Characterization of Nonwoven Structures Made from Luffa Cylindrica Fibres

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Abstract.
This study is a fraction of a larger research, on potential alternatives, to polyethylene shopping-bags. Dry-laid adhesively-bonded nonwoven structure was produced, from *luffa cylindrica* fibres. Testing parameters of the produced nonwoven structure were limited to: a mass-per-unit-area, tested according to ISO 9073-1:1989; thickness (ISO 9073-2:1995); tensile-strength and elongation (ISO 9073-3:1989); tearing-strength (ISO 9073-4:1997); and bursting-strength (ISO 13938-2:1999). The data-analysis was conducted using Microsoft Excel, 2010 software. The nonwoven structure had mass-per-unit-area of (645-3386) g/m\(^2\); thickness of (1.48-1.80) mm; tensile strength of (1.4-110.2) N; elongation of (2.8-13.8) %; tearing-strength of (2,292.5-47,952.0) mN; and bursting-strength of (79.4-338.2) KPa. From the test-results, it was obvious, that the nature of bonding has significant effect, on the mass per-unit-area, tensile-strength and elongation, tearing-strength and bursting-strength of the nonwoven structure made from *luffa cylindrica* fibres. The selected properties, of the nonwoven structure, are comparable, with the requirements, for bursting-strength and tearing-strength, specified by Kenya Bureau of Standards (KEBS), for shopping-bags. The study, thus, presents a potential opportunity of replacing polyethylene shopping-bags, on the Kenyan market, with a nonwoven structure from *luffa cylindrica*, as a potential biodegradable substitute material for shopping-bags. Recommendations for further research are also identified.

Keywords: sustainable shopping bags, textile testing, natural fibres.

1. Introduction

1.1. Background situation: Impacts of polyethylene shopping-bags and the need for alternatives.
Plastic-pollution is a pervasive global environmental threat. Environmental impacts of plastic bags can be ordered into three groups: (1) aesthetic disturbance, (2) ecological impacts, and (3) socio-economic impacts. Readers, interested in more details on environmental impacts of plastic bags, could refer to Starovoytova et al (2016).

The environmental devastations, caused by synthetic bags are both direct and indirect, when considered, in terms of outcome effects. Among the direct effects, synthetic bags lead to floods, especially in urban locations and towns, when they block the drainage channels; in a bid to destroy these synthetic bags, most people opt for burning. When burnt, polyethylene bags, apparently, emit dioxin toxic flames, which pollute the air and present a danger of damage to human lungs, when inhaled (Harkin, 2016; Graham, 2012). Indirectly, the storage of hot food in plastic bags (a common practice, among urban dwellers) can result in the chemicals, such as Bisphenol-A and dioxins, to leach into the food and, hence, be ingested. When ingested over time, dioxins get fixed to human fats, resulting in the potential, to cause tissue changes, which may lead to cancer, in breast and prostate cells (Uwera, 2016), hormonal imbalance, in the adolescents, which may result in early puberty (eHow-UK, 2016), increase the risk of heart disease, aggravate respiratory ailments, such as asthma and emphysema, and cause rashes, nausea, headaches, damages in the nervous system, kidney or liver, in the reproductive and development system (WECF, 2012).

Considering the large scale damaging effects of plastic bags, many countries, all over the world, have already prohibited, the production and use of plastic bags, by enacting parliamentary legislations. However, the implementation of this complete ban, on the use of plastic bags, has not been successful, in Kenya, due to inadequate research and unavailability of suitable substitutes, for the polyethylene plastic bags. According to UNEP (2005), there are no satisfactory and affordable alternatives, to plastic shopping bags, in Kenya, except for some paper bags. Although shopping bags, made of natural fibers, are present in the market, their use is limited, because of the convenience and extensive availability of plastic shopping bags and their low cost or no cost, to the consumer.

1.2. Research purpose
In Kenya, the ban, on plastic bags was meant to take effect, on the midnight of the 14th of June, 2007, as stated by Amos Kimunya, the then finance minister of Kenya, in a bid to encourage, industrial players to come up with innovative ways, which are environmentally friendly. However, supermarkets and shops, in Kenya, still distribute, up to 11 million plastic bags, a year (Bahri, 2005).

The absence of innovative alternatives and biodegradable bags, which can serve the same purpose, with minimal negative impact, to the environment, has also fueled the delayed enforcement of the ban.
Therefore, the need for research, in-the-area of potential-environmentally-friendly-materials, for packaging-bags, suitable for the Kenyan-shopping-market, is apparent. The main-purpose of this-study is to produce a nonwoven-structure from *luffa cylindrica* fibres and characterize its-selected-properties.

