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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 cylindrical,* 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-fumes, 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-fuelled 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-fibers, 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 '*muratina'*, 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-retting-process, to-separate the-fibres, from the extra-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-fibers, 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-economical-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 1: Summary of preparation of *luffa cylindrica* fibres for different-webs

Batt Prefix	Treatment media
IL	Ionic liquid
2	2% NaOH
4	4% NaOH
8	8%NaOH

The-treated-fibres were then dry-laid by-hand, as shown in Figure 1(a), on the-previously-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

Batt Code	Treatment media	Bonding agent
IL	Ionic liquid	Ionic Starch
2IS	2% NaOH	Ionic Starch
4IS	4% NaOH	Ionic Starch
8IS	8%NaOH	Ionic Starch
2S	2% NaOH	Synemul TB 341
4S	4% NaOH	Synemul TB341
8S	8%NaOH	Synemul TB341

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).

(a) (b) (c)

Figure 1: Production of the-nonwoven-structure.

Key: (a) The-random dry-laid-web, from *luffa cylindrica* fibres; (b) The-adhesively-bonded web, from *luffa cylindrica* fibres; (c) Consolidating the nonwoven-structure, from *luffa cylindrica* fibres

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 ± 2^0C 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 50000mm^2, 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 determined, under standard-atmosphere for testing (Indian Standard, 2011).

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.

$$Mass\ per\ unit\ area = sample\ mass\ in\ grams/sample\ area\ in\ sq.metres \qquad \text{(ISO 9073-1:1989)}$$

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, 2500mm^2, and a-reference-plate, having a plane-surface of diameter, at least-50mm greater-than that, of the-presser-foot. A measuring-device with graduations of 0.01mm 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 pre-conditioning 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).

Bursting strength = mean bursting pressure – 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 tearin,g 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.

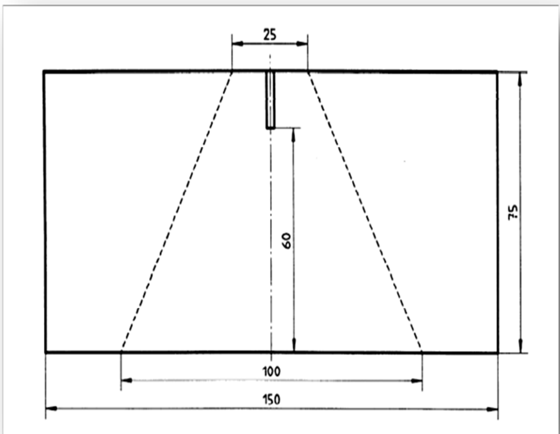


Figure 2: Template for trapezoidal testing of bursting strength (ISO 9073-4:1997).

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 *tsx* (longitudinal tearing strength) and *tsy* (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 *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.

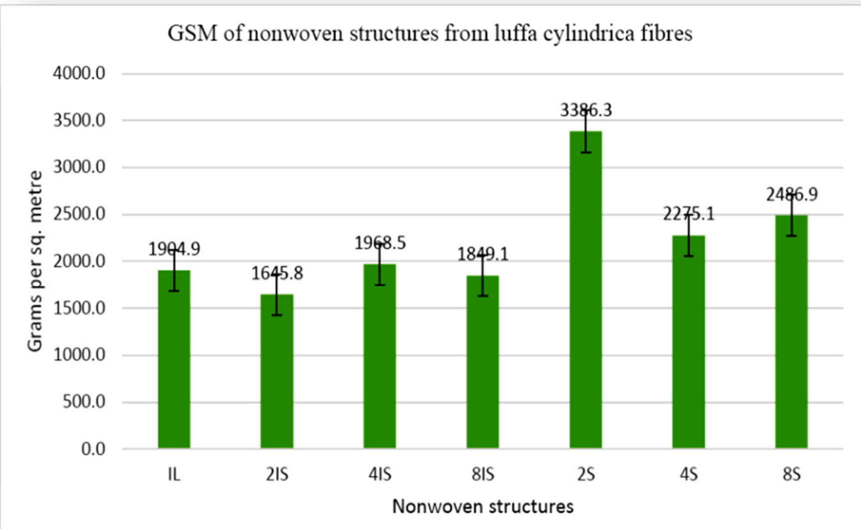


Figure 3: GSM of nonwoven structures from *luffa cylindrica* fibres

Keys (*see table below*):

