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(54) **PREPARATION OF ENGINEERED FABRICS WITH SUPERIOR ABSORPTION PROPERTIES**

(57) This disclosure relates generally to the preparation of eco-friendly engineered fabric, and more particularly to terry fabric and variations thereof. In one embodiment, a terry fabric is comprised of a soluble fiber

blend, blended with cotton fibers, where the soluble fibers are dissolved in a caustic or enzyme solution to create highly porous yarns.

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Description

TECHNICAL FIELD

[0001] This disclosure relates generally to the preparation of eco-friendly engineered yarns and fabrics, and more particularly to terry fabric and variations thereof. These eco-friendly engineered fabrics may be used in a variety of applications, including toweling, bathrobes, rugs, and bedding articles. This eco-friendly yarn, and the resulting eco-friendly fabrics and textile articles provide desirable softness and absorptive properties by increasing the yarn's porosity. Porosity is increased by implementing, and later dissolving, wool fibers in the yarns that make up the fabric, and more specifically the loops and tufts of terry fabric. The present disclosure further relates to the technical aspect of producing the engineered yarn, as well as the external appearance and characteristics of the engineered terry fabric. More specifically, in certain embodiments of this disclosure, an eco-friendly engineered yarn is comprised of cotton blended with soluble fibers, where the soluble fibers are dissolved in an alkali or enzyme solution to create highly porous yarns. These highly porous eco-friendly engineered yarns are then used for making terry fabrics and variations thereof.

BACKGROUND

[0002] Fabrics used in various applications, such as toweling, rugs, bedding, and leisure fabrics, are often designed to maximize the absorptive properties of the fabric. For example, towels are generally thick textile articles with a piled surface (i.e., looped surface) on the front and/or back of the fabric. Thicker towels typically have a deeper pile with a greater surface area.

[0003] This increased surface area generally increases the absorption properties of the fabric. For example, when a terry toweling fabric contacts a water droplet, the pile loops first remove the droplet by drawing the droplet into the spaces between the fibers in the yarn. The water is then wicked throughout the length of the pile and into the ground weave of the fabric. Further, once the water is drawn into the yarn, the water may be absorbed into the lumen of the cotton fiber. The density of the fibers in the yarn impacts the yarn's ability to dry; this in turn impacts the yarn's ability to absorb more water.

[0004] Generally, woven fabrics are made with two sets of yarns: the warp and the weft; however, terry fabrics are generally formed with three sets of yarns. The first set, the ground warp, is a longitudinal set of yarns forming the ground fabric. The second set, the pile warp, is set of longitudinal warp yarns that are used to form the loop piles on the fabric surface. The third set, the weft yarn, forms the transverse yarn that interlaces with the ground and the pile warps to form the fabric. Any of these two (or three) sets of yarns, and the resulting fabric, may be designed to absorb water.

[0005] While cellulose, and more specifically cotton, fibers are generally preferred due to their many desirable properties (for example, softness, absorptive properties, and sustainability), there is a desire to further increase the absorptive properties of a fabric used in applications such as toweling, rugs, bedding, and leisure fabrics. Therefore, a need exists for a method to further increase the absorptive properties. The present invention addresses this need and provides a method for sustainably engineering a fabric with superior absorptive properties.

SUMMARY

[0006] Embodiments of the present disclosure present technological improvements as solutions to one or more of the above-mentioned technical problems recognized by the inventors in the field of art.

[0007] In one embodiment, a method of creating a sustainable engineered fabric comprises creating an engineered yarn with primary and soluble fibers, dissolving the soluble fibers, and weaving the engineered yarn into a fabric. In certain embodiments, the primary fibers may comprise at least one of: cotton, linen, hemp, kapok, nettle, bamboo, lyocell, viscose, polyester (sustainable or recycled), PLA, PBT, nylon, acrylic, etc., or any suitable combinations thereof. In certain embodiments, the soluble fibers comprise one or more of wool and/or silk. It is to be understood that when referring to wool that the wool may be recycled, virgin, or a combination thereof. It is to be understood that when referring to silk that the silk may be recycled, virgin, or a combination thereof. In certain embodiments, the primary fibers comprise cotton. In certain embodiments, the soluble fibers comprise wool. In certain embodiments, the primary fibers comprise cotton and the soluble fibers comprise wool.

[0008] In another embodiment, a method of creating an engineered fabric comprises creating with primary fibers and wool and/or silk soluble fibers wherein the soluble fibers; dissolving the soluble fibers during yarn dyeing stage, using a process involving a wetting agent, desizing agent, alkali, hydrogen peroxide, peroxide stabilizer, lubricant, core alkali neutralizer/buffer, and a leveling agent, dyes; and weaving the yarn into a fabric. In certain embodiments, the primary fiber includes cotton, linen, hemp, kapok, nettle, bamboo, lyocell, viscose, polyester (sustainable or recycled), PLA, PBT, nylon, acrylic, etc., and suitable combinations thereof. In certain embodiments, the primary fiber is cotton, and the soluble fiber is wool. In certain embodiments, the wetting agent is an ionic or non-ionic wetting agent. In certain embodiments, the wetting agent is a commercially available wetting agent. In certain embodiments, the desizing agent is a group of enzymes. In certain embodiments, the desizing agent is a commercially available desizing agent. In certain embodiments, the hydrogen peroxide stabilizer is anionic in nature. In certain embodiments, the hydrogen peroxide stabilizer is a commercially available hydrogen peroxide stabilizer. In certain embodiments, the lubricant

is cryptanionic in nature. In certain embodiments, the lubricant is a commercially available lubricant. In certain embodiments, the core alkali neutralizer/buffer is anionic in nature. In certain embodiments, the core alkali neutralizer/buffer is a commercially available alkali neutralizer/buffer. In certain embodiments, the leveling agent is anionic in nature. In certain embodiments, the leveling agent is a commercially available leveling agent. It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are not restrictive of the invention, as claimed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The accompanying drawings, which are incorporated in and constitute a part of this disclosure, illustrate exemplary embodiments and, together with the description, serve to explain the disclosed principles.

Figure 1A is a flowchart of a yarn manufacturing method that comprises a yarn dyeing process and continuous post-processing.

Figure 1B is a flowchart of a fabric manufacturing method that comprises a yarn dyeing process and continuous post-processing.

Figure 2A is a flowchart of a yarn manufacturing method that comprises a yarn dyeing process and batch post-processing.