The-packaging, used for shopping-bags, in most-urban-supermarkets, in-Kenya, is made of synthetic non-biodegradable-material, which is not-environment-friendly. The-biodegradable-paper alternatives for some-foodstuff, like maize-flour, are not-reusable. It is, thus, necessary to develop an environmentally-friendly-nonwoven-material, which can-cater, for this-vast-market-segment, with consideration, to sustainable-environmental-management. Several-fibres have the-potential of producing such-materials. In this-study the-focus was on *luffa cylindrica* fibres. This-project used *Luffa cylindrica* fibres adhesively-bonded with-environmentally-friendly bonding-agents (resins), to-produce a-nonwoven- structure, which was-assessed for its-suitability as-shopping-bags, on a-Kenyan-market. Subject to-success of the-study, Luffa-farmers will-be able, to get a-value-addition, for-their-products, generating more-income, from the-sale, of-their-products, to-the-nonwoven-manufacturers. Also, due to-the-simplicity, of producing the nonwoven-structure, from this-material, farmers involved in-producing luffa can-be-encouraged, to take-up commercial-initiatives, of producing and supplying, not only *luffa* fibres, but the-nonwoven structures made of these-fibres, to-the-already-available-market in-both; Kenya and the East African-region, as-a-whole.

1.3. Fibres to be used for production of the nonwoven-structure

Natural-fibres, are nowadays, increasingly-employed, for-making nonwoven, replacing the-synthetic materials, due-to-economic and environmental-considerations (Ghali, 2014).

*Luffa cylindrica* is a natural-fibre, locally known as ‘maratina’, is an-annual-climbing-vine, which produces a-fruit, containing a-fibrous-vascular-system. When separated, from the-skin, flesh and seeds, the fibre-network can-be-used, as a-bathroom-sponge (due-to the-fact that fibre has-very light-weight and considerable-wet and dry-strength, which enables its-multiple-reusability, in both-states). Since luffa has a compact-network of close-fibres, its-resiliency makes it-useful, for many-products, such as: packing material, for-making-crafts, filters, slipper-soles, and baskets. In-addition, immature-gourds are used, as vegetables. Luffa is environmentally-safe, biodegradable and a-renewable-resource (Aluyor, 2009). To-obtain the-fibres, it-is-necessary, to-subject the-gourds, to a-rettting-process, to-separate the-fibres, from the-extrax-pectin.

1.4. Production of nonwoven fabrics

From ISO 9092, nonwoven is defined, as-a-manufactured-sheet, web or batt of directionally or randomly-oriented-fibres, bonded by friction, and/or cohesion and/or adhesion, excluding paper and products which-are woven, knitted, tufted, stitch-bonded, incorporating binding-yarns, or filaments, or felted by wet-milling, whether or not additionally-needled (ISO 9092:2011).

Nonwoven-fabrics are the-oldest-technique, of fabric-production, discovered around 3500-3000 BC as-a-felt of-animal-hair (Ghosh, 2014). They essentially-consist of fibres, laid-together, by-different bonding-processes, instead of weaving, knitting or crocheting. The-processes are characterized, by producing a fibre-batt, bonding the-batts, to-form a-nonwoven-web, and finishing the-nonwoven (Anderson, 2016; Singh, 2014). The-desired-properties and applicability, of nonwovens, is-mainly influenced, by-choice of the-fibres, for developing the-nonwoven, technological-process of web-production, methods of web-bonding and finishing, imparted to-the-developed-nonwoven (Dubrovski, 2005). There is a number of batt-formation methods, used in-nonwoven-technology today, such as: dry- laying, wet-laying, spun-bonding, and melt blown-batt, formation-technologies.

A-study, by Andreassen et al (1995) shows, that the-tensile-properties, of nonwoven-fabrics, are governed by the-bonding-properties, of the-constituent-fibres, and not the-fibre-strength (Andreassen, 1995). A-bonding-agent works as-glue, as it-binds, the-fibre-laid-web, firmly-together, to-make-bonded nonwoven fabric (Ghosh, 2014). There are several-methods of web-bonding, such-as: (1) Resin-bonding (use of starch, as-bonding-agents, for cellulosic-fibres, and use of vinyl-acetate-emulsions, as-bonding-agents, for cellulosic-fibres); (2) Thermal-Bonding; (3) Hydrogen-bonding; (4) Needle-punching; (5) Multi-bonding; (6) Hydro- entanglement; and (7) Ultrasonic-bonding. The-choice of the-method, often-depends, on the-characteristics and required fabric-quality, in the-end-products. In-this-research, resin-bonding was used.

The-resin helps to-bind the-fibres, in-the-nonwoven-structure, by means of adhesive-forces. There is a-number of theories, which explain the-phenomenon, involved during-adhesion. Adhesion-theories, in the bonding of cellulosic-fibres, include: mechanical-interlocking, adsorption or wetting-theory, chemi-sorption theory, electrostatic-theory, diffusion-theory, and the-theory of weak-boundary-layers (Beardmore, 2011; Douglas, 2008).

