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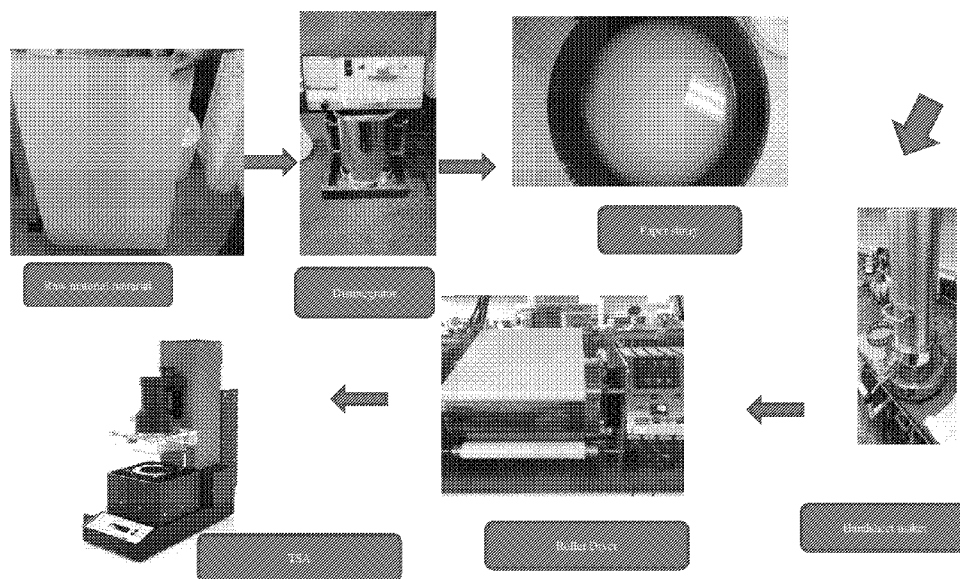


FIG. 1

(57) Abstract: A method of making a paper product including incorporating a sufficient amount of a man-made fiber into the paper product to impart in it a softness characterized by a lamellas vibration of less than or equal to about 10 dB and a bail burst strength greater than or equal to about 4 N.



**TISSUE PRODUCTS INCORPORATING MAN-MADE FIBERS,
AND METHODS OF MAKING AND USING THE SAME**

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Application No. 62/570,933, filed October 11, 2017, which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] The present disclosure pertains, generally, to tissue products incorporating man-made fibers to improve, among other things, softness and strength, as well as methods of making and using the same.

BACKGROUND

[0003] For paper based tissues, towels, napkins, facial tissues, and toilet tissues, the softness, strength (dry and/or wet), and absorbency are all key factors in how a consumer evaluates the value of the product. Typically, to improve the strength of tissue paper based hygiene products, one of four different approaches is undertaken.

[0004] First, the fiber used to create the sheet may be refined or beaten to increase fibrillation, and make the fiber more flexible in the wet state. This leads to consolidation of the sheet during the tissue making process. This increased consolidation (density) of the sheet has a negative impact on the softness of the sheet. Thus, this approach presents a softness/strength trade-off.

[0005] The second approach is to increase the wet pressing of the sheet. If a tissue machine has a wet press, it is typically run at a relatively low pressure so as to provide some water removal and consolidation of the sheet, but not high enough to over consolidate the sheet. Over consolidation leads to improved strength, but decreased softness.

[0006] Another approach to improving sheet strength is to increase the amount of softwood (long) fiber in the sheet. An issue with this is that softwood does not create a soft sheet due to its

rather large fiber size and overall coarseness. Thus, once again, additional strength is provided while softness is sacrificed.

[0007] Lastly, one can add strength additives to the fiber furnish. This enhances the bonding between the fibers and makes the overall strength of the material greater, but this also tends to bond surface fiber to the sheet, which in effect reduces the surface softness of the sheet. Thus, strength improvements are achieved, but with a sheet that has reduced softness.

[0008] Thus, there is a need for an approach that increases strength and/or softness without decreasing the other.

SUMMARY

[0009] In one aspect, provided is a tissue product with an apparent density less than about 450 kg/m³ and a basis weight less than about 75 g/m².

[0010] In another aspect, provided is a tissue product comprising man-made fibers, the tissue product having a softness characterized by a lamellas vibration (TS7 peak) of less than or equal to about 15 dB, and a ball burst strength of greater than or equal to about 2 N.

[0011] In yet another aspect, provided is a method of making a tissue product, the method comprising incorporating a sufficient amount of man-made fibers into the tissue product to impart in the tissue product a softness characterized by a lamellas vibration (TS7 peak) of less than or equal to about 15 dB, and a ball burst strength of greater than or equal to about 2 N.

[0012] Other aspects of the invention will become apparent by consideration of the detailed description and accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] FIG. 1 illustrates a modified handsheet making process.

[0014] FIG. 2 illustrates results from a Tissue Softness Analyzer (TSA) measurement.

[0015] FIG. 3A and FIG. 3B illustrate the effect on ball burst resistance by percent Microfiber for hardwood (FIG. 3A) and softwood (FIG. 3B) based handsheets.

[0016] FIG. 4A and FIG. 4B illustrate the effect on ball burst resistance by percent Microfiber and denier/cut length ratio for hardwood based handsheets.

[0017] FIG. 5 illustrates the effect on ball burst resistance by percent Microfiber and denier/cut length ratio for softwood based handsheets.

[0018] FIG. 6A and FIG. 6B illustrate the effect on tensile strength by percent Microfiber for hardwood (FIG. 6A) and softwood (FIG. 6B) based handsheets.

[0019] FIG. 7A and FIG. 7B illustrate the effect on tensile strength by percent Microfiber and denier/cut length ratio for hardwood based handsheets.

[0020] FIG. 8 illustrates the effect on tensile strength by percent Microfiber and denier/cut length ratio for softwood based handsheets.

[0021] FIG. 9A and FIG. 9B illustrate the effect on softness by percent Microfiber for hardwood (FIG. 9A) and softwood (FIG. 9B) based handsheets.

[0022] FIG. 10 illustrates the effect on softness by percent Microfiber and denier/cut length ratio for hardwood based handsheets.

[0023] FIG. 11 illustrates the effect on softness by percent Microfiber and denier/cut length ratio for softwood based handsheets.

[0024] FIG. 12 illustrates the linear relationship between softness and ball burst strength for hardwood based handsheets according to the present disclosure.

[0025] FIG. 13 illustrates the linear relationship between softness and ball burst strength for softwood based handsheets according to the present disclosure.

[0026] FIG. 14A and FIG. 14B illustrate the effect on water uptake by percent Microfiber for handsheets according to the present disclosure.

DETAILED DESCRIPTION

[0027] The disclosure generally provides for tissue products having improved properties (particularly, with respect to softness and strength) through the use of various man-made fibers.

[0028] One of the greatest challenges facing manufacturers of tissue products, such as tissue and toweling, is the ability to make a tissue product that has both softness and strength. Consumers generally require a minimum strength, below which the product is considered of little utility. For some grades (e.g., facial tissue and toilet tissue), the softness is of high importance. Consumers will generally pay a higher amount for softer and more absorbent products. Thus, producers compete by trying to make increasingly softer tissue while maintaining the minimal functional strength. Typically, the strength of tissue or paper toweling is increased by densifying the sheet or by adding chemicals. When using these traditional strengthening techniques, however, the softness of the sheet is typically reduced. This results in a strength versus softness trade off. One aspect of the disclosure is the use of man-made fibers having specified geometric shapes, mechanical properties, and bonding abilities that impart the desired softness and strength to the paper products.

[0029] The present invention is now described more fully hereinafter with reference to the accompanying drawings, in which embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather these embodiments are provided so that this disclosure will be thorough and complete and will fully convey the scope of the invention to those skilled in the art.

Definitions

[0030] The terminology used in the description of the invention herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the invention. As used in the description of the invention and the appended claims, the singular forms “a,” “an” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise.

[0031] Unless otherwise defined, all terms, including technical and scientific terms, used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. It will be further understood that terms, such as those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the present application and relevant art and should not be interpreted in an idealized or overly formal sense unless expressly so defined herein. The terminology used in the description of the invention herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the invention. All publications, patent applications, patents and other references mentioned herein are incorporated by reference in their entirety. In case of a conflict in terminology, the present specification is controlling.

[0032] Also as used herein, “and/or” refers to and encompasses any and all possible combinations of one or more of the associated listed items, as well as the lack of combinations when interpreted in the alternative (“or”).

[0033] Unless the context indicates otherwise, it is specifically intended that the various features of the invention described herein can be used in any combination. Moreover, the present invention also contemplates that in some embodiments of the invention, any feature or combination of features set forth herein can be excluded or omitted. To illustrate, if the specification states that a complex comprises components A, B, and C, it is specifically intended that any of A, B, or C, or a combination thereof, can be omitted and disclaimed.

[0034] As used herein, the transitional phrase “consisting essentially of” (and grammatical variants) is to be interpreted as encompassing the recited materials or steps “and those that do not materially affect the basic and novel characteristic(s)” of the claimed invention. See, *In re Herz*, 537 F.2d 549, 551-52, 190 U.S.P.Q. 461, 463 (CCPA 1976) (emphasis in the original); see also MPEP § 2111.03. Thus, the term “consisting essentially of” as used herein should not be interpreted as equivalent to “comprising.”

[0035] The term “about,” as used herein when referring to a measurable value such as an amount or concentration and the like, is meant to encompass variations of $\pm 10\%$, $\pm 5\%$, $\pm 1\%$, $\pm 0.5\%$, or even $\pm 0.1\%$ of the specified value as well as the specified value. For example, “about X” where X is the measurable value, is meant to include X as well as variations of $\pm 10\%$,

$\pm 5\%$, $\pm 1\%$, $\pm 0.5\%$, or even $\pm 0.1\%$ of X. A range provided herein for a measureable value may include any other range and/or individual value therein.

[0036] As used herein, the terms “increase,” “increases,” “increased,” “increasing,” “improve,” “enhance,” and similar terms indicate an elevation in the specified parameter of at least about 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, 100%, 150%, 200%, 300%, 400%, 500%, or more.

[0037] As used herein, the term “Microfiber” refers to microfiber made according to U.S. Publication No. 2012/0178331 published July 12, 2012 (U.S. Patent Application No. 13/273,692 filed on October 14, 2011), which is hereby fully incorporated by reference.

[0038] As used herein, the term “tissue product” refers to a fiber based product that is formed from a suspension into a sheet and generally has a basis weight below 75 g/m² and an apparent density below 450 kg/m³ in the final product form. In addition, tissue may be defined according to the Technical Association of the Pulp and Paper Industry (TAPPI), which identifies 12 major paper grades and more than 300 specific grades (Paper grade classification TIS 0404-36).

[0039] As used herein, the term “furnish” refers to a mixture of fibers and additives in a suspension and other additives in solution prior to forming a tissue sheet.

[0040] As used herein, the terms “reduce,” “reduces,” “reduced,” “reduction,” “inhibit,” and similar terms refer to a decrease in the specified parameter of at least about 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, 97%, or 100%.

Fibers

[0041] The man-made fibers of the present disclosure may comprise different materials and have different properties.

[0042] In some embodiments, the man-made fibers may comprise a regenerated cellulose, cellulose acetate, polylactic acid, polyethylene terephthalate, high density polyethylene, low density polyethylene, polypropylene, nylon, polycarb lactate, polyester, rayon, starch, chitin,

chitosan, collagen, soy protein, a composite thereof, or a combination thereof. In one preferred embodiment, the man-made fibers comprise polyethylene terephthalate.

[0043] The man-made fibers may have at least one of the following characteristics: a cross sectional geometry that is round, rectangular, lobular, oval, “eye shaped,” square, x-shaped, or another defined geometry; a length in the range of about 0.2 mm to about 10 mm; a calculated bending moment of inertia around at least one axis smaller than about $1000 \mu\text{m}^4$; a calculated bending stiffness in at least one direction smaller than about $75 \text{ N} \cdot \mu\text{m}^2$; and dispersability in water without the aid additional suspending agents.

[0044] In certain embodiments, the fibers may have a length between about 0.2 mm and about 10 mm long. The fiber may be at least 0.2 mm, at least 0.3 mm, at least 0.4 mm, at least 0.5 mm, at least 1 mm, at least 2 mm, at least 3 mm, or at least 4 mm in length. The fiber may be less than 10 mm, 9 mm, 8 mm, 7 mm or 6 mm in length. Typically, the fibers have at least one dimension that is less than about $1/100^{\text{th}}$ of the length of the fiber.

[0045] In certain embodiments, the fibers may have a calculated bending moment of inertia around at least one axis less than or equal to about 1500, about 1400, about 1300, about 1200, about 1150, about 1100, about 1050, about 1000, about 950, about 900, about 850, about 800, about 700, about 600, or about $500 \mu\text{m}^4$.

[0046] In certain embodiments, the fibers may have a calculated bending stiffness in at least one direction less than or equal to about 100, about 95, about 90, about 85, about 80, about 70, about 75, about 60, about 65, about 55, or about $50 \text{ N} \cdot \mu\text{m}^2$.

[0047] The man-made fibers also have a geometry such that they have very low stiffness (high flexibility) in at least one direction. For example, a thin flat fiber will easily bend around one axis due to the reduced moment of inertia created by the flat fibers. In contrast, conventional wood fibers used for papermaking tend to maintain their tubular structure in the tissue sheet and thus exhibit a higher bending stiffness. Adding the man-made fibers results in a softer tissue structure as indicated by the Emtech Tissue Softness Analyzer, for example. The Emtech Tissue Softness Analyzer uses a combination of mechanical and acoustic measurements which correlate to the softness of the sheet, as measured by hand panel scores.

[0048] The fibers may be made of a material with an elastic modulus less than that of cellulose (about 10 GPa), such that when the fiber is bent it has a significant lower stiffness when compared to a traditional papermaking fiber. The fibers may have an elastic modulus of less than or equal to about 10 GPa, about 9 GPa, about 8 GPa, about 7 GPa, about 6 GPa, or about 5 GPa.

[0049] Furthermore, the fiber may have the ability to bond to traditional papermaking fibers and/or itself without the addition of other binder materials. That is to say, the fiber may have a binder integrated into it or be naturally capable of bonding to traditional papermaking fibers and/or itself.