Abbreviation	Meaning
IL	Nonwoven structure from fibres treated with ionic liquid and bonded with ionic liquid/starch adhesive.
2IS	Nonwoven structure from fibres treated with 2%NaOH and bonded with ionic liquid/starch adhesive.
4IS	Nonwoven structure from fibres treated with 4%NaOH and bonded with ionic liquid/starch adhesive.
8IS	Nonwoven structure from fibres treated with 8%NaOH and bonded with ionic liquid/starch adhesive.
2S	Nonwoven structure from fibres treated with 2%NaOH and bonded with synemul TB 341 adhesive.
4S	Nonwoven structure from fibres treated with 4%NaOH and bonded with synemul TB 341 adhesive.
8S	Nonwoven structure from fibres treated with 8%NaOH and bonded with synemul TB 341 adhesive.

*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 Synemul 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 Synemul 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. Synemul 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.

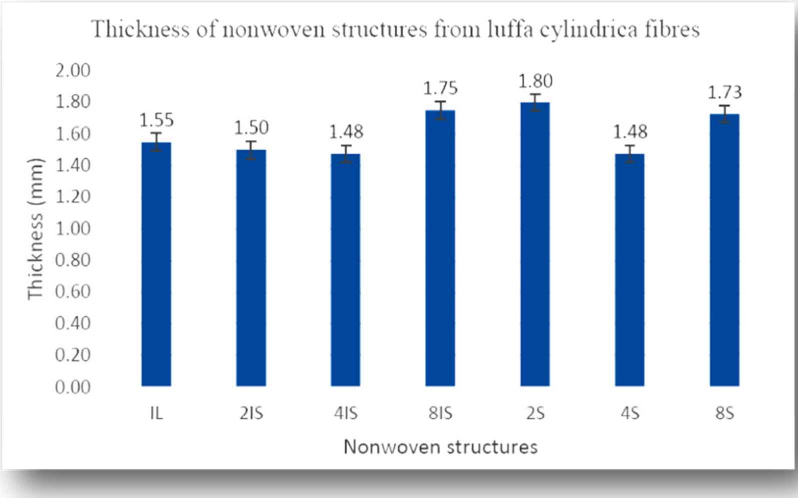
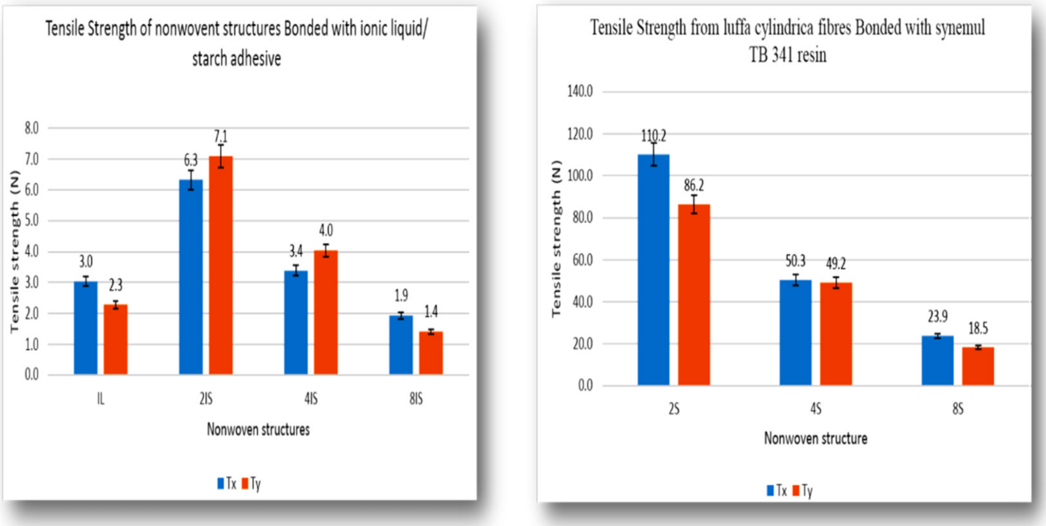


Figure 4: Thickness for different nonwoven-structures

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.