Resin can-be-applied, to-nonwoven-fabrics, with the-help of a-size-press, as a-liquid or foam, or spraying, or by rotary-screen-printing, impregnation and foam-techniques. Resin can-be-added, to-the-batt, using a-size-press, as a-liquid or foam, or spraying, or by rotary-screen-printing. In-the-spray-technique, the top of the batt, is sprayed with-resin, dried in-the-oven, and then flipped, so that the-other-side, can-be sprayed, with resin,
oven-dried and cured, before cooling, slitting and winding into rolls. The application of resin to-batts, using foam-techniques, avails a-cleaner and most-economic-use of resin, especially on materials exceeding 100gsm. The-properties of webs, bonded in-this-way, depend on the-base-web-structure and properties, the-characteristics of the-resin-polymer-relative-stiffness or softness, relative-strength and resilience, the-relative-proportions, of the-bonding-agent and substrate-web, after drying and cross-linking, and the-method, of addition (Dahiya, 2004).

This study used Synemul TB 341 resin, which is a VAM-Veova Emulsion (Synresins Limited, 2016) as a-bonding-agent, in-the-production of a-nonwoven, from luffa cylindrica fibres. This is for the-reason that the-emulsion exhibits exceptional-binding-properties, coupled-with excellent colour-holding potential and tough-bonding, to-fabrics, when used, in-textile-printing (Synresins Limited, 2016). Upon disposal, the-emulsion can partition, to air, where it-is rapidly-degraded, without any-likelihood of bio-accumulation (The Dow Chemical Company, 2014).

1.5. Previous-Relevant studies
Researchers have-studied the-use of luffa cylindrica fibres, in-composites, as-a-matrix-material, with polyester-resin (Valcineide, 2014), resorcinol-formaldehyde (Parida, 2013), recycled low-density polyethylene (rLDPE) (Paschal, 2015); epoxy (Acharya, 2015); a-comparative-study of the-composites from the-different-resins has also-been-investigated (Contreras-Andrade, 2014). Luffa cylindrica fibres have also been-studied for application, as-reinforcement, in-polymer-concrete (Martínez-Barrera, 2014). Wetaka et al. (2016), also-reported, the-combined-effect of water-retting and alkali-treatment, on-tensile-properties of luffa cylindrica fibres. Besides the-use, as a-matrix, cellulose, from luffa cylindrica fibres, has found application, as a-binder, in-Acetaminophen-tablets (Macuja, 2015). The-use of luffa cylindrica as a-filler material, has also been-found, to-improve sound-absorption-properties, of soft-foam, at-frequency-ranges of 540Hz to 6300Hz (Ekici, 2012). However, there-is no-research, which has-been-published, in-open-literature (at-the-time, this-study was performed), as regards the-use of luffa cylindrica fibres, in-nonwovens, suitable for packaging-materials.

This-study, hence, provides an-insight of the-effect of different-bonding-agents, on-selected properties, of a-nonwoven-structure, from luffa cylindrica fibres.

2. Materials and Methods
2.1 Materials.
The-equipment, required for this-study included: buckets, beakers, conical-flasks, burets and pipettes, for measuring and handling chemicals; universal-tensile-testing-machine, bursting-strength-machine, high precision weighing-balance, drying-oven and micro-metre-disc-gauge, available, at the-Textile-Testing Laboratory, of Rivatex, East Africa, Limited.

2.2 Production of the nonwoven structure
2.2.1. Preparation of the materials
The-materials, for the-production, of the nonwoven-structure, were: luffa cylindrica fibres, ionic-liquid, maize-starch, Synemul TB 341 resin, and a woven-fabric-screen, for laying the nonwoven-structure.

First, the-woven-fabric-screen was prepared, by nailing a-screen-mesh onto a 50cm X 30cm wooden-frame. The water-retted luffa cylindrica fibres were then treated with pure-ionic-liquid and Sodium Hydroxide, at concentrations of 2% (w/v), 4% (w/v), and 8% (w/v) and neutralized with mild-acetic-acid, to remove Sodium Hydroxide, before rinsing, with distilled-water. Table 1 shows-the-summary of preparation of luffa cylindrica fibres, for different-webs. Batt-prefix is the-prefix, used in the-sample-labelling, to represent the-treatment-media, which the-materials were subjected-to.

<table>
<thead>
<tr>
<th>Batt Prefix</th>
<th>Treatment media</th>
</tr>
</thead>
<tbody>
<tr>
<td>IL</td>
<td>Ionic liquid</td>
</tr>
<tr>
<td>2</td>
<td>2% NaOH</td>
</tr>
<tr>
<td>4</td>
<td>4% NaOH</td>
</tr>
<tr>
<td>8</td>
<td>8% NaOH</td>
</tr>
</tbody>
</table>

The-treated-fibres were then dry-laid by-hand, as shown in Figure 1(a), on the-previousl-formed-screens and allowed to-settle-overnight. Four-kinds of webs were dry-laid, according to Tanchis (2008) for ionic-starch-bonding and three-webs for Synemul TB 341 resin. These included three-webs, treated with Sodium
Hydroxide at 2%, 4% and 8% used for both; ionic-starch-bonding and Synemul-TB-341-resin. One-web was made from *luffa cylindrica* fibres, boiled in-ionic-liquid for one-hour, in-order to-investigate the total-effect, of ionic-liquid, on the-properties *luffa cylindrica* nonwoven-structure.