Figure 2B is a flowchart of a fabric manufacturing method that comprises a yarn dyeing process and batch post-processing.

Figure 3A is a flowchart of a yarn manufacturing method that comprises a continuous fabric dyeing process.

Figure 3B is a flowchart of a fabric manufacturing method that comprises a continuous fabric dyeing process.

Figure 4A is a flowchart of a yarn manufacturing method that comprises a batch fabric dyeing process.

Figure 4B is a flowchart of a fabric manufacturing method that comprises a batch fabric dyeing process.

DETAILED DESCRIPTION

[0010] The specification describes the preparation of sustainably engineered fabrics with superior absorption properties. The illustrated steps are set out to explain the exemplary embodiments shown, and it should be anticipated that ongoing technological development will

change the manner in which particular functions are performed. These examples are presented herein for purposes of illustration, and not limitation. Further, the boundaries of the functional building blocks have been arbitrarily defined herein for the convenience of the description.

[0011] Alternative boundaries can be defined so long as the specified functions and relationships thereof are appropriately performed. Alternatives (including equivalents, extensions, variations, deviations, etc., of those described herein) will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternatives fall within the scope of the disclosed embodiments. Also, the words "comprising," "having," "containing," and "including," and other similar forms are intended to be equivalent in meaning and be open ended in that an item or items following any one of these words is not meant to be an exhaustive listing of such item or items, nor are they meant to be limiting to only the listed item(s). It must also be noted that as used herein and in the appended claims, the singular forms "a," "an," and "the" include plural references unless the context clearly dictates otherwise.

[0012] With terry, a ground fabric made of a first warp yarn and provided with loops of a second warp yarn interlaced with weft yarns forms the fabric. The desired engineered terry fabric has a final weight between 200 and 1800 g/m². This engineered terry fabric may have 16 to 34 ends per centimeter in the warp direction, and 10 to 28 picks per centimeter in the weft direction.

[0013] Typically, in terry fabrics, the pile yarns (i.e., the loop-forming yarns) used in terry fabrics are coarse and range from about 6 to 50 Ne (Cotton Count) in single ply yarn. These yarns may be plied as well. Coarser yarns have a greater number of fibers in the cross section. The warp and weft yarns used in the ground weave of the fabric are more varied, ranging from 6 to 120 Ne. Like the pile yarn, the yarns used in the ground weave may be plied. The yarn count and weave construction are generally engineered based on the desired construction. For example, where a heavier basis weight fabric is desired, a coarser yarn may be implemented. And, similarly, the ends and/or picks per inch may be increased.

[0014] Generally, the yarns used in terry fabrics implement cotton where absorptive properties are desired. In addition to the yarns used for the warp and weft, decorative designs and/or embellishments (e.g., embroidery) may be formed using any desirable material, for example, polyester filament yarn.

[0015] A yarn's absorption properties depend on a variety of characteristics, including: fiber type, blend ratios of selected fiber types, and yarn structure. Modifying the yarn structure can increase the wicking properties of the yarn, which may lead to an increase in the hydrophilic properties of the yarn. Additionally, the amount of twist in a yarn affects the properties of the resultant towel. For example, since pile yarn is a commonly a low-twist yarn,

pile loops have a greater fiber surface area for the absorption of water. This also imparts wicking properties to the yarn. The pile yarn properties can contrast with the properties of the ground warp and weft yarn, which generally possess higher twist ratios than the pile yarn.

[0016] While cellulose, and more specifically cotton, fibers are generally preferred by consumers due to their many desirable properties (e.g., softness, absorptive properties, and sustainability), cellulose holds moisture longer than many synthetic fibers. Therefore, there is a need to engineer a fabric in sustainable manner with superior properties to reduce dry time. Because it is of interest to increase the amount of free space within yarn to increase absorbency of water, structural changes in the yarn need to be engineered. Further research has revealed that hollow and zero twist yarns are excellent for use in toweling. To manufacture hollow yarn, polyvinyl acetate (PVA) has been blended into cotton and spun into a yarn. These yarns have been woven into fabrics and then treated to dissolve the PVA to create a hollow yarn structure that increases the absorbency of the finished towels. PVA, however, is not an environmentally friendly fiber. Further research determined that wool and/or silk, natural protein fibers, tended to dissolve in sodium hydroxide solution (a caustic solution) at a certain concentration. Due to these fibers' excellent properties with regards to its elasticity, resilience, and absorbency, they were explored as a fiber for use in the preparation of the disclosed engineered terry fabric.

[0017] In certain embodiments of this disclosure, an environmentally friendly and organic approach was taken to create an engineered yarn with desirable properties. In the present invention disclosure, wool, silk, or a blend of wool and silk was used to increase the porosity of a cellulose (or more specifically, a cotton yarn). Additionally, a new attachment in the ring spinning system was utilized to eliminate the spinning triangle formed in a conventional ring system. This attachment provides multiple benefits, including reducing yarn hairiness and yarn breakage during spinning, and increasing yarn strength (making lower twist ratios possible) and yarn evenness (lower coefficient of variation). These yarn benefits also provide greater weaving efficiency (i.e., enables higher picks per minute and decreases downtime due to broken yarns). Additionally, a finer yarn count may be obtained by changing the blend ratios.

[0018] The yarn, which maybe be spun with wool, silk, or a blend of wool and silk, may be used in an engineered terry or flat woven fabric to increase the fabric's absorptive properties. The wool and/or silk may be removed during the yarn or fabric stage of a batch or continuous production using an enzyme and/or alkali solution. The combination of enzyme and alkali may be preferred where a more environmentally friendly method is preferred. Where a finer yarn count is desirable in the resulting fabric, silk is preferred. The amount of soluble fiber present can comprise up to about 40 percent of the weight of the yarn prior to dissolution.

[0019] Accordingly, certain embodiments of the present disclosure describe an engineered fabric that comprises a yarn engineered to have superior absorptive properties.

[0020] Exemplary embodiments are described with reference to the accompanying drawings. In the figures, the left-most digit(s) of a reference number identifies the figure in which the reference number first appears. Whenever convenient, the same reference numbers are used throughout the drawings to refer to the same or like parts. While examples and features of disclosed principles are described herein, modifications, adaptations, and other implementations are possible without departing from the scope of the disclosed embodiments. It is intended that the following detailed description be considered as exemplary only, with the true scope being indicated by the following claims.