[0050] The fibers may be made by spinning an “X” denier mother fiber, which can be reduced to length. From this, “Y” daughter fibers are created during the dissolving process. They have a lower denier than the mother fiber by a certain factor. There is also a distribution of deniers in the daughter fibers depending on exactly where they are located in the mother fiber. Thus, the deniers reported herein are generally nominal deniers for the mother fiber, to which the daughter fiber denier should be directly proportional.

[0051] In other words, the denier is a nominal denier of the fiber as spun. However, the final denier of the fibers varies as multiples of the final fibers derived from the parent fibers and may have different deniers than the nominal denier. Thus, the fiber properties described in this application may be nominal fiber dimensions, unless described in more detail, or may be considered as the average fiber property if a measurement, or as a reasoned measure of the fiber property based on the inputs into the process.

[0052] In certain embodiments, the “X” value for a mother fiber may be 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, or 30. In certain embodiments, the “Y” value for a daughter fiber may be 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, or 30. In certain embodiments, the reduction factor between the denier of the mother fiber and the daughter fiber may be about 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, or 20.

[0053] One example of a suitable man-made fiber is microfiber from Eastman made according to U.S. Publication No. 2012/0178331 published on July 12, 2012 (U.S. Patent Application No. 13/273,692 filed on October 14, 2011), which is hereby incorporated by reference in its entirety. These fibers may have flat, circular, or irregular cross sections. When added to papermaking process in an amount from about 5% to about 100%, the resulting tissue sheet exhibits improved softness, as measured by the EmTech Tissue Softness Analyzer, and the same or improved strength when compared to a sheet made with traditional papermaking fibers.

[0054] The fibers may have a specified bending modulus (bending stiffness). Bending modulus is calculated based on the following method. For natural fibers, such as unrefined wood fibers, three different fiber measurements are used to characterize the fiber: length, width, and coarseness (mass per unit length). The fiber is taken to have a cylindrical shape in the dry state. The width of the fiber is taken to be equal to the outer diameter of cylinder. The thickness of the cell wall is determined by using the density of cellulose (about 1500 kg/m³) and coarseness to determine the cross sectional area of the fiber (coarseness divide by density). The inner radius of the cylinder is then defined by the following:

$$r_{inner} = \sqrt{\left(r_{outer}^2 - \left(\frac{Cross\ Sectional\ Area}{\pi} \right) \right)}$$

[0055] Using the inner and outer radius, the bending moment of inertia can be calculated as the value of π times the difference of the outer radius raised to the fourth power and the inner radius raised to the fourth power. Nominally flat fibers can be approximated as rectangular cross sections, where the bending moment of inertia is equal to width of the fiber times the cubed of the thickness divided by 12. To calculate bending stiffness, the bending moment of inertia is multiplied by the elastic modulus of the material. This may be from a measured value of the fiber, the material as a bulk, or reference literature.

Tissue Products

[0056] Tissue products are typically non-woven articles. Examples of tissue products include, but are not limited to, tissues, tissue paper, facial tissues, toilet tissues, multi-use tissues,

napkins, paper towels, kitchen papers, face wipes, cleansing wipes, makeup remover wipes, wet wipes, wet towels, moist towelettes, bath wipes, dry wipes or combinations thereof.

[0057] The processes used to create tissue products are distinctly different and have distinctly different objectives when compared to regular paper grades. The objective in creating regular paper is to create a smooth and consolidated sheet of material that is rigid and has good stiffness qualities. For tissue products, the objective is to create a textured surface with minimal consolidation and maximum flexibility.

[0058] While some processes are similar between paper and tissue product making, tissue making includes different processes to create the desired characteristics. For example, a tissue product may be dried on a Yankee dryer. This is a very large (about 150 ton) drum dryer to which the wet tissue sheet is adhered with chemical agents. After drying, the tissue sheet is scraped off using a creping doctor. This creping action imparts softness and flexibility to the sheet. Another drying system, which may be used in combination with the Yankee dryer or by itself to dry the tissue sheet, is a Through Air Dryer (TAD). In the TAD system, air is forced through the sheet to create a textured soft surface and bulky tissue sheet. These technologies may be used for toweling and napkins as well.

Tissue Products Comprising Man-Made Fibers Having Improved Properties

[0059] Incorporating the man-made fibers described herein improve certain properties of the tissue products. Typically, tissue products are made on relative high speed tissue machines, which may have speeds of up to about 10,000 feet per minute. The forming sections on the machines may be in the form of a Fourdrinier table, a C-former, a twin wire former, or a hybrid former, for example. They may have a wet press that removes water from the sheet by pressing against a felt. The press may also have a structured belt that is feed into the press to impart areas of high density and low density of the sheet. There may also be a molding box where vacuum is applied to the sheet to create a structured tissue sheet. The man-made fibers may be incorporated by mixing and other techniques known by those skilled in the art. The man-made fibers may be incorporated into a stock preparation system or an approach system of the paper machine. Typically, this is done prior to drying.

[0060] The sheet may then be dried on a Yankee dryer using various amounts and types of creping agents applied to the Yankee dryer. There also may be no creping agent applied. There may be creping of the sheet using a doctor blade off of the Yankee dryer when the sheet is substantially dry (greater than about 90% dry) commonly known in the art as dry creping. If the sheet is creped when it still has significant moisture in it (greater than about 10% residual moisture), it may be creped from the Yankee dryer in what is known in the art as a wet creping process. If the sheet needs further drying it may be dried using a through air dryer where air is forced through the sheet to remove water and improve softness of the sheet. Furthermore, no creping or drying may take place and the sheet may be dried entirely using through air drying. The ratio in the speed of the tissue after to before creping is known in the art as the creping ratio. The creping ratio may range from about 1 to about 0.2, and it may create different final properties in the tissue sheet, including more softness and better handfeel. Furthermore, it may be possible to form a tissue sheet using a foam forming technology where the furnish has foam intentionally introduced into it to reduce the amount of water required to form the tissue sheet.

[0061] The disclosure relates to the use of particular man-made fibers to make tissue products that provide a synergistic effect in strength and softness. When these fibers are used in conventional papermaking application, (i.e., to produce printing and writing grades and/or paper board grades where the typical apparent density of the paper sheet is greater than 450 kg/m^3), the addition of the fibers results in the decrease in strength of the sheet with increasing additional of the microfiber, as indicated by tensile testing of the samples (see, for example, Palwak, J.J., Sadeghifar, H., Allen, J., Perri, S., “Highly dispersible synthetic fibers for paper manufacturing”, Progress in Paper Physics Seminar, Darmstadt, Germany, 2016.; Pawlak, J.J., Sadeghifar, H., Allen, J., Perri, S., “Highly dispersible synthetic fibers for wet laid applications”, Tappi NetInc. Innovative Nonwovens Conference, PaperCon, Tappi Press, Atlanta, Georgia, 2017; all incorporated by reference in their entirety).

[0062] Contrary to the behavior in papers, the behavior of these fibers in tissue sheets with apparent density below about 450 kg/m^3 and grammages below about 100 g/m^2 results in increasing strength with the addition of the man-made fibers. Without being limited to a specific mechanism, this may be attributed to the difference in the flexibility of the fibers and the ability of the fibers to bond within the tissue sheet.

[0063] For tissue products, the strength is believed to be dominated primarily by the bonding between the fibers. Because these synthetic fibers bond to each other and to the unrefined or lightly refined conventional tissue making fibers (e.g., Bleached Kraft softwood fibers, bleached Kraft hardwood eucalyptus fibers, or mixed hardwood chemical pulps) better than the conventional fibers bond to each other, the net results is improved strength the resulting tissue structure.

[0064] The tissue product may comprises conventional or other tissue making fibers, such as non-wood fibers, wheat fibers, bamboo fibers, and/or recycled fibers, in addition to the man-made fibers described herein. The tissue products of the disclosure may comprise at least 0.1%, 0.2%, 0.3%, 0.4%, 0.5%, 1%, 2%, 3%, 4%, 5%, 6%, 7%, 8%, 9%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, 50%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, or 99% man-made fiber by weight. The tissue product may comprise at least 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, or 95% of other tissue making fibers, such as non-wood fibers, wheat fibers, bamboo fibers, and/or recycled fibers by weight. As shown in the Figures, incorporating different amounts of man-made fibers results in different properties.

[0065] In some embodiments, the tissue product comprising the man-made fibers of the disclosure may have a softness that is increased by at least 1%, 2%, 3%, 4%, 5%, 6%, 7%, 8%, 9%, 10%, 15%, 20%, or 25% compared to a tissue product without the man-made fibers. The tissue product comprising the man-made fibers may have the same, or substantially the same, softness as a conventional tissue paper (e.g., of the same type) compared to a tissue paper (e.g., of the same type) prepared solely from traditional fibers. Softness may be measured by an EmTec Tissue Softness Analyzer, the measurement on the EmTec Tissue Softness Analyzer being the decibels at 6500 Hz of sound frequency, also referred to as the TS7 peak. Lower values in this peak are associated with improved softness of the tissue product.

[0066] The tissue product comprising the man-made fibers of the disclosure may also have a softness as characterized by a lamellas vibration (TS7 peak) of less than or equal to about 15 dB, about 14 dB, about 13 dB, about 12 dB, about 11 dB, about 10 dB, about 9 dB, about 8 dB, about 7 dB, about 6 dB, or about 5 dB.

[0067] Tissue products comprising the man-made fibers of the disclosure may also have increased strength compared to the same tissue product without the man-made fibers. The tissue products may have increased strength compared to the same type (e.g., a tissue product prepared not in accordance with a method of the present disclosure) with traditional or conventional fibers. The tissue products may have a ball burst strength of greater than or equal to about 2 N, about 2.5 N, about 3 N, about 3.5 N, about 4 N, about 4.5 N, or about 5 N. A method of the present disclosure may allow for more flexibility in materials selection, the ability to improve the properties of tissue products, and/or the ability to reduce costs of production by reducing basis weight and/or maintaining a similar strength.

[0068] In certain embodiments, when formed into a laboratory tissue sheet using 100% composition of the man-made fiber, the tissue sheet has a dry ball burst strength about equal to or greater than a sheet formed in the same method using a convention tissue making fiber.

[0069] Water absorption (water uptake) describes the amount of water absorbed by a tissue product, for example, under specified conditions. Water uptake is typically expressed as a weight fraction: (wet weight - dry weight) / dry weight. In certain embodiments, when formed into a laboratory tissue sheet using greater than 0% to 100% composition of the man-made fiber, the tissue sheet has a water uptake fraction from about 5 to about 12, about 5 to about 9, or about 5.5 to about 7.5.

[0070] The tissue products comprising the man-made fibers may have a basis weight in a range from about 15 g/m² to about 75 g/m², about 25 g/m² to about 65 g/m², or about 25 g/m² to about 55 g/m². The basis weight may be greater than 15 g/m², greater than 20 g/m², 2 greater than 5 g/m², greater than 30 g/m², greater than 35 g/m², or greater than 40 g/m², or less than 75 g/m², less than 70 g/m², less than 65 g/m², less than 60 g/m², or less than 55 g/m². The caliper of the tissue product may be measured by DS/EN ISO 12625-3 ("Tissue paper and tissue products — Part 3: Determination of thickness, bulking thickness and apparent bulk density and bulk) and/or may be used to determine the apparent density of the article (e.g., sheet) in combination with the grammage (basis weight) of the article.

[0071] The apparent density of the tissue product comprising the man-made fibers may be less than about 450 kg/m³, which includes creping, through air drying, embossing, and/or

converting to form multiply sheets. The apparent density may be less than 450 kg/m^3 , less than 425 kg/m^3 , less than 400 kg/m^3 , less than 375 kg/m^3 , or less than 350 kg/m^3 . The minimum density can be set by the density at which a continuous web of fibers can no longer be formed. This value depends on the type of fiber used as well as the forming process. Tissue papers formed at low density (e.g., less than about 450 kg/m^3) may have their strength properties dominated by the inter-fiber bonding strength in shear modes, peeling modes, and/or tension modes. Due to the overall strength of the tissue product and/or sheet(s), the strength of the fibers themselves may be of little importance. This is contrary to papers formed at densities greater than about 450 kg/m^3 , whose strength properties are dependent on a number of factors, as described previously by Page ("A theory for the tensile strength of paper", TAPPI JOURNAL 52(4): 674(1969)), including fiber length, fiber coarseness (mass per unit length), inter-fiber shear bond strength, amount of inter-fiber bonding, and fiber strength.

[0072] Sheets made for testing purposes may be manufactured with a modified handsheet making process so that the sheet properties of tissue are mimicked. This process involves forming the sheets at basis weights below about 40 g/m^2 and a density of less than about 250 kg/m^3 . After sheet forming, the sheets are not pressed and are dried directly on a heated cylinder. This results in a sheet that is similar in weight, density, and properties to an un-creped tissue sheet. This process is illustrated in FIG. 1.

Examples

[0073] It should be kept in mind that the following described embodiments are only presented by way of example and should not be construed as limiting the inventive concept to any particular physical configuration.

Example 1

[0074] Sheets were formed using hardwood fiber NIST reference material 8496, softwood fiber NIST reference material 8495 and/or hardwood market pulp according to the North Carolina State University protocol for forming handmade tissue sheets. This process is a modified version of TAPPI Method T 205-sp 95 Forming Handsheets for Physical Testing of Pulp (TAPPI Press, Atlanta, Georgia).

[0075] The modification are as follows: sheets are formed at a target basis weight of 25 g/m²; after couching from the forming wire, one blotter is removed and a fresh blotter is placed over the sheet so that the tissue is pinched between the old blotter sheet and the fresh blotter sheet; the “sandwich” of the blotter sheets and the tissue sheet is then passed through a rotating dryer drum five times. The dryer drum is set at an RPM of 2 and the temperature is set at 110 °C; after drying, the sheets are placed in a TAPPI standard atmosphere overnight. Note that the sheets are not dried under restraint.

[0076] The properties of the tissue sheets were then measured using established methods. Some such methods are listed in Table 1.

Table 1: Test methods for the evaluation of Tissue Properties.

Test	Method
Basis Weight	T410 Grammage of paper and paperboard (gravimetric method)
Caliper	DS/EN ISO 12625-3 Tissue paper and tissue products – Part 3: Determination of thickness, bulking thickness and apparent bulk density and bulk
Tensile Strength	T494 Tensile breaking properties of paper and board (using constant rate of elongation apparatus)
Ball Burst	EmTec Specified Method
Softness	EmTec Tissue Softness Analyzer Protocol
Water Absorption	ISO 12625-8:2010 Tissue paper and tissue products – Part 8: Water-absorption time and water-absorption capacity, basket-immersion test method

The following Microfibers were incorporated into the hardwood and softwood described above in the amounts shown in the Figures, and the corresponding properties are shown therein.