Figure 1(b) shows examples of the-dry-laid-webs, after impregnation, with-bonding-agents. Bonding-agents used were-made of maize-starch, boiled in-ionic liquid and Synemul TB 341 resins, as summarized in Table 2, below. The-produced-nonwoven-structures were allowed to-dry, until they were free from tackiness and completely-solid, for one-week. For easy-identification, the-structures were given codes, instead of the-complete-descriptive-names. Batt-code represents the-combination of the batt-prefix, explained in the-previous-section and the-initials of the-bonding-agent employed. For-example, 2IS has prefix 2, which implies 2% NaOH and suffix IS which implies ionic liquid/starch adhesive.

Table 2: Summary of web-bonding-adhesive, to produce nonwoven-structures

<table>
<thead>
<tr>
<th>Batt Code</th>
<th>Treatment media</th>
<th>Bonding agent</th>
</tr>
</thead>
<tbody>
<tr>
<td>IL</td>
<td>Ionic liquid</td>
<td>Ionic Starch</td>
</tr>
<tr>
<td>2IS</td>
<td>2% NaOH</td>
<td>Ionic Starch</td>
</tr>
<tr>
<td>4IS</td>
<td>4% NaOH</td>
<td>Ionic Starch</td>
</tr>
<tr>
<td>8IS</td>
<td>8% NaOH</td>
<td>Ionic Starch</td>
</tr>
<tr>
<td>2S</td>
<td>2% NaOH</td>
<td>Synemul TB 341</td>
</tr>
<tr>
<td>4S</td>
<td>4% NaOH</td>
<td>Synemul TB341</td>
</tr>
<tr>
<td>8S</td>
<td>8% NaOH</td>
<td>Synemul TB341</td>
</tr>
</tbody>
</table>

The-dry-nonwoven-structures were then finished, by-passing-through pressing-rollers, as-shown in-Figure 1(c), to make the nonwoven-structure more-compact and stronger, according to Desai & Balasubramanian (1994).

2.2. Methods

2.2.1. Testing of the produced nonwoven-structure from *luffa cylindrica* fibres

*Testing* is the-process of verifying conformity-to-requirements, with the-help of either-artificial or natural means. In-this-study, testing will, mainly, refer to the-activities of establishing the-practicality of the-nonwovens-performance, in-relation to-what will-be-expected of it, in-real-applications. For-this-reason, the-nonwoven will-be-required, to-conform, to-acceptable loading-strength, bursting-strength, and appreciable-resistance, to-abrasive-forces. It-is, thus, crucial to-review, the-available and best-practice, on how-to-simulate the-performance, of the-nonwoven, through-these-tests, so-as-to-avoid cognitive dissonance, in the-intended-market.

All-the-testing was done, under standard-laboratory-conditions; at a-temperature of 20±2°C and 65±2% Relative Humidity (RH). All the-tests, identified-below, were conducted, according-to their -respective-standards. The nonwoven-structures were pre-conditioned for 24-hours, prior to the-analysis.

2.2.1.1 Mass-per-unit-area and thickness-test of the nonwoven-structure

According to ISO 9073-1:1989 Textiles – test methods for nonwovens - part 1: Determination of mass per unit area, the-principle involves measurement of an-area and mass of a-test-piece and calculation of its-mass per unit area in grams per square-meter. From each-sample, at least three-test-pieces are cut, with an-area of 50000mm², using either the-die or the-template and a sharp-razor-blade. In-case of insufficient-material, a largest-possible-rectangle is cut, and its-area determined, with the-help of a-meter-rule. The-mass per-unit area is then
In this study, the structure-samples were cut into rectangular shape and their length and width were obtained, using a meter-rule. The obtained length and width was used to calculate the area by multiplying the length by width. The same sample was then weighed, using a high-precision weighing-balance, and the weight was recorded. The mass per unit area was determined, from dividing the sample mass, by calculated area, as shown, in equation below. For each nonwoven structure, 5 specimens were evaluated and the average reading was recorded, as the mass per unit area.

\[
\text{Mass per unit area} = \frac{\text{sample mass in grams}}{\text{sample area in sq. metres}} \quad \text{(ISO 9073-1:1989)}
\]

ISO 9073-2:1995 specifies a method for the determination of the thickness of both normal and bulky nonwoven structures, under specific pressure. The principle involves measuring the distance, between the reference plate, on which the nonwoven rests, and a parallel presser-foot, which exerts a specified pressure, on the area under test. For normal nonwoven structures, the principle involves the use of two circular horizontal plates, attached to a stand, comprising an upper plate, or presser-foot, capable of moving vertically and having an area of, approximately, 2500 mm\(^2\), and a reference plate, having a plane surface of diameter, at least 50 mm greater than that of the presser-foot. A measuring device with graduations of 0.01 mm is used, for measuring the distance, between the reference plate, and the presser foot. To obtain results, 10 test pieces are taken and their thickness readings used, to calculate the mean thickness, of the nonwoven in mm, and the coefficient of variation, if required (Indian Standard, 2011).