[0021] It is intended that the disclosure and examples be considered as exemplary only, with a true scope of disclosed embodiments being indicated by the following claims.

[0022] To manufacture a fabric for use in applications such as toweling, rugs, bedding, and leisure fabrics, the fibers must be selected, the yarn must be spun, and the fabric must be woven. After fabric is woven, it may undergo various processes like preparatory or pretreatment processing, dyeing, and/or finishing. In the following detailed description of the invention, different methods are described for engineering a fabric with increased absorptive properties.

[0023] **Figure 1A** is a flowchart of a yarn manufacturing method that comprises a yarn dyeing process and continuous post processing illustrating an exemplary method **100** of processing fibers to form yarn for use in the preparation of fabrics. In one embodiment, method **100** starts with step **105**, in which primary fiber (e.g., the fiber that remains after the soluble fibers are dissolved) is received from a supplier. The primary fiber may be a one of a variety of fibers or a blend of fibers. For example, the primary fibers may be one or more of cotton, linen, hemp, kapok, nettle, bamboo, lyocell, viscose, polyester (sustainable or recycled), PLA, PBT, nylon, acrylic, etc. More specifically, the primary fiber may be cotton fibers. Where a finer yarn is desired, finer fibers may be preferred (e.g., fibers with smaller diameters). Likewise, for coarser yarn, coarser fibers may be preferred (e.g., fibers with larger diameters).

[0024] In step **110**, the primary fiber may be stored. When stored, the primary fibers may be conditioned to a certain temperature or relative humidity to prepare the fibers for spinning. As one of skill in the art would understand, the desired temperature and humidity would be dependent, in part, upon the type of fiber and type of processing that will occur.

[0025] In step **115**, the fibers may be processed in a blow room. A person of skill in the art would recognize that a blow room is where fiber is processed to prepare the fiber for yarn manufacturing. In the blow room, fibers

are selected for opening, cleaning, and blending.

[0026] In step **120**, the fibers undergo carding. At this stage, the fibers are passed through carding machines to remove short fibers, and trash (e.g., seed particulate), and individualize and align the fibers into slivers. After carding, the slivers are subjected to a drawing process to further align the fibers. During drawing, a number of carded slivers are fed through a drawing frame where they are drafted to create a more uniform sliver. At this stage, the slivers made of the primary fiber may be drafted with wool, silk, or wool/silk blended slivers to create a blended sliver with soluble fibers. In slivers comprised of a wool and silk blend, the ratio may be anywhere from 99:1 to 1:99. The content of the soluble fiber may make up 3% to 40% of the sliver prior to dissolving. Low blend ratios are preferred, such as 3% to 10% because these ranges are the most cost viable. It would be further preferred to have a 3.5% to 7% ratio of soluble fiber. Generally, the resulting sliver should have a count of 0.100 to 0.180 Ne (cotton count).

[0027] In optional step **125**, the fibers may optionally undergo lapping and followed by combing operation in step **130** to remove shorter fibers and produce a more lustrous resulting yarn. Generally, lapping followed by combing is done where a longer fiber is required (for example, to form a low twist yarn). In this step, 20 to 24 slivers are fed into the lapping machine to produce one lap. A person of skill in the art would understand that laps are then input into a combing machine (thus, if optional step 125 is performed, optional step 130 is also performed). Generally, the resulting lap should have a count of 0.0079 to 0.0091 Ne. These steps are generally used where a premium quality product is desired.

[0028] In optional step **130** (which is performed if optional step **125** is performed), the fibers undergo combing. During combing, the laps are passed through a set of combs that further orient the fiber, as well as remove additional short fibers. Generally, in this step, 6 to 8 laps are fed into the combing machine to produce one sliver. As previously discussed, lapping and combing are not required. These steps are generally used where a premium quality product is desired.

[0029] In step **135**, the resulting slivers undergo breaker drawing. Breaker drawing may be done whether or not the fibers were combed (the process that occurs in optional steps **125** and **130**). In certain embodiments, where carding but not combing occurs, the fibers may proceed from carding in step **120** directly to step **135** to undergo breaker drawing. Generally, in this step, 6 to 8 slivers are fed through the drawing frame together. These slivers are subjected to drafting, most commonly: a breaker draft and a main draft. During each of the drafting stages, a set of rollers (appropriately spaced to minimize fiber breakage) is calibrated to ensure that the resulting weight per length is appropriately sized.

[0030] In some embodiments, the fibers which underwent combing in step **130**, may be combined with the fibers that underwent carding and breaker drawing to un-

dergo a finisher drawing in step **140**. Generally, in this step, 6 to 8 slivers are fed through the drawing machine to produce one blended sliver. The fibers may be blended in such a way as to create bundles or tufts of wool and/or silk dispersed throughout the primary fiber in the resulting blended sliver. These tufts, when dissolved, leave pores in treated yarns' cross-section. These pores are desirable in certain applications where their unique absorbency and wicking properties are desirable. Alternatively, the wool and/or cotton may be evenly distributed throughout the cotton-blend sliver. Where the soluble fiber is evenly distributed, the pores left after dissolving are smaller than the pores that result from tufts of wool and/or silk. These pores are desirable in certain applications where their unique absorbency and wicking properties are desired.

[0031] In a parallel process, in step **145**, the soluble fibers may be received. Desirable soluble fibers include wool, silk, and/or any other suitable fiber, and combinations thereof. A person of skill in the art would understand that suitable fibers would include any fiber that offers eco-friendly or sustainable properties. As a person of skill in the art would understand, wool and silk fibers have varying properties. For example, wool may be fine (i.e., possess a small diameter) or coarse (i.e., possess a large diameter). When engineering a fabric, the fiber properties of the variety of soluble fiber must be considered, as well as other factors such as ratio of primary to soluble fiber, and blend characteristics (e.g., if the soluble fiber is dispersed in tufts or as single fibers).

[0032] In step **150**, the soluble fibers may be stored. When stored, the processed fibers may be conditioned to a certain temperature or relative humidity to prepare the fibers for spinning. As one of skill in the art would understand, the desired temperature and humidity would be dependent, in part, upon the type of fiber and type of processing that will occur.

[0033] In step **155**, the soluble fibers may be processed in a blow room. A person of skill in the art would recognize that a blow room is where fiber is processed to prepare the fiber for yarn manufacturing. In the blow room, fibers are selected for opening, cleaning, and blending. In the blow room, the soluble fibers may be blended together to achieve the desired ratio.