ID	24-4	24-5	24-3	24-2	24-6	5d30	10101	24-1	HW	SW
Nominal Coarseness (mg/km)	47	47	78	47	78	78	47	78		
Length (mm)	6	4.5	6	3	4.50	3	1.5	1.5		
Coarseness/Length	0.50	0.67	0.83	1	1.10	1.67	2	3.33	0.90	0.75

Example 2

[0077] FIG. 2 illustrates a typical Tissue Softness Analyzer (TSA) plot. Briefly, the TSA uses sound to objectively correlate smoothness and softness. The first peak, known as TS750, represents surface vibration and correlates with roughness. The second peak, known as TS7, represents lamellas vibration and correlates with softness as determined by consumer panels.

Example 3

[0078] FIG. 3A and FIG. 3B show that ball burst strength increased for both hardwood and softwood based handsheets for all tested amounts of Microfiber incorporation, relative to identical handsheets without Microfiber.

Example 4

[0079] FIG. 4A and FIG. 4B show that for hardwood based handsheets, ball burst strength increased with increased amount of Microfiber. An increased denier/cut length ratio tended to decrease the strength.

Example 5

[0080] FIG. 5 shows that for softwood based handsheets, ball burst strength increased with increased amount of Microfiber, although the improvement was less than for the hardwood based handsheets. An increased denier/cut length ratio tended to decrease the strength.

Example 6

[0081] FIG. 6A and FIG. 6B show that tensile strength increased for hardwood based handsheets with increasing amounts of Microfiber. However, tensile strength decreased with softwood based handsheet with increasing amount of Microfiber, after a certain amount of Microfiber.

Example 7

[0082] FIG. 7A and FIG. 7B show that for hardwood based handsheets, tensile strength increased by adding Microfiber, but surprisingly, excessive Microfiber did not provide the highest strength.

Example 8

[0083] FIG. 8 shows that for softwood based handsheets, tensile strength increased by adding Microfiber up to about 16%. Excessive Microfiber decreased the tensile strength significantly. Five denier grades provided higher strength at high percentages of Microfiber.

Example 9

[0084] FIG. 9A and FIG. 9B show that the handfeel (HF) coefficient increased significantly at high percentage additions of Microfiber. The about 64% Microfiber improved the softness of softwood based handsheets most significantly.

Example 10

[0085] FIG. 10 shows that the handfeel (HF) coefficient increased significantly at high percentage additions of Microfiber. These fibers have been described in more detail by Allen and Dema (2015 PaperCon, Tappi, Atlanta, Georgia; 2016 Innovative Nonwovens Conference, Tappi Net Inc., Cincinnati, Ohio, incorporated hereby by reference in its entirety). In this example, five denier grades improved the HF coefficient higher than the three denier grades.

Example 11

[0086] FIG. 11 shows that for softwood based handsheets, the handfeel (HF) coefficient increased significantly at all levels of Microfiber addition. Three denier grades improved the HF coefficient higher than the five denier grades. Smaller denier to cut length ratios provided higher softness.

Example 12

[0087] FIG. 12 shows that an approximately linear relationship was obtained for most samples (except 5d30 which was probably due to variation in moisture content). Typically, increased ball burst strength also gave increased HF coefficient.

Example 13

[0088] FIG. 13 shows that samples 24-4 and 24-3 provided the best linear fitting, which indicates that with increased amounts of these two grades, one could expect the most stable and linear simultaneous increases of strength and softness.

Example 14

[0089] FIG. 14A and FIG. 14B show that softwood based handsheets held more water than hardwood based handsheets. With increased amounts of Microfiber, the water uptake fraction decreased for all grades.

Example 15

[0090] Fiber Quality Analysis (FQA) and scanning electron microscopy (SEM) will facilitate understanding of the mechanism behind the measured property changes.

Example 16

[0091] Other man-made fibers, including fibers made from poly-lactic acid, regenerated cellulose, and cellulose acetate, among others, may be used to form tissue products as described herein.

[0092] Various features and advantages of the invention are set forth in the following claims.

CLAIMS

What is claimed is:

1. A tissue product with an apparent density less than about 450 kg/m^3 and a basis weight less than about 75 g/m^2 .
2. The tissue product of claim 1, wherein the tissue product comprises man-made fibers in an amount from about 5% to about 100% of the total weight of the tissue product.
3. A tissue product comprising man-made fibers, the tissue product having a softness characterized by a lamellas vibration (TS7 peak) of less than or equal to about 15 dB, and a ball burst strength of greater than or equal to about 2 N.
4. A method of making a tissue product, the method comprising incorporating a sufficient amount of man-made fibers into the tissue product to impart in the tissue product a softness characterized by a lamellas vibration (TS7 peak) of less than or equal to about 15 dB, and a ball burst strength of greater than or equal to about 2 N.
5. The method of claim 4, further comprising drying the tissue product with a Yankee dryer.
6. The method of claim 4 or 5, further comprising drying the tissue product and dry creping it from a Yankee dryer.
7. The method of claim 4 or 5, further comprising drying the tissue product and wet creping it from a Yankee dryer.
8. The method of claim 4, further comprising drying the tissue product with a Through Air Drying system.
9. The method of claim 4 or 8, further comprising drying the tissue product with a wet creped Yankee dryer and a Through Air Drying system.

10. The tissue product of any one of claims 2 to 9, wherein the man-made fibers have a cross sectional geometry that is round, rectangular, lobular, oval, “eye-shaped”, square, x-shaped, or another well-defined geometry.
11. The tissue product of any one of claims 2 to 10, wherein the man-made fibers have a length from about 0.2 mm to about 10 mm.
12. The tissue product of any one of claims 2 to 11, wherein the man-made fibers have a calculated bending moment of inertia around at least one axis that is less than or equal to about $3000 \mu\text{m}^4$.
13. The tissue product of any one of claims 2 to 12, wherein the man-made fibers have a calculated bending stiffness in at least one direction that is less than or equal to about $150 \text{ N} \cdot \mu\text{m}^2$.
14. The tissue product of any one of claims 2 to 13, wherein the man-made fibers are dispersible in water without aid from any additional suspending agents.
15. The tissue product of any one of claims 2 to 14, wherein the man-made fibers are selected from the group consisting of regenerated cellulose, cellulose acetate, polylactic acid, polyethylene terephthalate, high density polyethylene, low density polyethylene, polypropylene, nylon, polycarb lactate, polyester, rayon, starch, chitin, chitosan, collagen, soy protein, and a composite thereof.
16. The tissue product of any one of claims 2 to 15, wherein the man-made fibers have at least one dimension less than or equal to about one one-hundredth of the longest dimension of the man-made fibers.
17. The tissue product of any one of claims 2 to 16, wherein the man-made fibers have an elastic modulus less than or equal to about 10 GPa.
18. The tissue product of any one of claims 2 to 17, wherein the man-made fibers are arranged within a furnish in a pattern of islands.

19. The tissue product of any one of claims 2 to 18, wherein the man-made fibers comprise polyethylene terephthalate.
20. The tissue product of any one of claims 3 to 19, wherein the tissue product has an apparent density less than or equal to about 450 kg/m^3 .
21. The tissue product of any one of claims 3 to 20, wherein the tissue product has a basis weight less than or equal to about 75 g/m^2 .
22. The tissue product of any one of claims 1 to 21, wherein the tissue product is a facial tissue, a multi-use tissue, a napkin, a paper towel, a kitchen paper, a face wipe, a cleansing wipe, a makeup remover wipe, a wet wipe, a wet towel, a moist towelette, a bath wipe, or a dry wipe.
23. The tissue product of any one of claims 1 to 22, wherein the tissue product is non-woven.
24. The tissue product of any one of claims 2 to 23, wherein the tissue product comprises greater than or equal to about 30% of the man-made fiber by total fiber weight and further comprises a hardwood fiber.
25. The tissue product of any one of claims 2 to 23, wherein the tissue product comprises less than or equal to about 16% of the man-made fiber by total fiber weight and further comprises a softwood fiber.
26. The tissue product of any one of claims 1 to 25, wherein the tissue product has a tensile strength greater than or equal to about 6 N.
27. The tissue product of any one of claims 1 to 26, wherein the tissue product comprises a non-wood fiber, a wheat fiber, a bamboo fiber, or a recycled fiber in an amount from greater than 0% to less than or equal to about 95% by total fiber weight.
28. The tissue product of any one of claims 1 to 28, wherein the tissue product has a handfeel coefficient greater than or equal to about 60.
29. The tissue product of any one of claims 3 to 28, wherein the tissue product comprises about 5% to about 100% of the fiber by total fiber weight.