The technique for determining thickness, of normal nonwoven structures, was employed, in this study. The nonwoven structures were pressed, under a constant pressure and the thickness was measured, using a Vanier calliper. For each nonwoven structure, 10 specimens reading were conducted and the average computed thickness, was recorded, as the thickness, of the nonwoven structure.

2.2.1.3 Tensile strength and elongation of the nonwoven structure

Tensile strength is indicative of the strength, derived from factors, such as: fibre strength, fibre length, and bonding. It may be used, to realize information, about these factors, especially when used, as a tensile strength index. For quality control purposes, tensile strength has been used, as an indication of the serviceability of many nonwovens, which are subjected, to a simple and direct tensile stress. When evaluating the tensile strength, the stretch and the tensile energy absorption for these parameters can be of equal or greater importance in predicting the performance of nonwovens, especially when that paper is subjected to an uneven stress, such as gummed tape, or a dynamic stress, such as when a sack full of granular material, is dropped.

The exposure of the nonwoven fabric, to a high relative humidity, before preconditioning and conditioning, can lead to erratic results, varying from a decrease in stretch and tensile, to a substantial increase, in these properties. Careful protection, of the sample, from the time of sampling until testing is, therefore, very important.

ISO 9073-3:1989 Textiles - Test methods for nonwovens. Part 3: Determination of tensile strength and elongation, specifies a method for the determination of the tensile properties of nonwovens, by the cut strip method. The principle involves application of a force longitudinally, to a test piece, of a specified length and width, at a constant rate of extension. Values for breaking strength and elongation, are then determined, from the recorded force elongation curve.

Preparation and conditioning of test pieces: Unless otherwise specified, cut 5 test pieces in the machine direction and 5 in the cross machine direction, ensuring that they are all taken, at least 100 mm from the edge, and are equally distributed, across the width and length of the specimen. Cut the test pieces 50 mm ± 0.5 mm wide and of sufficient length, to allow a jaw separation of 200 mm, thus avoiding risks, due to local heterogeneity of nonwovens, or to undue cutting of long fibre nonwovens.

Set the jaws of the tensile testing machine 200 mm + 1 mm apart, and clamp the test piece, between them, straighten out the test piece, until the force curve is on the zero line. Apply a constant rate of extension, of 100 mm/min, and record the force elongation curve, for each test piece. Determine the elongation, of the test piece, at the maximum breaking strength, and express this, as a percentage, of the nominal gauge length, that is, the original jaw separation. Discard the results, from any test piece, where the break occurs, in the clamp, or where any break reaches the jaws, at a minimum of one point. Determine the means of the results, expressing the average breaking strength, in Newtons, to the nearest 0.1 N, and the average percentage elongation at break, to the nearest 0.5 %. Calculate the coefficients of variation, of the results.

In this study, to achieve results, with minimal error, 6 test specimens were cut from the longitudinal and crosswise directions, to obtain the average, of each of the 7 fabric samples. The nonwoven dimensions were set, at 50 ± 0.5 mm wide, with sides, parallel within 0.1 mm and 100 ± 5 mm long gauge length, to facilitate easy clamping, of the fabrics, in the machine jaws. The fabric samples were checked for any abnormalities, creases and wrinkles, which may interfere, with the accuracy, of the findings.

2.2.1.4. Bursting strength of the nonwoven structure

Bursting strength is a measure of the strength of the material, when a multidirectional force is applied, on it.
Bursting-strength, thus, implies the-measure of resistance, of a-material to rupture (Rashed, 2014) or wear-damage of the-material (Das & Raghav, 2009). The-methods used, for determination of bursting-strength, of textile-structure, include the-Ball-burst-method (Wang, 2011), Pneumatic-bursting-method (Apurba, 2012), and Hydraulic-bursting-method (Akaydin, 2009). Generally, bursting-strength depends-upon the-kind, proportion, and amount of fibres present, in-the-sheet, their-method of preparation, their-degree of beating, and refining, upon sheet-formation, and the-use of additives.

ISO 13938-2:1999 describes a Pneumatic-method, for the-determination, of bursting-strength, and bursting-distension of knitted, woven, nonwoven and laminated-fabrics. The-principle involves clamping a test-specimen, over an-expansive-diaphragm, by-means of a-circular-clamping-ring. The-compressed air pressure, is, then, increased, on the-underside of the-diaphragm, causing swelling of the-diaphragm and the- test-specimen. The-pressure is increased smoothly, until the-test-specimen-bursts. The-mean bursting strength (KPa) and mean-height, at-burst (mm) are then recorded. The-bursting-strength and bursting- distortion are determined, via the-formula below (Indian Standard, 2009).

\[
\text{Bursting strength} = \text{mean bursting pressure} - \text{diaphragm pressure}.
\]

In-this-study, 10-specimens were-used, for each-reading; by-obtaining the-average-reading, for 5-tests, on each-fabric-surface i.e. five-tests were-done, on one-side, to-obtain the-average-reading, before turning to-the other-side, to-obtain the-average, of five-tests.