[0034] In step **160**, the soluble fibers may undergo carding and become sliver. At this stage, the fibers are passed through carding machines to remove short fibers and trash (e.g., vegetable matter and other undesirable particulate), individualize and align the fibers into slivers. After carding, the slivers are subjected to a drawing process to further align the fibers. During drawing, a number of carded slivers are fed through a drawing frame where they are drafted to create a more uniform sliver. In slivers comprised of a wool and silk blend, the ratio may be anywhere from 99:1 to 1:99. The content of the soluble fiber may make up 3% to 40% of the end sliver (e.g., the sliver comprising a blend of primary and soluble fiber). Low blend ratios are preferred, such as 3% to 10% because these ranges are the most cost viable. It would be further

preferred to have a 3.5% to 7% ratio of soluble fiber. Generally, the resulting sliver should have a count of 0.100 to 0.180 Ne (cotton count).

[0035] In step **165**, the soluble fibers may undergo drawing to ensure the unity of the fibers in the stream. After step **165**, drawn slivers are finisher drawn in step **140**. Generally, during finisher drawing, 6 to 8 slivers are fed through the drawing machine to produce one blended sliver. The fibers may be blended in such a way as to create bundles or tufts of wool and/or silk dispersed throughout the primary fiber in the resulting blended sliver. These tufts, when dissolved, leave pores in yarn cross-sections. These pores are desirable in certain applications where their unique absorbency and wicking properties are desirable. Alternatively, the wool and/or cotton may be evenly distributed throughout the cotton-blend sliver. Where the soluble fiber is evenly distributed, the pores left after dissolving are smaller than the pores that result from tufts of wool and/or silk. These pores are desirable in certain applications where their unique absorbency and wicking properties are desired.

[0036] In step **170**, the blended slivers produced through any combination of the forgoing processes undergo speed frame roving. A person of skill in the art will understand that roving is required for ring spinning. During roving, slivers are further drafted to reduce the weight per length and a low amount of twist is inserted.

[0037] In step **175**, the roving that was created in step **170** undergoes ring spinning. Ring spinning is desirable for applications, such as terry toweling, rugs, bedding, and leisure fabrics, where softness is desired. Further, yarn spinning produces yarns with desirable elasticity. During ring spinning roving is fed into the ring spinning machine and bobbins of yarn is output. Generally, the resulting yarn should have a count of 6 Ne to 120 Ne. Additionally, a new attachment in the ring spinning system was utilized to eliminate the spinning triangle formed in a conventional ring system. This attachment provides multiple benefits, including reducing yarn hairiness and yarn breakage during spinning, and increasing yarn strength (making lower twist ratios possible) and yarn evenness (i.e., lower coefficient of variation). These yarn benefits also provide greater weaving efficiency (i.e., enables higher picks per minute and decreases downtime due to broken yarns). Additionally, a finer yarn count may be obtained by changing the blend ratios. In place of Ring Spinning, a Rotor Spinning, Friction Spinning, Air Jet Spinning or Compact Spinning may also be used in the alternate.

[0038] In step **180**, after spinning the bobbins of yarn may be combined onto a cone using an autoconer. Cones are required to convert the bobbins to larger packages suitable for textile processing.

[0039] In step **185**, the yarns may optionally undergo plying. During this step, yarns of the same or different counts may be plied together. Similarly, yarns with the same fiber and blend content, or yarns with differing fiber and blend contents may be plied. The number of yarns

plied may be two or more.

[0040] In step **190**, the yarns may be wound onto suitable packages. For example, yarns may be wound off of tapered cones onto cylindrical tubes or other forms of packaging more suitable for warping and weaving.

[0041] **Figure 1B** is a flowchart of a fabric manufacturing method that comprises a yarn dyeing process and a continuous post processing illustrating an exemplary method 200 of processing yarns into fabrics.

[0042] In step **205**, yarn is received from a supplier or the spinning room.

[0043] In step **210**, the yarn may be stored. When stored, the yarns may be conditioned to a certain temperature or relative humidity to prepare the yarns for weaving. As one of skill in the art would understand, the desired temperature and humidity would be dependent, in part, upon the type of fiber and type of processing that will occur.

[0044] In step **215**, the soluble fibers may be dissolved and, if desired, the yarn may be dyed. For example, the wool and/or silk fibers may be dissolved in sodium hydroxide (NaOH), an enzyme, or a combination thereof. Further, when the soluble fibers are dissolved, scouring and bleaching may occur. During this process, the packages may be loaded into a machine where they are placed in a water bath. The temperature of the water bath may be increased before a wetting agent is applied. A wetting agent lowers the surface tension of a liquid, allowing easier spreading, and lower the interfacial tension between two liquids, and aid in cleaning the surface of fibers and improving the solidity of reactive and disperse dyeing. A stabilizer for hydrogen peroxide bleaching may be used to achieve uniform bleaching by suppressing rapid decomposition of hydrogen peroxide. A stabilizer prevents degradation of strength and pinholes by suppressing decomposition. Thus, a stabilizer plays an important role to obtain high quality bleached products. A core alkali neutralizer (or "buffer") may be added after the bleaching process to remove the alkali and control the pH for further processing. A leveling agent (or "retarding agent" or "retarder") may be used to aid in fixing the dye to the yarn and obtain a uniform shade. On of skill in the art would understand that the appropriate yarn package (e.g., tube or cone) should be selected for the desired processes, and that the yarn package may need to be changed prior to dyeing. After the soluble fibers are dissolved (and repacked if necessary) the yarn may be dyed using any suitable dyeing process.

[0045] In step **220**, the yarn undergoes warping. Any known process for warping, including high speed/direct warping, sectional/indirect warping, and/or ball warping, may be utilized in this step.

[0046] In step **225**, the yarn undergoes sizing. Any known process for sizing, including wet sizing, solvent sizing, cold sizing, and/or hot melt sizing, may be utilized in this step.

[0047] In step **230**, the yarn undergoes weaving. Any known process for weaving, including terry weaving, may

be utilized. For example, in terry weaving, two warp beams are prepared (one for the ground warp and one for the pile warp). These two warps are fed through the loom at different speeds to create loops on the pile warp. The weft and ground warp form a ground weave that supports the pile loops.