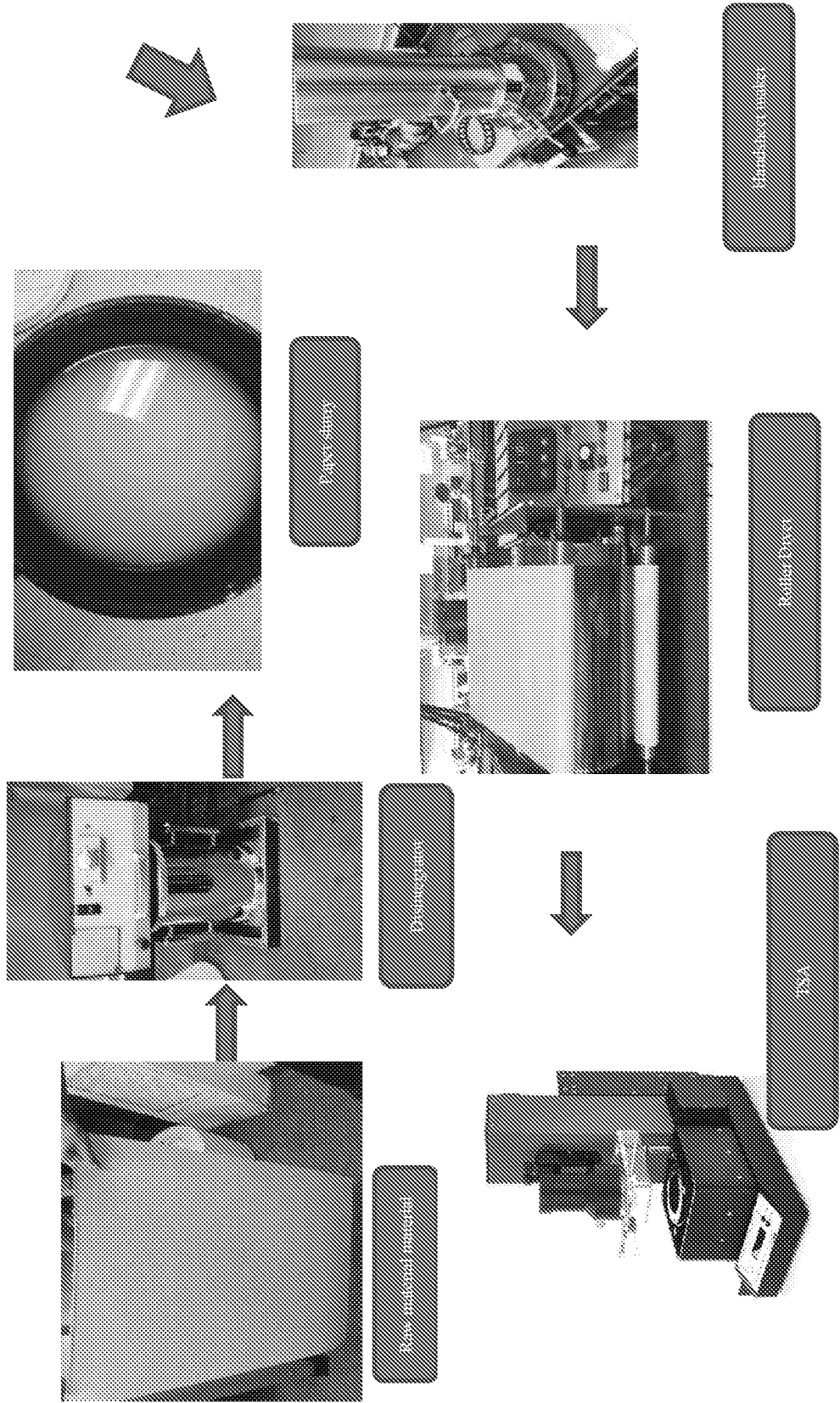


FIG. 1

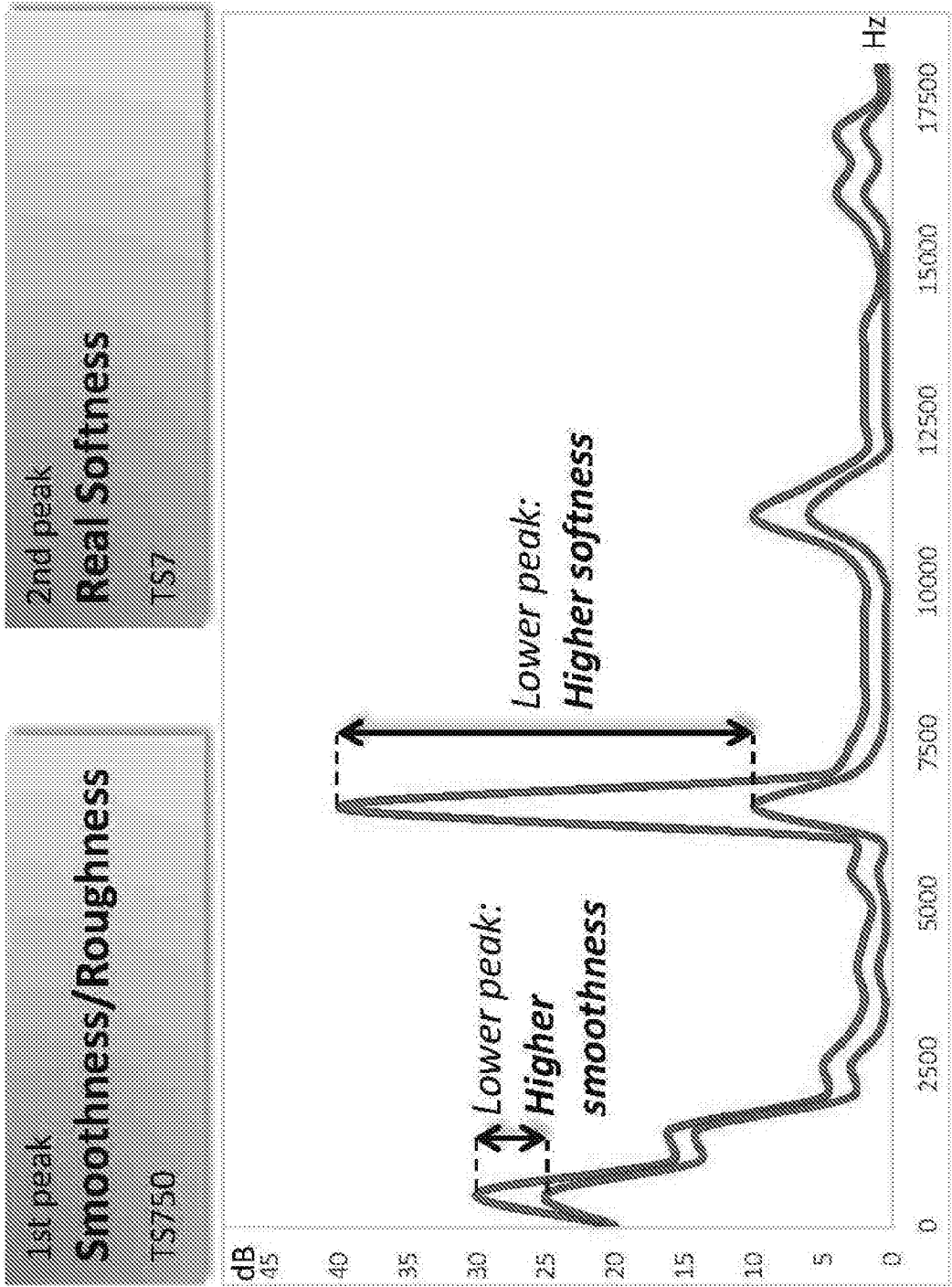


FIG. 2

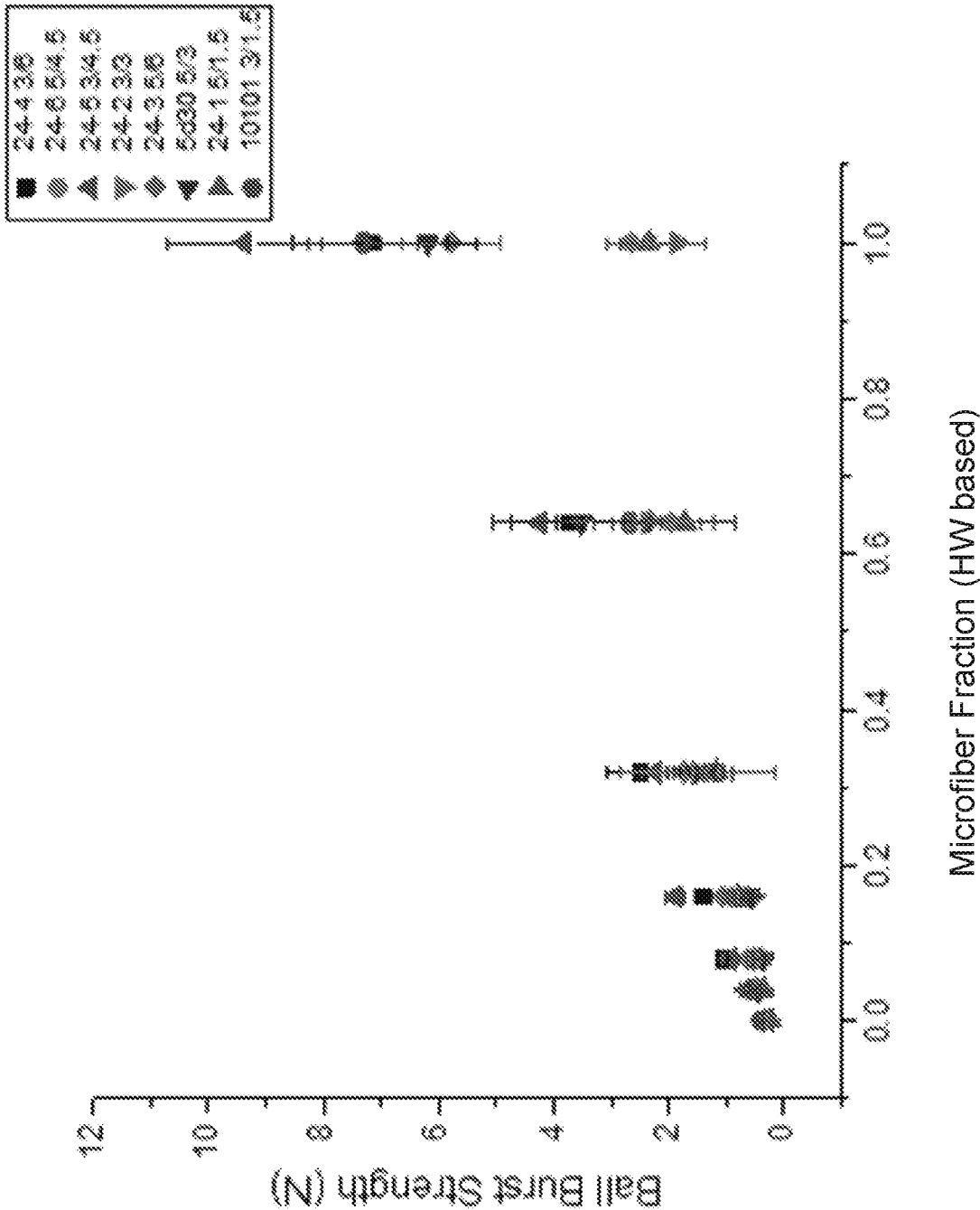


FIG. 3A

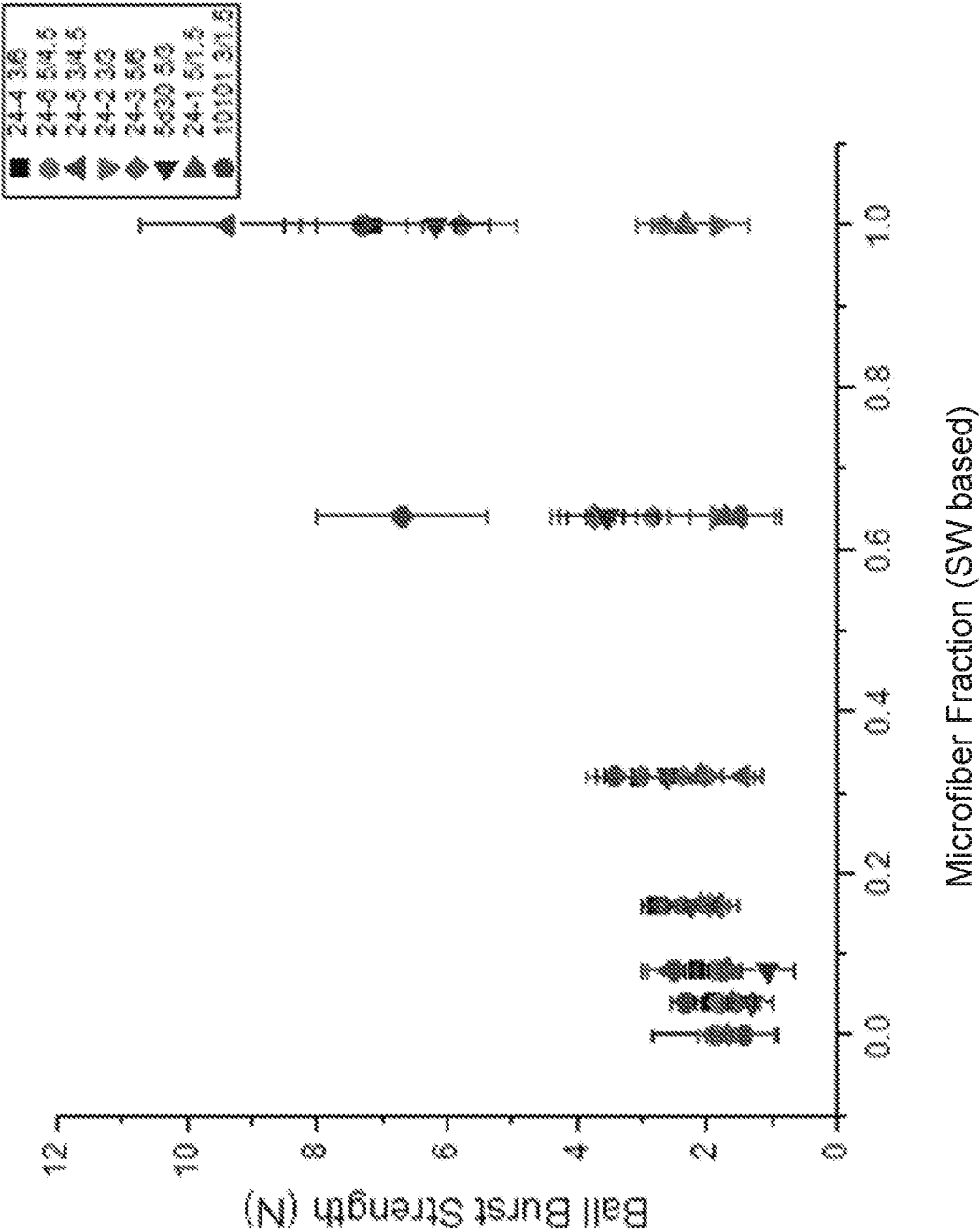


FIG. 3B

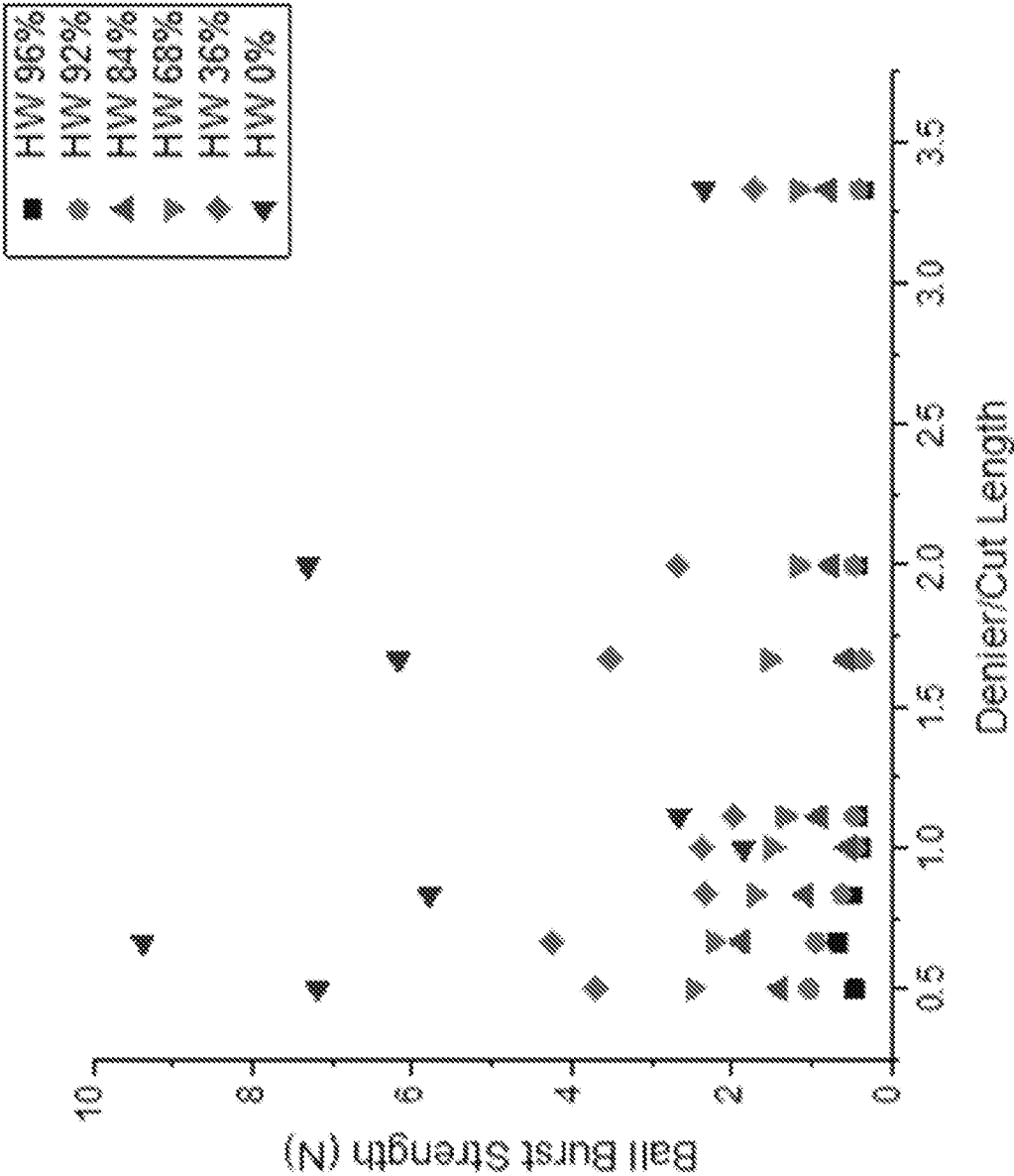


FIG. 4A

6/20

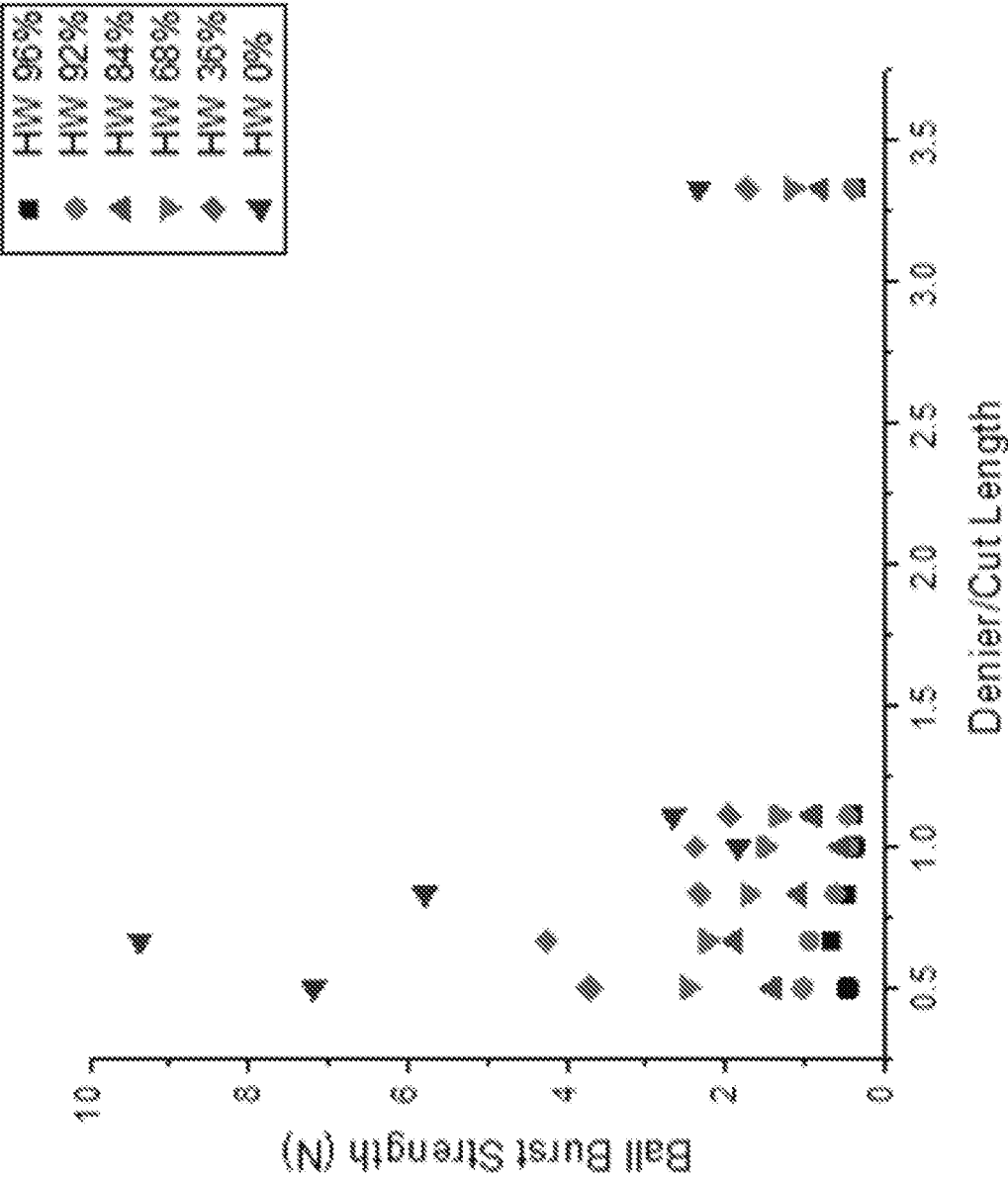


FIG. 4B

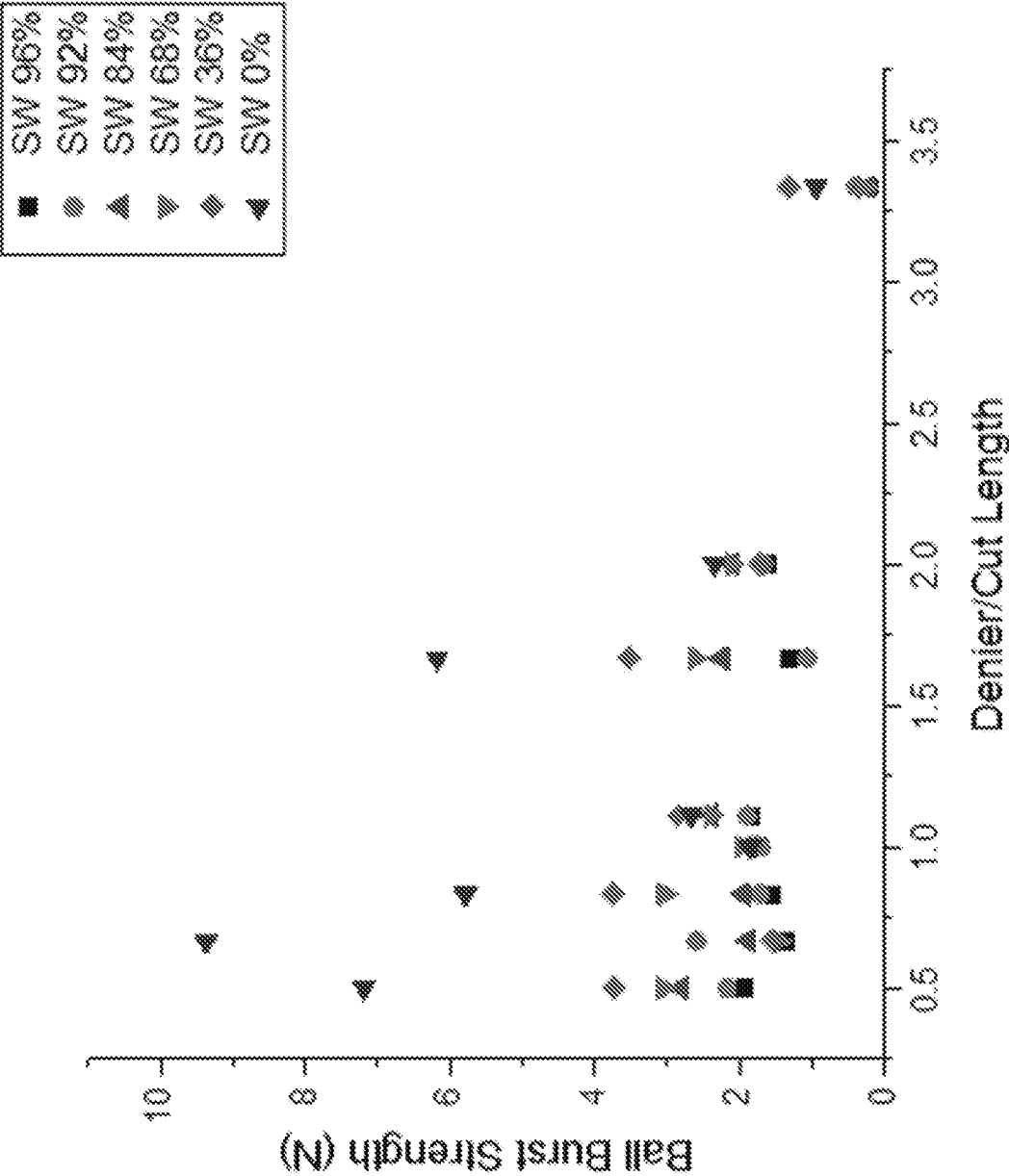


FIG. 5

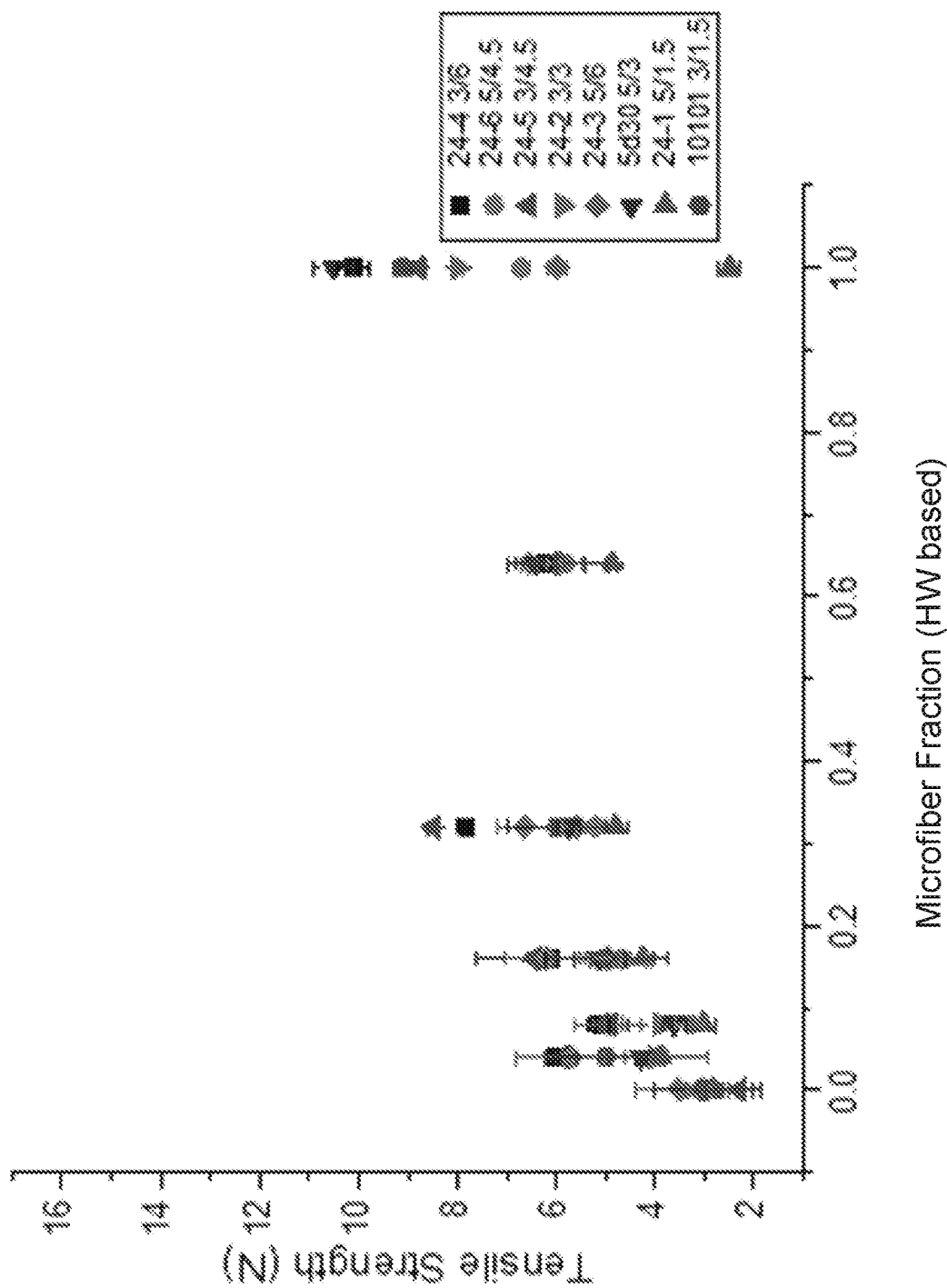


FIG. 6A

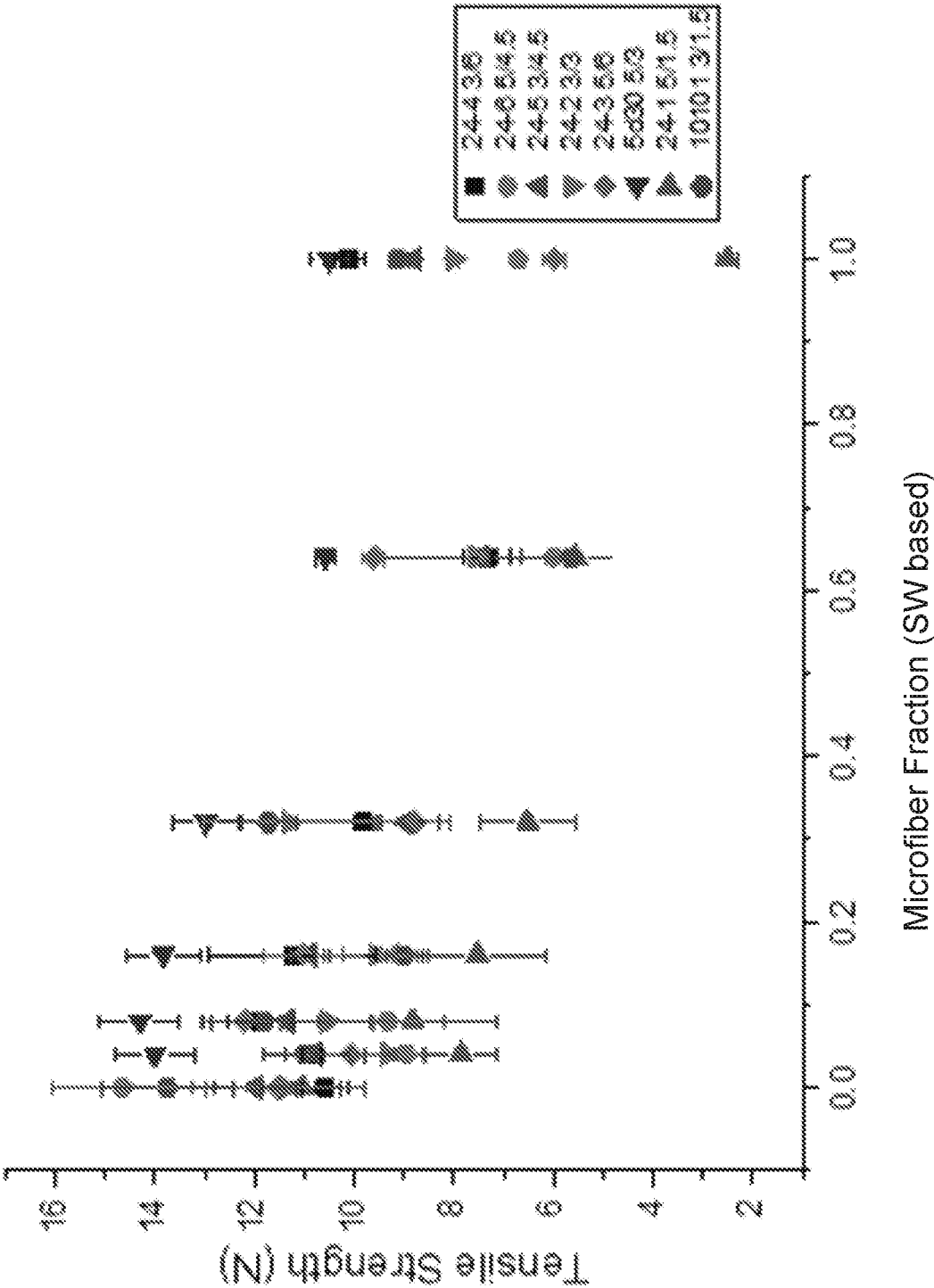


FIG. 6B

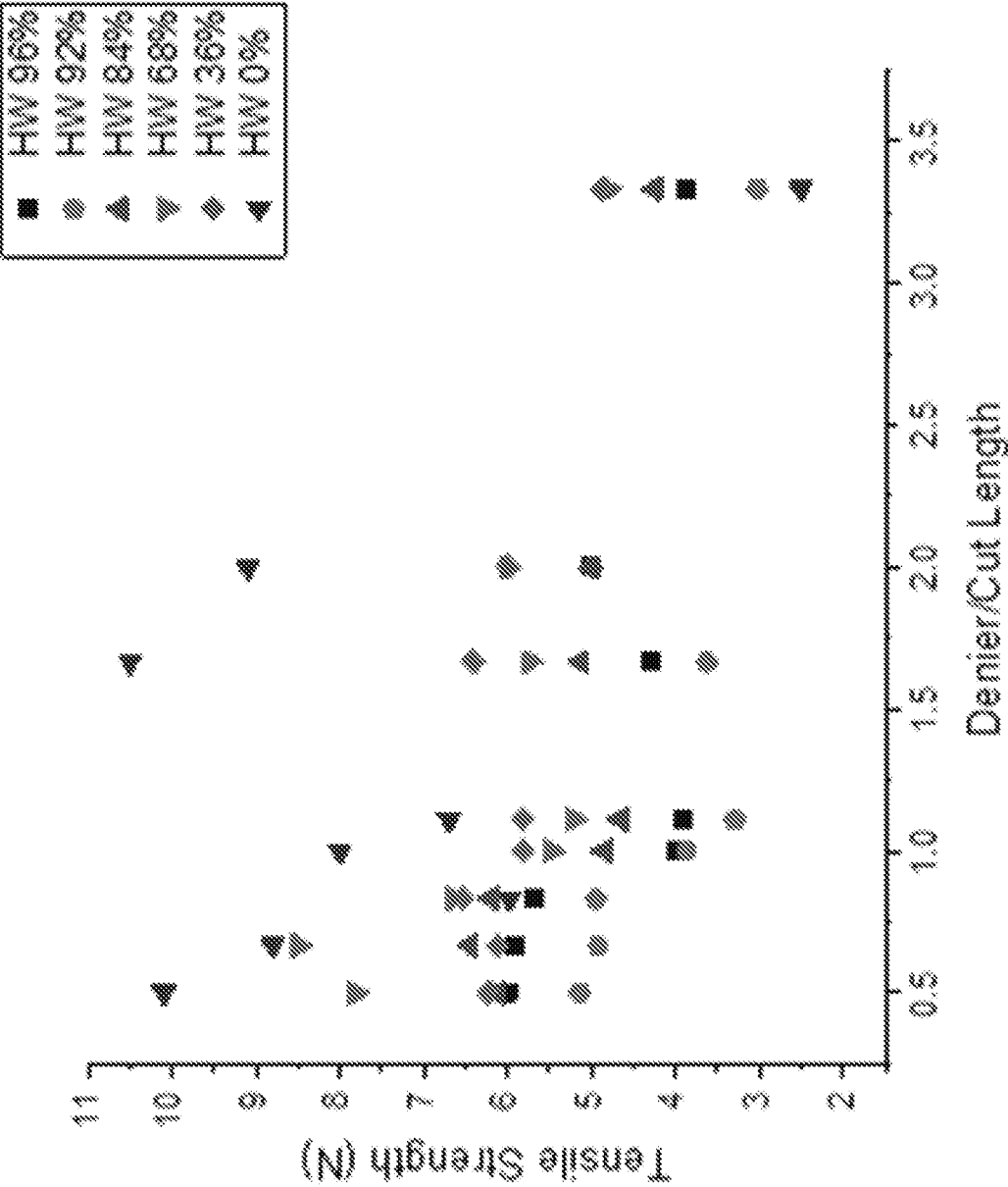


FIG. 7A