2.2.1.5 Tearing strength of the nonwoven structure

Tearing and tensile-tests are two-main-domains of interest, of research, as-regards the-physical-behaviour, of a textile-structure. However, only rupture, caused-by tearing, is much-more-closely related, to real-life-usage of the-structures (Kan, 2012). Tearing-tests can-be conducted, using the-Trapezoidal-method, Elmendorf- method, Trouser-method, or Wing and Tongue-tear-method. The-trouser-tear-test is mainly-used, for evaluating elastomeric-materials (Chang, 2002). Elmendorf-method is commonly-used for testing cotton and cotton-blended-fabrics (Dhamija & Chopra, 2007). The-wing-tear-method has been used by Beata & Iwona (2010), for determining, the static-tear-resistance, of woven-fabrics (Witkowska & Frydrych, 2010).

ISO 9073-4:1997 specifies a-method, for the-determination, of tear-resistance of nonwovens, by the trapezoid-method. The-method involves marking a-trapezoid, on a-test-piece; clamping of the-non-parallel- sides of the-trapezoid, in the-jaws of a-tensile-testing-machine, and application of a-continuously increasing-extension, to the-test-piece, in-such-a-way, that a-tear-propagates, across its-width. The-average maximum-tear-resistance is then determined, in Newtons (Indian Standard, 2011). The-samples were cut, according to-the-template, shown in Figure 2 below, from regions, with minimal to no-imperfections.

![Figure 2: Template for trapezoidal testing of bursting strength (ISO 9073-4:1997).](image)

The-machine-jaws were adjusted, to an-initial-length of 25-mm, and the-sample-piece, was clamped, along the-dotted-lined, shown in Figure 2 above. The tearing-strength, was then read from the-peaks of the graphs, plotted by the-machine, on a-monitor. 10-tests were conducted, for each-sample, 5 for each perpendicular and parallel-direction, to-obtain-average, for both-directions, of the-structure, as outlined in ISO 9073-4:1997. The-averages of the-tearing-strength, computed as \( t_{xx} \) (longitudinal tearing strength) and \( t_{sy} \) (crosswise tearing strength) were used for the-analysis.

2.3. Analysis of the nonwoven structure properties.

The-results, from testing of the-nonwoven-structure, from \textit{luffa cylindrica} fibres, were analyzed using Microsoft Excel, 2010-software and presented via bar-charts with percentage-error-bars, generated by the- software, from input-data.
3. Results, Analysis of results and Discussion

For ease of logical follow-up and comprehension, Results, Analysis of results, and Discussion, are presented jointly, in the following respective sections:

3.1 Mass per unit area

Figure 3 shows the variation of grams-per-square-meter of different nonwoven structures, from *luffa cylindrica* fibres.

![GSM of nonwoven structures from luffa cylindrica fibres](image)

**Figure 3:** GSM of nonwoven structures from *luffa cylindrica* fibres

**Keys (see table below):**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>IL</td>
<td>Nonwoven structure from fibres treated with ionic liquid and bonded with ionic liquid/starch adhesive.</td>
</tr>
<tr>
<td>2IS</td>
<td>Nonwoven structure from fibres treated with 2% NaOH and bonded with ionic liquid/starch adhesive.</td>
</tr>
<tr>
<td>4IS</td>
<td>Nonwoven structure from fibres treated with 4% NaOH and bonded with ionic liquid/starch adhesive.</td>
</tr>
<tr>
<td>8IS</td>
<td>Nonwoven structure from fibres treated with 8% NaOH and bonded with ionic liquid/starch adhesive.</td>
</tr>
<tr>
<td>2S</td>
<td>Nonwoven structure from fibres treated with 2% NaOH and bonded with Symemul TB 341 adhesive.</td>
</tr>
<tr>
<td>4S</td>
<td>Nonwoven structure from fibres treated with 4% NaOH and bonded with Symemul TB 341 adhesive.</td>
</tr>
<tr>
<td>8S</td>
<td>Nonwoven structure from fibres treated with 8% NaOH and bonded with Symemul TB 341 adhesive.</td>
</tr>
</tbody>
</table>

*NOTE: This key applies to all the subsequent Figures, with similar abbreviations.*

As shown in Figure 3, the mass per unit area, of the nonwoven structures, bonded with the Symemul TB 341 adhesive, is higher than that of the structures, bonded with ionic liquid/starch adhesive. For the same fibre-treatment of 2% NaOH and approximate thickness of 1.5mm, the nonwoven structure from Symemul TB 341 weighed 51.4% more than, the nonwoven structure, made from ionic liquid/starch adhesive.