[0048] In step 235, the article may undergo inspection. Any known process for inspection may be utilized. For example, terry fabric may be manually inspected by a trained employee using a light board (sometimes called a light box) or automatically inspected using a camera-based visual inspection system.

[0049] In step 240, the article may undergo singeing and desizing in open width form. Singeing is only applied to flat woven fabrics, such as bedding. Singeing is used to remove fine fibers from the surface of the fabric to create a smoother fabric with a less hairy appearance. In contrast, where a piled fabric is created, bio-polishing is done. Bio-polishing is used decrease a fabric's tendency to pill by removing protruding fibers. Desizing agents aid in the removal of added impurities in the form of starch and synthetic sizes without having any effect on the fibers and yarn. It is important that these impurities are removed to ensure better realization of further processing. Thus, desizing is done to remove the sizing that was applied on the warp yarns prior to weaving.

[0050] In step 245, the fabric is washed in its open width form.

[0051] In step 250, the fabric is finished using a stenter. During this step the fabric is pulled and held tight in the weft direction and subjected to finishing treatments. This step ensures that the yarns are properly oriented prior to cutting and sewing.

[0052] In step 255, the finished fabric undergoes a second inspection.

[0053] In step 260, the fabric is cut apart.

[0054] In optional step 265, if the resulting textile is intended for use as a terry towel, length hemming occurs to finish the raw edges of the towel. After length hemming, partially finished towel may undergo cross-cutting in step 270 and cross hemming in step 275.

[0055] In optional step 280, where the resulting textile article is not a terry towel, the fabric may be stitched or sewn in the manner required for the end application.

[0056] In step 285, the resulting article is subjected to a final inspection.

[0057] In step 290, the inspected article is packed into a bag.

[0058] In step 295, the textile article is carton packaged.

[0059] Figure 2A is a flowchart of an exemplary method 300 of processing fibers to form yarn for use in the preparation of fabrics. Method 300 comprises a yarn manufacturing method that comprises a yarn dyeing process and a batch process for post-processing. In one embodiment, method 300 starts with step 305, in which primary fiber (e.g., the fiber that remains after dissolution) is received from a supplier. The primary fibers may be a

variety of fibers or a blend of different fibers. For example, the primary fibers may be one or more of cotton, linen, hemp, kapok, nettle, bamboo, lyocell, viscose, polyester (sustainable or recycled), PLA, PBT, nylon, acrylic, etc. More specifically, the primary fiber may be cotton fibers. Where a finer yarn is desired, finer fibers may be preferred (e.g., fibers with smaller diameters). Likewise, for coarser yarn, coarser fibers may be preferred (e.g., fibers with larger diameters).

[0060] In step 310, the primary fiber may be stored. When stored, the primary fibers may be conditioned to a certain temperature or relative humidity to prepare the fibers for spinning. As one of skill in the art would understand, the desired temperature and humidity would be dependent, in part, upon the type of fiber and type of processing that will occur.

[0061] In step 315, the fibers may be processed in a blow room. A person of skill in the art would recognize that a blow room is where fiber is processed to prepare the fiber for yarn manufacturing. In the blow room, fibers are selected for opening, cleaning, and blending.

[0062] In step 320, the fibers undergo carding. At this stage, the fibers are passed through carding machines to remove short fibers and trash (e.g., vegetable matter and other undesirable particulate), and individualize and align the fibers into slivers. After carding, the slivers are subjected to a drawing process to further align the fibers. During drawing, a number of carded slivers are fed through a drawing frame where they are drafted to create a more uniform sliver. At this stage, the slivers made of the primary fiber may be drafted with wool, silk, or wool/silk blended slivers to create a blended sliver with soluble fibers. In slivers comprised of a wool and silk blend, the ratio may be anywhere from 99:1 to 1:99. The content of the soluble fiber may make up 3% to 40% of the end sliver. Low blend ratios are preferred, such as 3% to 10% because these ranges are the most cost viable. It would be further preferred to have a 3.5% to 7% ratio of soluble fiber. Generally, the resulting sliver should have a count of 0.100 to 0.180 Ne (cotton count).

[0063] In optional step 325, the fibers may undergo lapping to remove shorter fibers and produce a more lustrous resulting yarn. Generally, lapping is done where a longer fiber is required (for example, to form a low twist yarn). In this step, 20 to 24 slivers are fed into the lapping machine to produce one lap. A person of skill in the art would understand that laps then input into a combing machine (thus, if optional step 125 is performed, optional step 130 is also performed). Generally, the resulting lap should have a count of 0.0079 to 0.0091 Ne. These steps are generally used where a premium quality product is desired.

[0064] In optional step 330 (which is performed if optional step 325 is performed), the fibers undergo combing. During combing, the laps are passed through a set of combs that further orient the fiber, as well as removing additional short fibers and noils. Generally, in this step, 6 to 8 laps are input into the combing machine to produce

one sliver. As previously discussed, lapping and combing are not required. These steps are generally used where a premium quality product is desired.

[0065] In step **335**, the resulting slivers undergo breaker drawing. Breaker drawing may be done whether or not the fibers were combed. In certain embodiments, the fibers may proceed from carding in step **320** directly to step **335** to undergo breaker drawing. Generally, in this step, 6 to 8 slivers are fed through the drawing frame together. These slivers are subjected to drafting, most commonly: a breaker draft and a main draft. During each of the drafting stages, a set of rollers (appropriately spaced to minimize fiber breakage) is calibrated to ensure that the resulting weight per length is appropriately sized.

[0066] In some embodiments, the fibers which underwent combing in step **330**, may be combined with the fibers that underwent carding and breaker drawing to undergo a finisher drawing in step **340**. Generally, in this step, 6 to 8 slivers are fed through the drawing machine to produce one blended sliver. The fibers may be blended in such a way as to create bundles or tufts of wool and/or silk dispersed throughout the primary fiber in the resulting blended sliver. These tufts, when dissolved, leave pores in yarn cross-sections. These pores are desirable in certain applications where their unique absorbency and wicking properties are desirable. Alternatively, the wool and/or cotton may be evenly distributed throughout the cotton-blend sliver. Where the soluble fiber is evenly distributed, the pores left after dissolving are smaller than the pores that result from tufts of wool and/or silk. These pores are desirable in certain applications where their unique absorbency and wicking properties are desired.