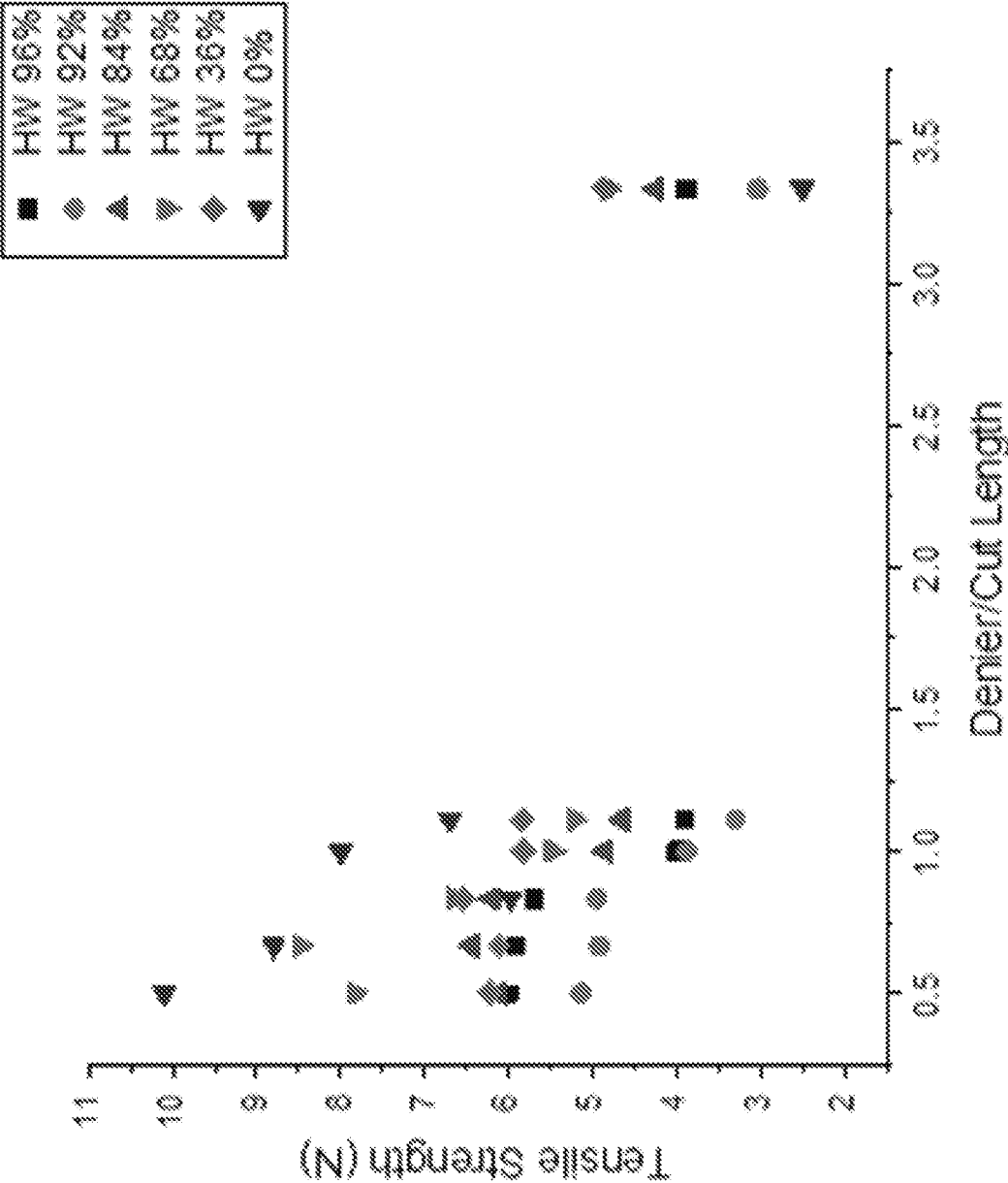


FIG. 7B

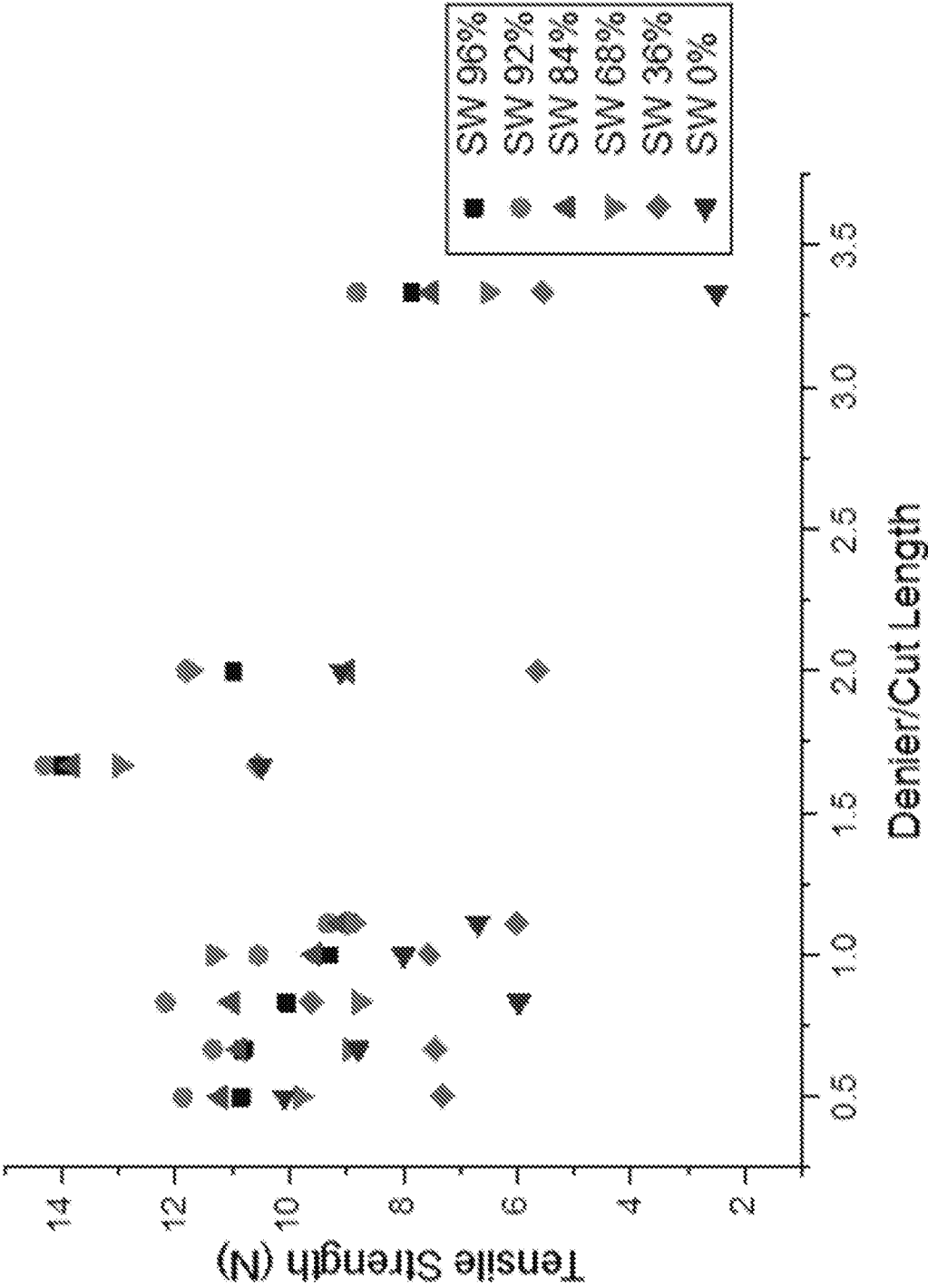


FIG. 8

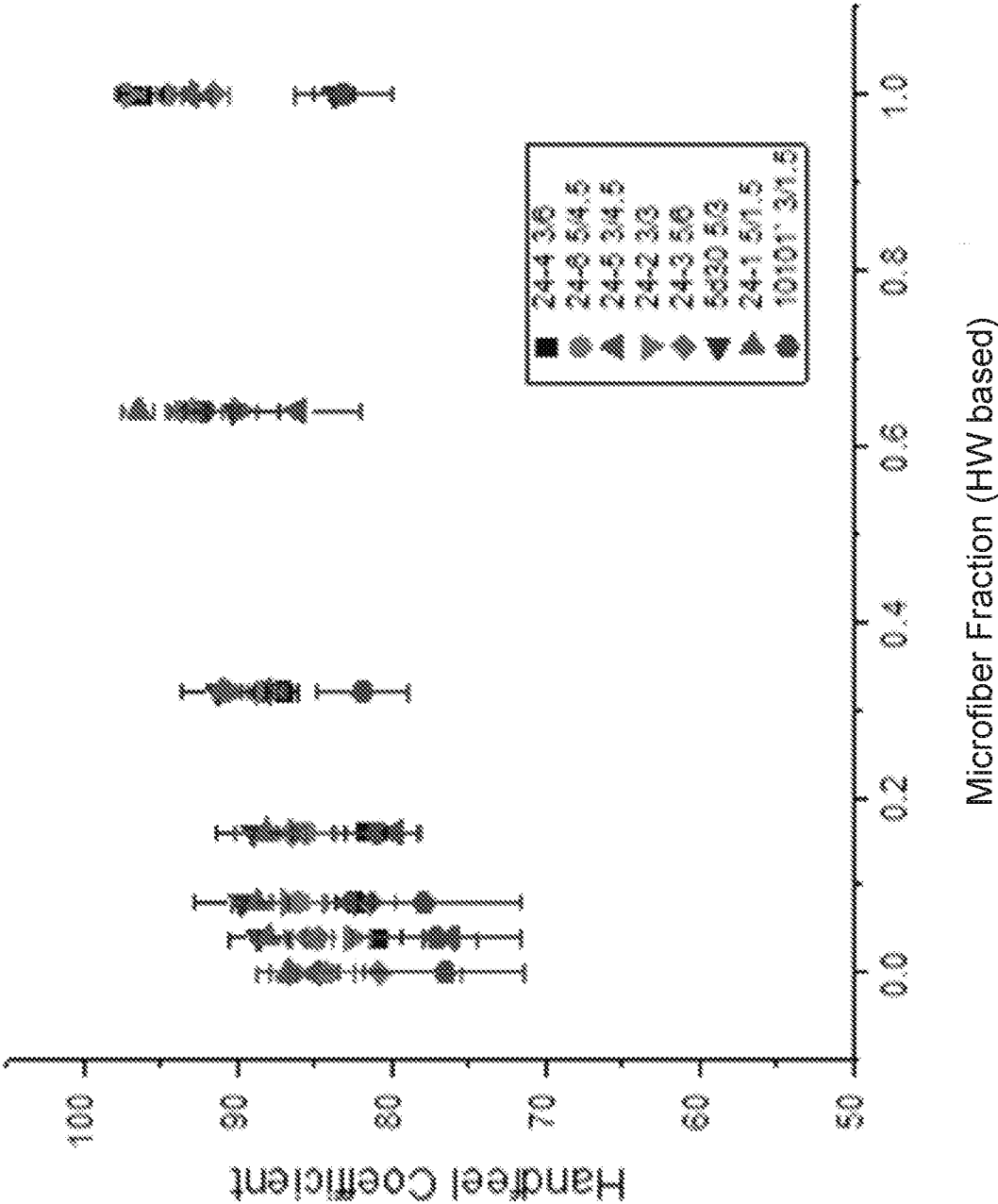


FIG. 9A

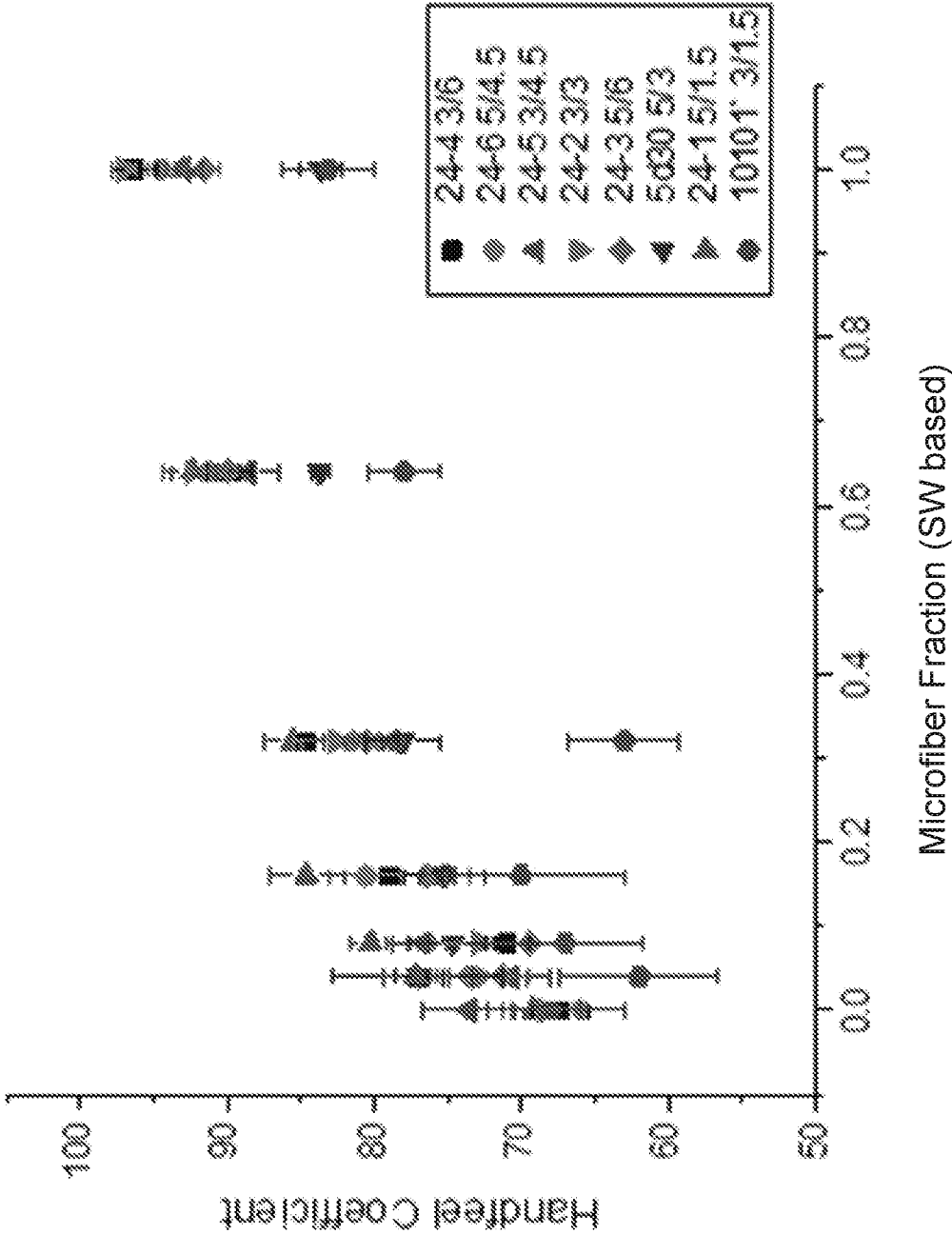


FIG. 9B

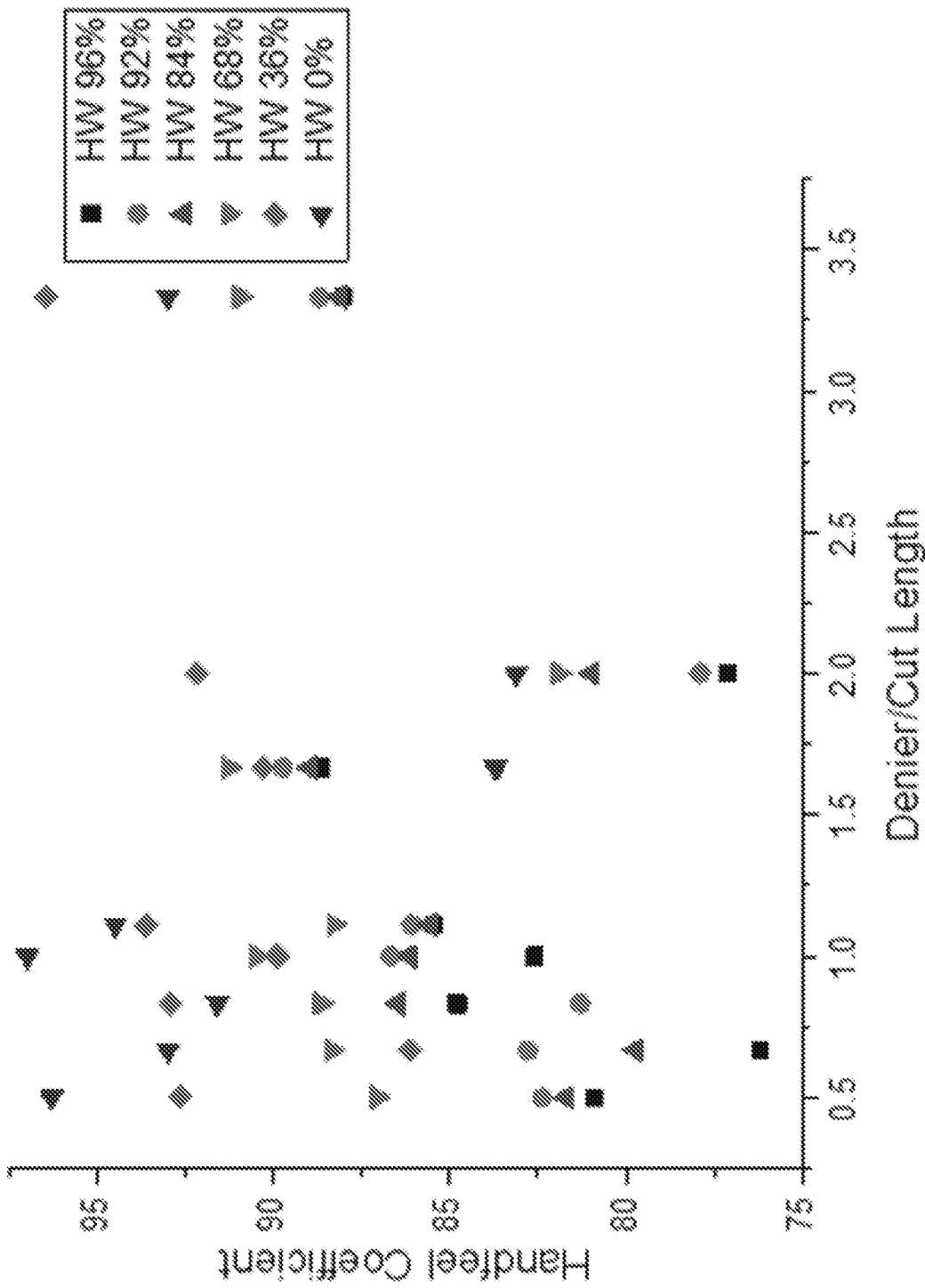


FIG. 10

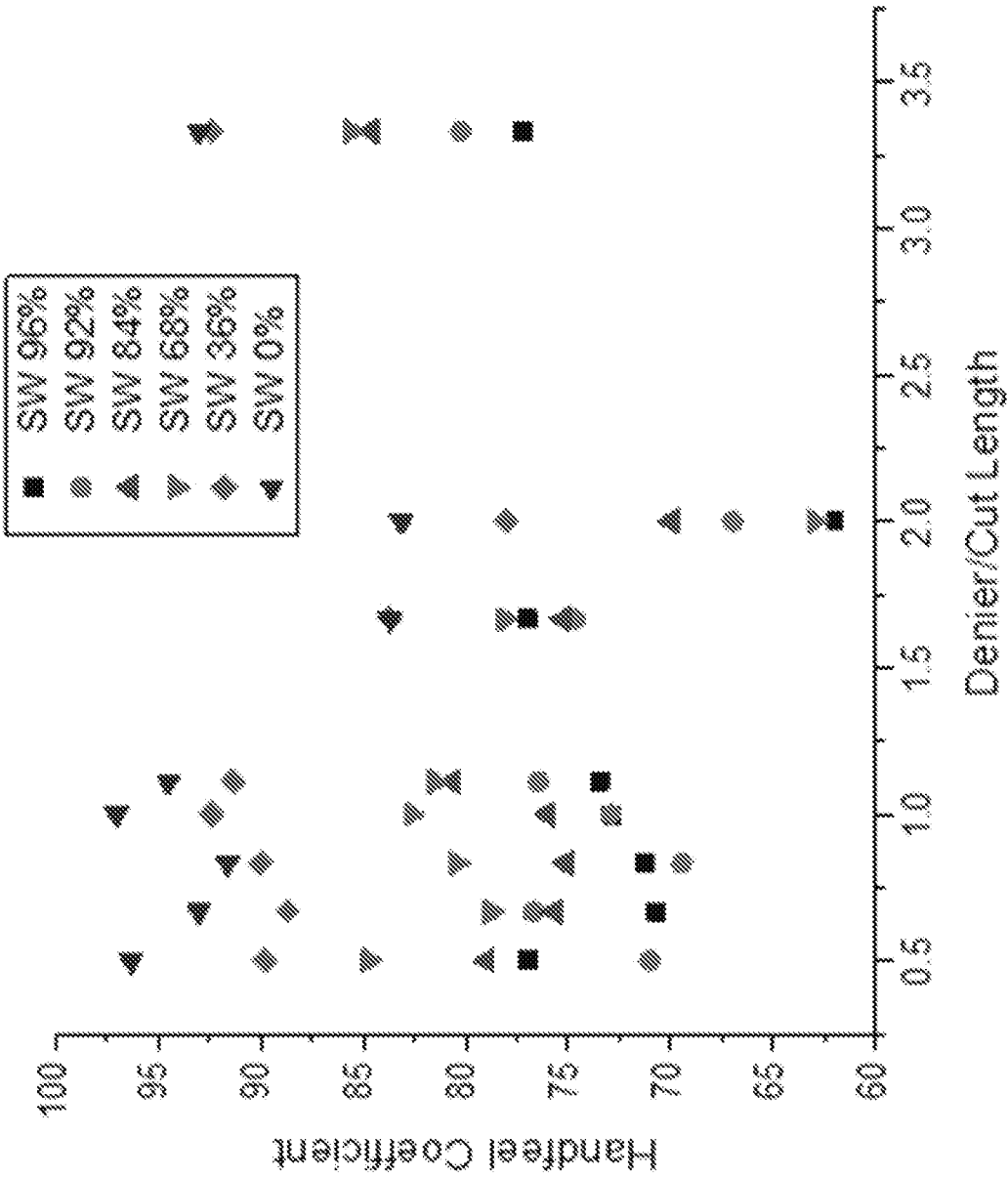


FIG. 11

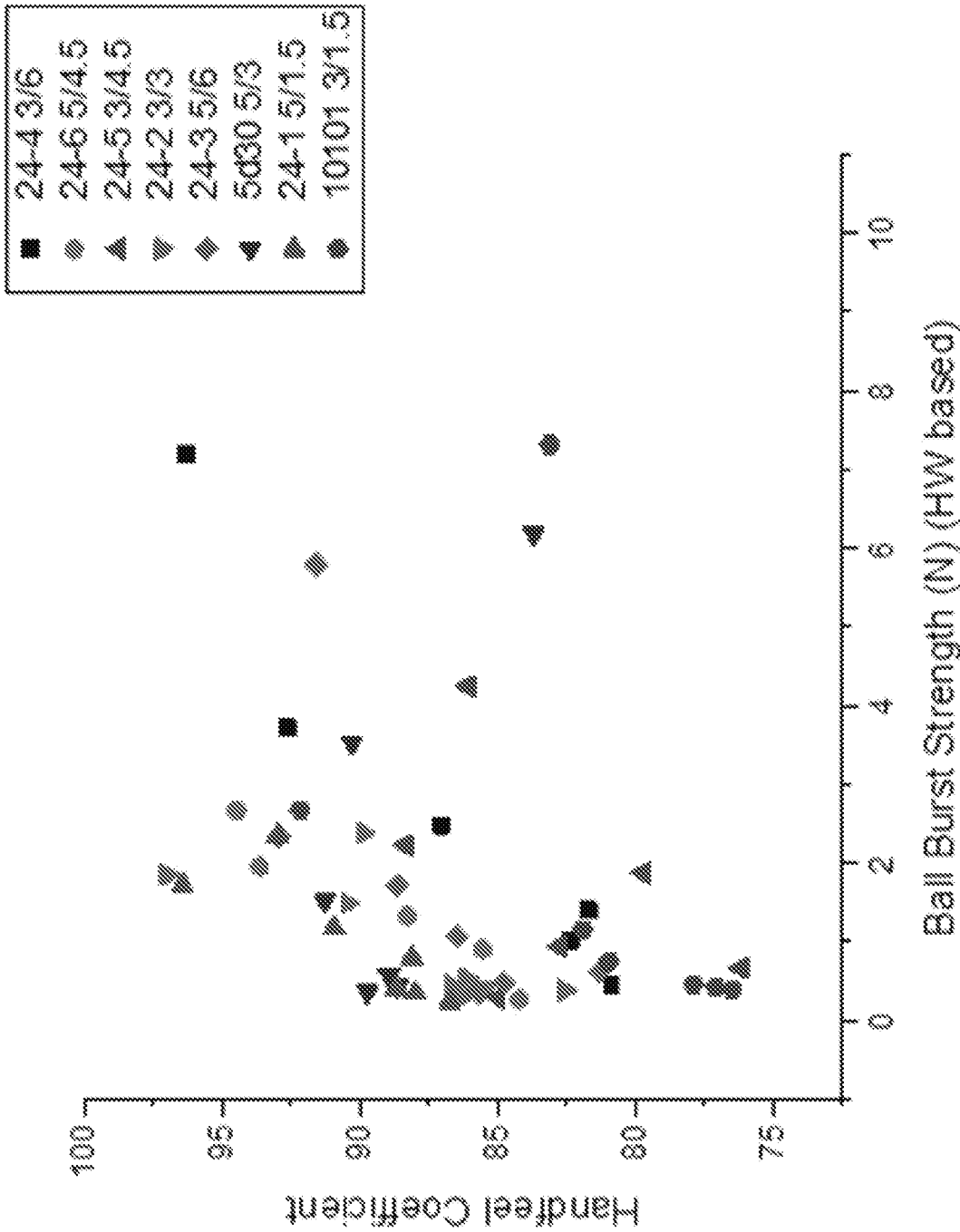


FIG. 12

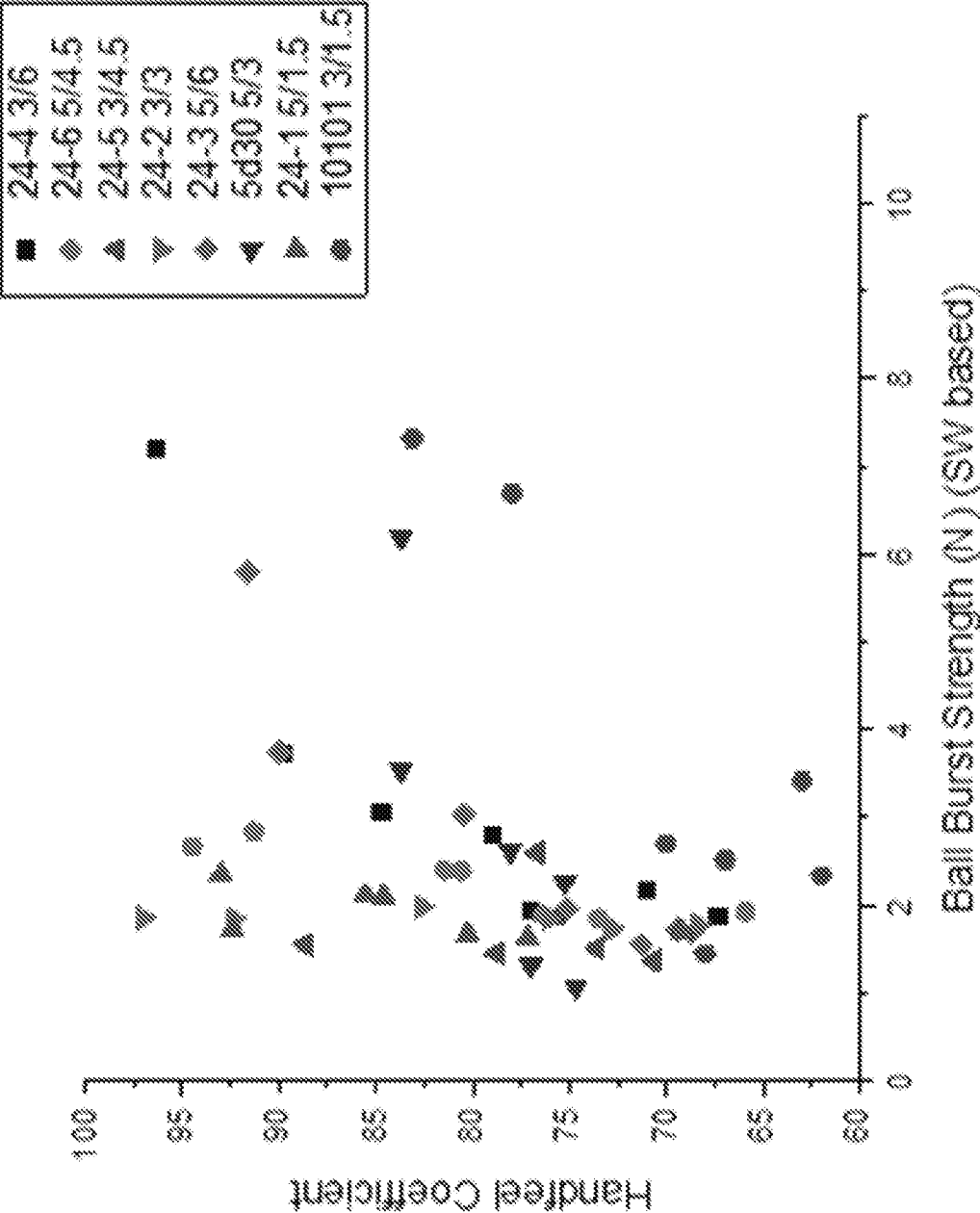
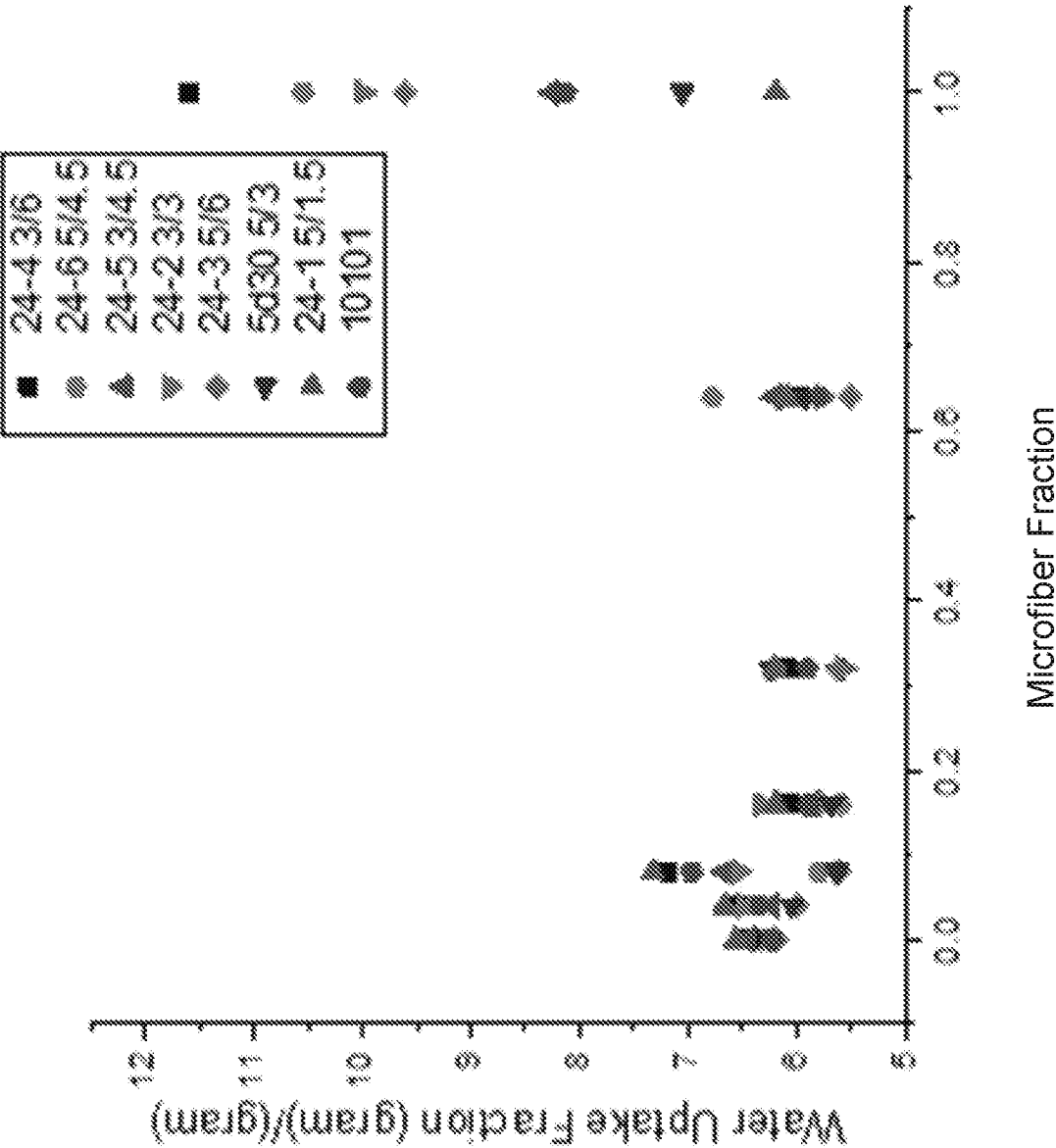


FIG. 13



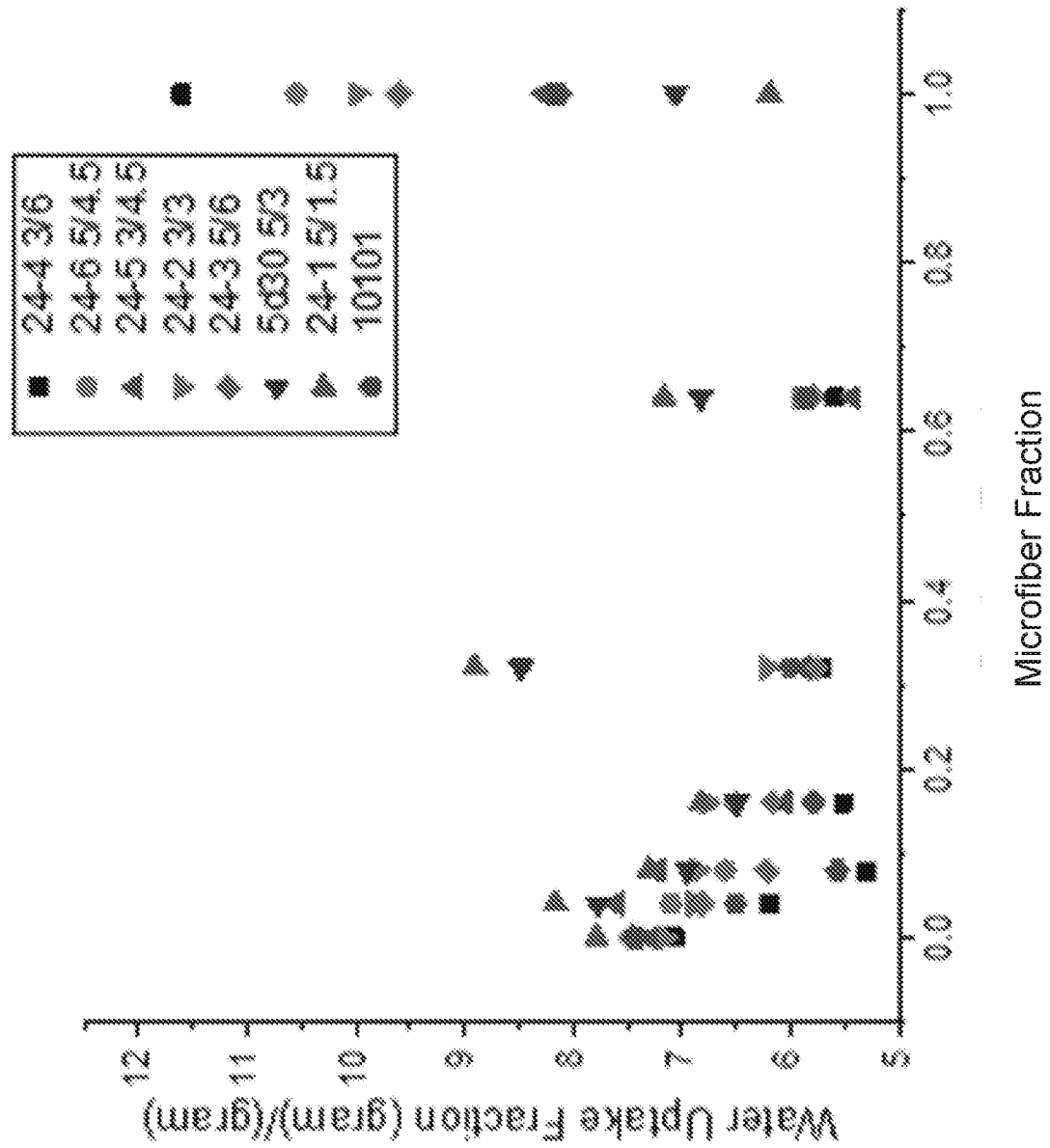


FIG. 14B