(a) **(b)**

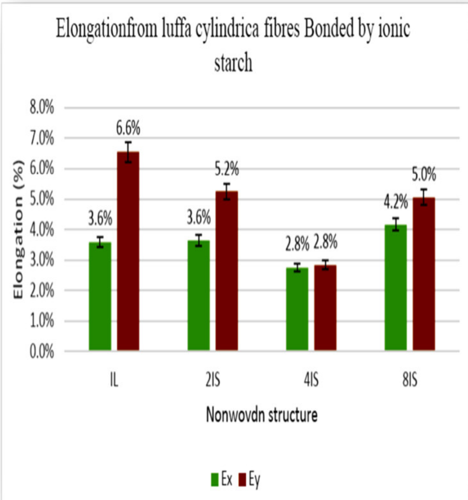
Figure 5: Tensile-strength for nonwoven structures from *luffa cylindrica* fibres.
Key: (a) Bonded with ionic liquid/ starch adhesive, (b) Bonded with Synemul TB 341 resin.

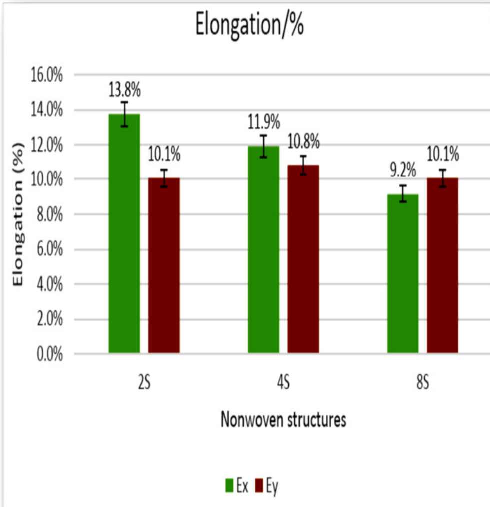
Figure 5(b) shows the-tensile-behaviour of *luffa cylindrica* random-laid nonwoven-structures bonded with Synemul-TB-341-adhesive. It-shows that the-tensile-strength of the nonwoven-structures were highly dependent, on the-pre-treatment given to *luffa cylindrica* fibres, before laying. The strength-reduction 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 (= $1/\pi$) (Batra, 2012).

As regards the-effect of bonding-agent, nonwoven-structures bonded with the Synemul TB 341 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.





(a) **(b)**

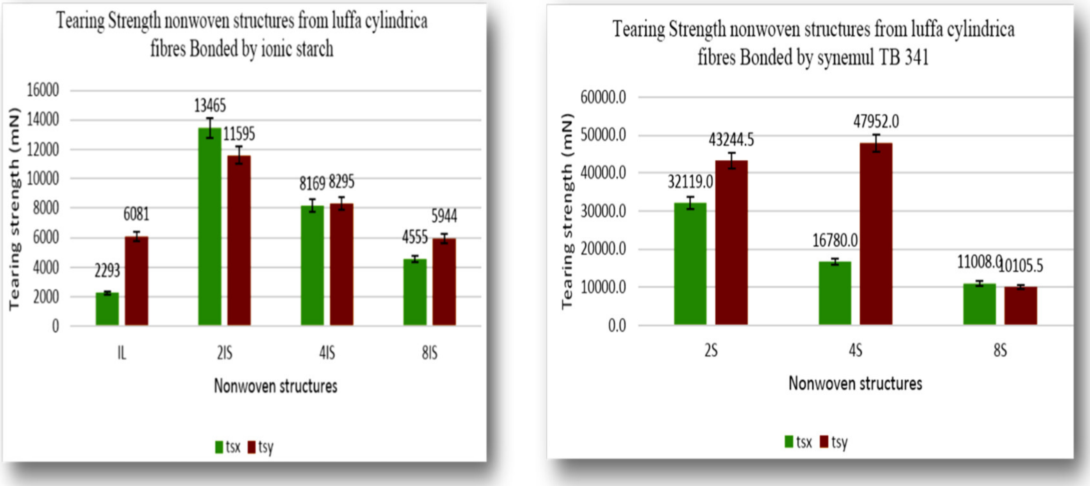
Figure 6: Percentage elongation for nonwoven structures from *luffa cylindrica* fibres.
Key: (a) Bonded with ionic liquid/ starch adhesive, (b) Bonded with Synemul TB 341 resin.