[0067] In a parallel process, in step **345**, the soluble fibers may be received. Desirable soluble fibers include wool, silk, and suitable combinations thereof. As a person of skill in the art would understand, wool and silk fibers have varying properties. For example, wool may be fine (i.e., possess a small diameter) or coarse (i.e., possess a large diameter). When engineering a fabric, the fiber properties of the variety of soluble fiber must be considered, as well as other factors such as ratio of primary to soluble fiber, and blend characteristics (e.g., if the soluble fiber is dispersed in tufts or as single fibers).

[0068] In step **350**, the soluble fibers may be stored. When stored, the processed fibers may be conditioned to a certain temperature or relative humidity to prepare the fibers for spinning.

[0069] As one of skill in the art would understand, the desired temperature and humidity would be dependent, in part, upon the type of fiber and type of processing that will occur.

[0070] In step **355**, the soluble fibers may be processed in a blow room. A person of skill in the art would recognize that a blow room is where fiber is processed to prepare the fiber for yarn manufacturing. In the blow room, fibers are selected for opening, cleaning, and blending. In the blow room, the soluble fibers may be blended together to achieve the desired ratio.

[0071] In step **360**, the soluble fibers may undergo carding and become sliver. At this stage, the fibers are passed through carding machines to remove short fibers and trash (e.g., vegetable matter and other undesirable particulate), and individualize and align the fibers into slivers. After carding, the slivers are subjected to a drawing process to further align the fibers. During drawing, a number of carded slivers are fed through a drawing frame where they are drafted to create a more uniform sliver. In slivers comprised of a wool and silk blend, the ratio may be anywhere from 99:1 to 1:99. The content of the soluble fiber may make up 3% to 40% of the end sliver (e.g., the sliver comprising a blend of primary and soluble fiber). Low blend ratios are preferred, such as 3% to 10% because these ranges are the most cost viable. It would be further preferred to have a 3.5% to 7% ratio of soluble fiber. Generally, the resulting sliver should have a count of 0.100 to 0.180 Ne (cotton count).

[0072] In step **365**, the soluble fibers may undergo drawing to ensure the unity of the fibers in the stream. After step **365**, drawn slivers are finisher drawn in step **340**. Generally, in during finisher drawing, 6 to 8 slivers are fed through the drawing machine to produce one blended sliver. The fibers may be blended in such a way as to create bundles or tufts of wool and/or silk dispersed throughout the primary fiber in the resulting blended sliver. These tufts, when dissolved, leave pores in yarn cross-sections. These pores are desirable in certain applications where their unique absorbency and wicking properties are desirable. Alternatively, the wool and/or cotton may be evenly distributed throughout the cotton-blend sliver. Where the soluble fiber is evenly distributed, the pores left after dissolving are smaller than the pores that result from tufts of wool and/or silk. These pores are desirable in certain applications where their unique absorbency and wicking properties are desired.

[0073] In step **370**, the blended slivers produced through any combination of the forgoing processes undergo speed frame roving. A person of skill in the art will understand that roving is required for ring spinning. During roving, slivers are further drafted to reduce the weight per length and a low amount of twist is inserted.

[0074] In step **375**, the roving created in step **370** undergoes ring spinning. Ring spinning is desirable for applications, such as terry toweling, rugs, bedding, and leisure fabrics, where softness is desired. Further, yarn spinning produces yarns with desirable elasticity. During ring spinning roving is fed into the ring spinning machine and bobbins of yarn is output. Generally, the resulting yarn should have a count of 6 Ne to 120 Ne. Additionally, a new attachment in the ring spinning system was utilized to eliminate the spinning triangle formed in a conventional ring system. This attachment provides multiple benefits, including reducing yarn hairiness and yarn breakage during spinning, and increasing yarn strength (making lower twist ratios possible) and yarn evenness (lower coefficient of variation). These yarn benefits also provide greater weaving efficiency (i.e., enables higher picks per

minute and decreases downtime due to broken yarns). Additionally, a finer yarn count may be obtained by changing the blend ratios. In place of Ring Spinning, a Rotor Spinning, Friction Spinning, Air Jet Spinning or Compact Spinning may also be used in the alternate.

[0075] In step 380, after spinning the bobbins of yarn may be combined onto a cone using an autoconer. Cones are required to convert the bobbins to larger packages suitable for textile processing.

[0076] In step 385, the yarns may undergo plying. During this step, yarns of the same or different counts may be plied together. Similarly, yarns with the same fiber and blend content, or yarns with differing fiber and blend contents may be plied. The number of yarns plied may be two or more.

[0077] In step 390, the yarns may be wound onto suitable packages. For example, yarns may be wound off of tapered cones onto cylindrical tubes or other forms of packaging more suitable for warping and weaving.

[0078] Figure 2B is a flowchart of a fabric manufacturing method that comprises a yarn dyeing process and a batch post process illustrating exemplary method 400 of processing yarns into fabrics.

[0079] In step 405, yarn is received from a supplier or the spinning room.

[0080] In step 410, the yarn may be stored. When stored, the yarns may be conditioned to a certain temperature or relative humidity to prepare the yarns for weaving. As one of skill in the art would understand, the desired temperature and humidity would be dependent, in part, upon the type of fiber and type of processing that will occur.

[0081] In step 415, the soluble fibers may be dissolved. For example, the wool and/or silk fibers may be dissolved in alkali (for example including but not limited to NaOH), an enzyme, or a combination thereof. As one of skill in the art would understand, it may be desirable to bleach and/or pre-treat the yarn before dyeing. During the bleaching and/or pretreating process, the packages may be loaded into a machine where they are placed in a water bath. The temperature of the water bath may be increased before a wetting agent is applied. A wetting agent lowers the surface tension of a liquid to allow easier spreading, lower the interfacial tension between two liquids, and aid in cleaning the surface of fibers, and improve the solubility of reactive and disperse dyeing. A stabilizer for hydrogen peroxide bleaching may be used to achieve uniform bleaching by suppressing rapid decomposition of hydrogen peroxide. A stabilizer prevents degradation of strength and pinholes by suppressing decomposition. Thus, a stabilizer plays an important role to obtain high quality bleached products. A lubricant in low liquor ratios and high temperature, when fabric is processed in full-loaded rope dyeing machines (jets, overflows or winch becks) fabric prone to crease (line caused by folding), chafe (damaged by rubbing) as well as wrinkle line. In high temperature, if crease or chafe marks or wrinkle lines are formed, these are permanently seen on

the fabric surface and cannot be removed easily. Thus, the lubricating agent is used to prevent running crease, crack, chafe, and crush marks, as well as wrinkle lines. It offers reliability in the pretreatment, dyeing and soaking bath for difficult textiles. A core alkali neutralizer (or "buffer") may be added after the bleaching process to remove the alkali and control the pH for further processing. A level agent (or "retarding agent" or "retarder") may be used to aid in fixing the dye to the yarn and obtain a uniform shade. After the soluble fibers are dissolved the yarn may be dyed.