3.2 Thickness

Figure 4 shows the thickness, of different nonwoven structures, from *luffa cylindrica* fibres. As shown in Figure 4, the thickness of the nonwoven structures was consolidated to 1.63±0.14mm. There was a variation of 6.25%, in the thickness of the nonwoven structures, bonded by ionic liquid/starch adhesive. Symemul TB341-adhesive-bonded-structures, exhibited a thickness variation of 16.67%. This can be attributed, to the observed plasticization effect, of sodium Hydroxide, on the-resin, since higher concentrations, resulted in higher viscosity.
3.3. Tensile-strength

As shown in Figure 5(a), the tensile-strength of the nonwoven-structures seems vary, with the pre-treatment, given to the fibres, more than the orientation, of the fibres in the nonwoven-structures. Nonwoven-structure, from *luffa cylindrica* fibres, treated with ionic-liquid, exhibited the second-lowest strength of only 36.67% and 39.13% better than the nonwoven-structure, from the fibres, treated with 8%NaOH, in the longitudinal and crosswise directions, respectively. The strength-percentage-range for fibres treated, with Sodium Hydroxide, and bonded with ionic-liquid/starch-adhesive, was 69.84% and 80.28%, in the longitudinal and crosswise directions, respectively. The strength-difference between orientations, of the different nonwoven-structures, was 20.00±6.05%, which is lower than the effect of pre-treatment used, implying that nonwoven-structures were fairly-random-laid.

Figure 5(b) shows the tensile-behaviour of *luffa cylindrica* random-laid nonwoven-structures bonded with Synemul-TB-341-adhesive. It shows that the tensile-strength of the nonwoven-structures were highly dependent, on the pre-treatment given to *luffa cylindrica* fibres, before laying. The strength-reduction from 2%NaOH to 8%NaOH was 78.33% and 78.54%, in the longitudinal and crosswise direction, respectively. This-high, but close-reduction in the-strength, of the nonwoven-structures bonded, with the Synemul-TB-341-adhesive, also reveals that the structures, were isotropic, in nature – that is, the probability, of a fibre-segment, in any-direction, between 0 and π is the same (= 1/π) (Batra, 2012).

As regards the effect of bonding-agent, nonwoven-structures bonded with the Synemul TB 341...
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exhibited much-higher tensile-strength of up to 97.28%, for same-pre-treated Luffa cylindrica fibres.

3.4. Elongation
As shown in Figure 6(a), the percentage-elongation, of the nonwoven-structures, seems vary, with the pre-treatment, given to the fibres, more than the direction of the nonwoven-structures, considering the 4IS structure. Nonwoven-structure from Luffa cylindrica fibres, treated with ionic-liquid, exhibited the highest-percentage-elongation, in the crosswise (Ey) direction of up to 6.6%, which was 57.58% greater than the lowest-percentage-elongation (exhibited by 4IS). The elongation-percentage-range, for fibres, treated with Sodium Hydroxide, and bonded-with ionic liquid/starch-adhesive, was 33.33% and 46.15%, in the longitudinal and crosswise-directions, respectively. The strength-difference between orientations of the different nonwoven-structures, was up to 0.00% (4IS) which is lower than the effect, of pre-treatment used, implying that nonwoven-structures, were fairly-random laid and isotropic.

As regards the effect of bonding-agent, nonwoven-structures, bonded with the Synemul TB 341, exhibited much-higher-percentage-elongation of up to 73.91%, for same pre-treated Luffa cylindrica fibres.

3.5. Tearing-strength
As shown in Figure 7(a), the tearing-strength of the nonwoven-structures, seems vary with the pre-treatment, given to the fibres, more than the direction, of the nonwoven-structures. Nonwoven structure from Luffa cylindrica fibres, treated with ionic-liquid, exhibited the lowest-strength, in the longitudinal (tsx) direction of 2293 mN, which was 82.97% lower than the exhibited-maximum by 2IS nonwoven-structure. The tearing-strength had percentage-range, for fibres, treated with Sodium Hydroxide and bonded-with ionic liquid/starch adhesive, of 66.17% and 48.74% in the longitudinal and crosswise directions, respectively. The strength-difference, between orientations of the different nonwoven-structures, was up to 1.52% (4IS), which is lower than the effect, of pre-treatment used, implying that nonwoven structures were, fairly-random laid, isotropic, in nature.
Figure 7: Tearing strength for nonwoven structures from *luffa cylindrica* fibres.

Key: (a) Bonded with ionic liquid/starch adhesive, (b) Bonded with Synemul TB 341 resin.