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 18/55513

A. CLASSIFICATION OF SUBJECT MATTER
 IPC(8) - D21F 7/06 (2018.01)
 CPC - D21F 11/14, D21F 7/06, D21G 9/0036

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

See Search History Document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

See Search History Document

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

See Search History Document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2001/012902 A1 (The Procter & Gamble Company) 22 February 2001 (22.02.2001); entire document, especially abstract pg 14 para 1	1-2
X	WO 2016/153462 A1 (Kimberly-Clark Worldwide, Inc.) 29 September 2016 (29.09.2016); entire document, especially abstract, pg 3 line 9, pg 8 lines 25 - pg 9 line 2, pg 8 lines 13-17, pg 9 lines 5-8, pg 12 lines 9-20, pg 14 lines 14-23, pg 16 Table 3, pg 17 Table 4	3-9
A	US 2008/0008853 A1 (Hupp et al.) 10 January 2008 (10.01.2008); entire document	1-9
X, P	US 2017/0328011 A1 (First Quality Tissue, LLC) 16 November 2017 (16.11.2017); entire document	3-9

☐ Further documents are listed in the continuation of Box C.

☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

10 December 2018

Date of mailing of the international search report

31 DEC 2018

Name and mailing address of the ISA/US

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Authorized officer:

Lee W. Young

PCT Helpdesk: 571-272-4300
 PCT USP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 18/55513

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☒ Claims Nos.: 10-29
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.