[0082] For example, the bleaching process may start out with a loading step where the yarn packages are placed in a water bath and the temperature of the bath is increased to 70 °C. When the bath reaches 70 °C, a wetting agent (e.g., a commercially available wetting agent 1.25±0.20 g/l) and, a peroxide stabilizer (e.g., a commercially available peroxide stabilizer 0.50±0.20 g/l), caustic soda (5.50 ± 0.50 g/l), and a lubricant (e.g., a commercially available lubricant 0.50±0.20 g/l) are added and the bath temperature is increased to 75 °C over the course of five minutes. Once the bath reaches 75 °C, hydrogen peroxide (4.75 ± 0.50 g/l) is introduced to the bath. The yarns dwell at 75 °C for approximately ten minutes before the temperature is increased to 100 °C over the course of five minutes. Once the temperature reaches 100 °C, the bath is maintained at that temperature for 25 minutes. The bath is then drained and the yarn is subjected to a hot water (90 °C) rinse. After the hot water rinse, the bath is once again drained. The bath is then refilled with 45 °C water and a core alkali neutralizer or buffer (e.g., a commercially core alkali neutralizer or buffer 0.35 ± 0.20 g/l) and an acid to maintain the bath pH (e.g., acetic acid or Green Acid (1.00 ± 0.20 g/l)) are introduced. The yarn dwells in this bath at 45 °C for 29 minutes before a lubricating agent (e.g., a commercially available lubricating agent 0.50 ± 0.20 g/l) and a peroxide stabilizer (e.g., a commercially available peroxide stabilizer 0.50 ± 0.20 g/l) are introduced. The yarn dwells in the modified bath for an additional five minutes before the bath is drained. The entire cycle may take 119 minutes.

[0083] Alternatively, the bleaching process may start out with a loading step where the yarn packages are placed in a water bath and the temperature of the bath is increased to 70 °C. When the bath reaches 70 °C, non-ionic wetting agent (e.g., a commercially available wetting agent) (1.25 ± 0.20 g/l) and caustic soda (10.00 ± 2.00 g/l), and lubricating agent (e.g., a commercially available lubricating agent 0.50 ± 0.20 g/l) are added and the bath temperature is increased to 75 °C over the course of five minutes. Once the bath reaches 75 °C, a peroxide stabilizer (e.g., a commercially available peroxide stabilizer 7.50 ± 1.00 g/l) is introduced to the bath. The yarns dwell at 75 °C for approximately ten minutes before the temperature is increased to 100 °C over the course of five minutes. Once the temperature reaches 100 °C, the bath is maintained at that temperature for 25

minutes. The bath is then drained and the yarn is subjected to a hot water (90 °C) rinse. After the hot water rinse, the bath is once again drained. The bath is then refilled with 45 °C water and core neutralizer (e.g., a commercially available core neutralizer 0.35 ± 0.20 g/l) and an acid to maintain the bath pH, such as acetic acid or Green Acid (1.50 ± 0.20 g/l) are introduced. The yarn dwells in this bath at 45 °C for 29 minutes before a lubricating agent (e.g., a commercially available lubricating agent 0.50 ± 0.20 g/l) and a levelling agent (e.g., a commercially available leveling agent 0.40 to 0.60 g/l) are introduced and followed by dye as per required depth of shade is dosed in the bath to complete the dyeing process. The yarn dwells in the modified bath for an additional five minutes before the bath is drained. The entire cycle may take 119 minutes.

[0084] In step 420, the yarn undergoes warping. Any known process for warping, including high speed/direct warping, sectional/indirect warping, and/or ball warping, may be utilized in this step.

[0085] In step 425, the yarn undergoes sizing. Any known process for sizing, including wet sizing, solvent sizing, cold sizing, and/or hot melt sizing, may be utilized in this step.

[0086] In step 430, the yarn undergoes weaving. Any known process for weaving, including terry weaving, may be utilized. For example, in terry weaving, two warp beams are prepared (one for the ground warp and one for the pile warp). These two warps are fed through the loom at different speeds to create loops on the pile warp. The weft and ground warp form a ground weave that supports the pile loops.

[0087] In step 435, the article may undergo inspection. Any known process for inspection may be utilized. For example, terry fabric may be manually inspected by a trained employee using a light board (sometimes called a light box) or automatically inspected using a camera-based visual inspection system.

[0088] In step 440, the article may undergo singeing and desizing in open width form. Singeing is only applied to flat woven fabrics, such as bedding. Singeing is used to remove fine fibers from the surface of the fabric to create a smoother fabric with a less hairy appearance. In contrast, where a piled fabric is created, bio-polishing is done. Bio-polishing is used decrease a fabric's tendency to pill by removing protruding fibers. Desizing agents aid in the removal of added impurities in the form of starch and synthetic sizes without having any effect on the fibers and yarn. It is important that these impurities are removed to ensure better realization of further processing. Thus, desizing is done to remove the sizing that was placed on the warp yarns prior to weaving.

[0089] In step 445, the fabric is washed in its rope form.

[0090] In step 450, if terry toweling or similar fabric is being manufactured, the washed "rope" of fabric is opened.

[0091] In step 452, the fabric is finished using a stenter. During this step the fabric is pulled taught in the weft

direction and subjected to finishing treatments. This step ensures that the yarns are properly oriented prior to cutting and sewing.

[0092] In step 455, the finished fabric undergoes a second inspection.

[0093] In step 460, the fabric is cut apart.

[0094] In step optional 465, if the resulting textile is intended for use as a terry towel or similar product, then length hemming occurs to finish the raw edges of the towel. After length hemming, partially finished towel may undergo cross-cutting 470 and cross hemming 475.

[0095] In optional step 480, where the resulting textile article is not a terry towel, the fabric may be stitched or sewn in the manner required.