Figure 6(b) shows the percentage-elongation-properties of *luffa cylindrica* random-laid nonwoven-structures bonded with Synemul TB 341 adhesive. It-shows that the-percentage-elongation of the-nonwoven-structures were highly-dependent, on the-pre-treatment, given to *luffa cylindrica* fibres, before laying, with a-gradual-decline, from 2S to 8S structures. The-reduction, in-percentage-elongation from 2%NaOH to 8%NaOH was 33.33% and 0.00%, in the-longitudinal and crosswise-direction, respectively. The 0.00% difference for the structures 2IS and 8IS implies, that the-percentage-elongation in nonwoven-structures, bonded by ionic liquid/starch adhesive, was independent of the pre-treatment, given to *luffa cylindrica* fibres.

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.



(a) **(b)**

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 2IS to 8IS. 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 8IS. Therefore overall, Synemul TB 341 bonded-nonwoven-structures exhibited superior-bursting strength, as-compared nonwoven-structures, bonded with ionic-liquid/starch-adhesive.

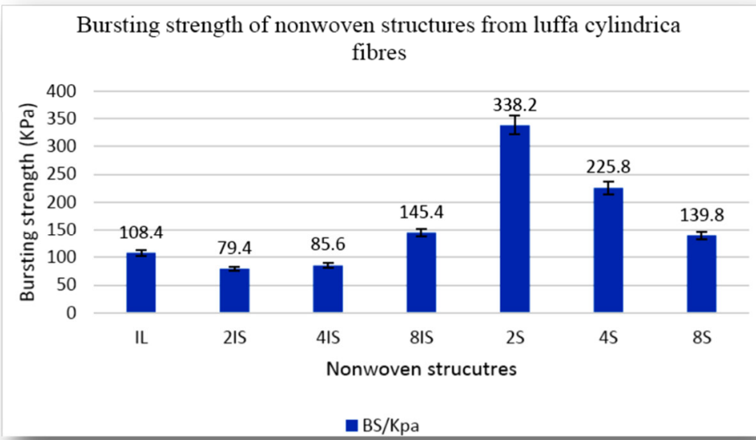


Figure 8: Bursting strength of nonwoven structures from *luffa cylindrica* fibres

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 bench-mark, 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)

s. no.	Characteristics	Requirements		
		Class 1	Class 2	Class 3
a.	Grammage g/m2 ±5%	50	60	70
b.	Bursting strength kPa min	90	124	162
c.	Tearing resistance (MD) mN, min	320	430	540

4. Conclusion and Recommendations

4.1. Conclusions
From the-tests, conducted on the-nonwoven-structures, it was evident, 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, made from *luffa cylindrica* fibres.

The-mass-per-unit-area of the-nonwoven-structures, ranged from 1645.85 g/m2 to 3386.26 g/m^2 with an-average-thickness, ranging from 1.5mm to 1.8mm. 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 Ty = 2.3N – 1.4N for ionic starch bonded nonwoven-structures. Synemul TB 341 bonded structures tensile-strength was Tx = 110.2N – 23.9N and Ty = 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 relative-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 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.

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