Figure 7(b) shows the tearing strength behaviour of *luffa cylindrical*, random-laid, nonwoven-structures, bonded with Synemul TB 341 adhesive. It shows that the tensile strength of the nonwoven-structures, were dependent on the pre-treatment, given to *luffa cylindrica* fibres, before laying, especially in the longitudinal (tsx) direction. The tearing strength reduction, from 2% NaOH to 8% NaOH was 65.73% and 76.63% in the longitudinal and crosswise-direction, respectively. This high reduction in the strength of the nonwoven structures bonded with the Synemul TB 341 adhesive, also reveals, that the structures were isotropic, in nature. This is because, when compared to 8.19% difference, between tsx and tsy of 8S nonwoven structure, except for tsy for 4S nonwoven-structure, which shows a tsx 65.01% greater than tsy. This can be attributed to some inevitable errors, which may result, from accidental orientation, of the fibres during consolidation, causing the internal fibres, to realign more in one-direction, leaving the other-direction, dependent on the adhesive, which has lower tearing strength.

As regards the effect of bonding agent, nonwoven-structures, bonded with the Synemul TB 341 exhibited much higher tearing strength of up to 73.19% (tsy 2) for same pre-treated *luffa cylindrica* fibres.

3.6. Bursting strength

As shown in Figure 8, the bursting strength increases, with concentration, of Sodium Hydroxide, used in pre-treatment, as observed in a 45.39%, increase from 2S to 8S. However when Synemul TB 341 was used, the bursting strength appears to decrease, by 58.66% from 2S to 8S nonwoven-structures. As much as the bursting strength of Synemul TB 341 bonded nonwoven-structures decreased, 8S nonwoven-structure was only 3.85%, weaker than 8S. Therefore overall, Synemul TB 341 bonded nonwoven-structures exhibited superior bursting strength, as compared nonwoven-structures, bonded with ionic liquid/starch adhesive.

Figure 8: Bursting strength of nonwoven structures from *luffa cylindrica* fibres
3.7. Specific requirements for shopping bags in Kenya

Table 3 shows specific requirements for shopping bags in Kenya, which used, in this study, as a benchmark, to assess the suitability of nonwoven structures for shopping bags.

Table 3: Specific requirements for paper shopping bags in Kenya (Kenya Standard KS 2523:2014)

<table>
<thead>
<tr>
<th>s. no.</th>
<th>Characteristics</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Class 1</td>
</tr>
<tr>
<td>a.</td>
<td>Grammage g/m² ±5%</td>
<td>50</td>
</tr>
<tr>
<td>b.</td>
<td>Bursting strength kPa min</td>
<td>90</td>
</tr>
<tr>
<td>c.</td>
<td>Tearing resistance (MD) mN, min</td>
<td>320</td>
</tr>
</tbody>
</table>

4. Conclusion and Recommendations

4.1. Conclusions

From the tests, conducted on the nonwoven structures, it was evident that the nature of bonding has a significant effect on the mass per unit area, tensile strength and elongation, tearing strength and bursting strength of the nonwoven, made from luffa cylindrica fibres.

The mass per unit area of the nonwoven structures, ranged from 1645.85 g/m² to 3386.26 g/m² with an average thickness, ranging from 1.5 mm to 1.8 mm. The tensile strength, in the longitudinal direction was found to be considerably greater, than the crosswise tensile strength. The ranges for were: Tₓ = 3.0N - 1.9N and Tᵧ = 2.3N - 1.4N for ionic starch bonded nonwoven structures. Synemul TB 341 bonded structures tensile strength was Tₓ = 110.2N – 23.9N and Tᵧ = 86.2N – 18.5N. The percentage elongation was in the range of 3.6% - 4.2% in Ex and 6.6% - 5.0% in Ey.

The tearing strength was ranging from 32119 mN to 4555 mN, in longitudinal direction and 47952 mN to 5944 mN, in the crosswise direction, which satisfies the range of 320 mN to 540 mN requirements, for shopping bags, in Kenya, specified by KEBS (Kenya Standard: KS 2523:2014).

The bursting strength was in the range of 79.4 KPa to 338.2 KPa, which satisfies the range of 90 KPa to 162 KPa requirements, for shopping bags, in Kenya, specified by KEBS (Kenya Standard: KS 2523:2014).

4.2. Recommendations for the nonwoven structure from luffa cylindrica fibres

1. Since the nonwoven, from ionic liquid/starch bonding-agent was fairly strong, but relatively stiff, this material can be used, as a space-filler, in packaging fragile objects, as a biodegradable substitute, to some plastics, which are not environmentally friendly.

2. The nonwoven, produced from ionic liquid, pre-treated fibres and ionic liquid/starch bonding agent, was relatively weak, but it can find good use, in packaging light items, which do not require excessive handling.

3. The nonwoven structure developed with Synemul TB-341-resin, exhibits very good mechanical properties, which satisfied most of the requirements, for shopping bags, on the Kenyan market.

4. There is an opportunity of blending luffa cylindrica fibres with other fibres, in order to avail more potential alternatives as regards substitutes to polyethylene bags on the Kenyan market.

5. There is an opportunity, for exploring different designs, of shopping bags, made from the proposed nonwoven structure, and subsequent testing of these bags, since this was outside of the scope of this concise study.

5. Acknowledgement

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