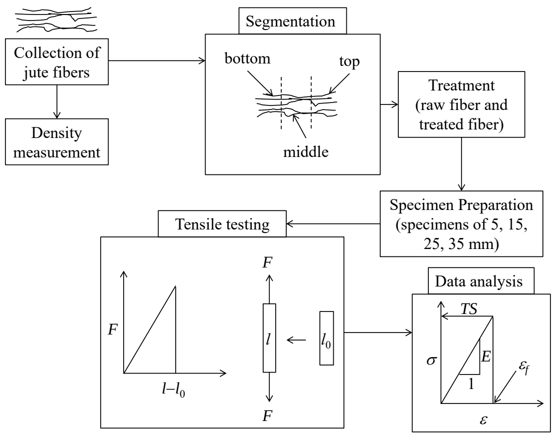

Fig. 2. The experimental procedure.

The first step is to collect the jute fibers and determine the density. For this particular case, the jute fibers are collected from the Faridpur regional station of Bangladesh Jute Research Institute (BJRI, http://www.bjri.gov.bd/), Bangladesh. To determine the density (ρ) of some fibers, first the mass (m) of the fibers is measured using precision weighting instrument. Afterwards, the fibers are socked into water to measure their volume (V). Therefore, ρ is calculated as follows: $\rho = \frac{m}{V}$.

In the second step, each jute fiber is cut into three pieces called top, middle, and bottom, as shown in Fig. 2. The average diameter of the fibers is also measured using scanning electron microscope. It is found that the diameters of the bottom segments are larger than those of the other segments, as expected. The diameters gradually increase in the direction of top, middle, and bottom segments, as expected.

In the third step, the fibers are conditioned either keeping them raw or treating them by using chemicals. In this study, some of the jute fibers are treated by using Copper Sulphate solutions at two different concentrations (20%, and 8%). The results corresponding to Copper Sulphate solutions with 20% concentration are reported in the next subsection.

In the fourth step, all specimens (treated, raw, bottom, middle, top) are cut to the lengths (l_0) of 5, 15, 25 and 35 mm, respectively. In the fifth step, the tensile tests are performed for the prepared specimens. In these tests, the tensile force (F) is applied to each specimen and the instantaneous length (l) is recorded. To do this, a universal tensile test machine