[0096] In step 485, the resulting article is subjected to a final inspection.

[0097] In step 490, the textiles are packed into bags.

[0098] In step 495, the bagged textiles are carton packaged.

[0099] Figure 3A is a flowchart of a yarn manufacturing method that comprises a continuous fabric dyeing process illustrating an exemplary method 500 of processing fibers to form yarn for use in the preparation of fabrics. In one embodiment, method 500 starts with step 505, in which primary fiber (e.g., the fiber that remains after dissolution) is received from a supplier. The primary fibers may be a variety of fibers or a blend of different fibers. For example, the primary fibers may be one or more of cotton, linen, hemp, kapok, nettle, bamboo, lyocell, viscose, polyester (sustainable or recycled), PLA, PBT, nylon, acrylic, etc. More specifically, the primary fiber may be cotton fibers. Where a finer yarn is desired, finer fibers may be preferred (e.g., fibers with smaller diameters). Likewise, for coarser yarn, coarser fibers may be preferred (e.g., fibers with larger diameters).

[0100] In step 510, the primary fiber may be stored. When stored, the primary fibers may be conditioned to a certain temperature or relative humidity to prepare the fibers for spinning. As one of skill in the art would understand, the desired temperature and humidity would be dependent, in part, upon the type of fiber and type of processing that will occur.

[0101] In step 515, the fibers may be processed in a blow room. A person of skill in the art would recognize that a blow room is where fiber is processed to prepare the fiber for yarn manufacturing. In the blow room, fibers are selected for opening, cleaning, and blending.

[0102] In step 520, the fibers undergo carding. At this stage, the fibers are passed through carding machines to remove short fibers and trash (e.g., vegetable matter and other undesirable particulate), and individualize and align the fibers into slivers. After carding, the slivers are subjected to a drawing process to further align the fibers. During drawing, a number of carded slivers are fed through a drawing frame where they are drafted to create a more uniform sliver. At this stage, the slivers made of the primary fiber may be drafted with wool, silk, or wool/silk blended slivers to create a blended sliver with

soluble fibers. In slivers comprised of a wool and silk blend, the ratio may be anywhere from 99:1 to 1:99. The content of the soluble fiber may make up 3% to 40% of the end sliver. Low blend ratios are preferred, such as 3% to 10% because these ranges are the most cost viable. It would be further preferred to have a 3.5% to 7% ratio of soluble fiber. Generally, the resulting sliver should have a count of 0.100 to 0.180 Ne (cotton count).

[0103] In optional step **525**, the fibers may undergo lapping to remove shorter fibers and produce a more lustrous resulting yarn. Generally, lapping is done where a longer fiber is required (for example, to form a low twist yarn). In this step, 20 to 24 slivers are fed into the lapping machine to produce one lap. A person of skill in the art would understand that the laps are then fed into a combing machine (thus, if optional step **525** is performed, optional step **530** is also performed). Generally, the resulting lap should have a count of 0.0079 to 0.0091 Ne. These steps are generally used where a premium quality product is desired.

[0104] In optional step **530** (which is performed if optional step **525** is performed), the fibers undergo combing. During combing, the laps are passed through a set of combs that further orient the fiber, as well as remove additional short fibers. Generally, in this step, 6 to 8 laps are input into the combing machine to produce one sliver. As previously discussed, lapping and combing are not required. These steps are generally used where a premium quality product is desired.

[0105] In step **535**, the resulting slivers undergo breaker drawing. Breaker drawing may be done whether or not the fibers were combed. In certain embodiments, the fibers may proceed from carding in step **520** directly to step **535** to undergo breaker drawing. Generally, in this step, 6 to 8 slivers are fed through the drawing frame together. These slivers are subjected to drafting, most commonly: a breaker draft and a main draft. During each of the drafting stages, a set of rollers (appropriately spaced to minimize fiber breakage) is calibrated to ensure that the resulting weight per length is appropriately sized.

[0106] In some embodiments, the fibers which underwent combing in step **530**, may be combined with the fibers that underwent carding and breaker drawing to undergo a finisher drawing in step **540**. Generally, in this step, 6 to 8 slivers are fed through the drawing machine to produce one blended sliver. The fibers may be blended in such a way as to create bundles or tufts of wool and/or silk dispersed throughout the primary fiber in the resulting blended sliver. These tufts, when dissolved, leave pores in yarn cross-sections. These pores are desirable in certain applications where their unique absorbency and wicking properties are desirable. Alternatively, the wool and/or cotton may be evenly distributed throughout the cotton-blend sliver. Where the soluble fiber is evenly distributed, the pores left after dissolving are smaller than the pores that result from tufts of wool and/or silk. These pores are desirable in certain applications where their unique absorbency and wicking properties are desired.

[0107] In a parallel process, in step **545**, the soluble fibers may be received. Desirable soluble fibers include wool, silk, and suitable combinations thereof. As a person of skill in the art would understand, wool and silk fibers have varying properties. For example, wool may be fine (i.e., possess a small diameter) or coarse (i.e., possess a large diameter). When engineering a fabric, the fiber properties of the variety of soluble fiber must be considered, as well as other factors such as ratio of primary to soluble fiber, and blend characteristics (e.g., if the soluble fiber is dispersed in tufts or as single fibers).

[0108] In step **550**, the soluble fibers may be stored. When stored, the processed fibers may be conditioned to a certain temperature or relative humidity to prepare the fibers for spinning. As one of skill in the art would understand, the desired temperature and humidity would be dependent, in part, upon the type of fiber and type of processing that will occur.

[0109] In step **555**, the soluble fibers may be processed in a blow room. A person of skill in the art would recognize that a blow room is where fiber is processed to prepare the fiber for yarn manufacturing. In the blow room, fibers are selected for opening, cleaning, and blending. In the blow room, the soluble fibers may be blended together to achieve the desired ratio.

[0110] In step **560**, the soluble fibers may undergo carding and become sliver. At this stage, the fibers are passed through carding machines to remove short fibers and trash (e.g., vegetable matter and other undesirable particulate), and individualize and align the fibers into slivers. After carding, the slivers are subjected to a drawing process to further align the fibers. During drawing, a number of carded slivers are fed through a drawing frame where they are drafted to create a more uniform sliver. In slivers comprised of a wool and silk blend, the ratio may be anywhere from 99:1 to 1:99. The content of the soluble fiber may make up 3% to 40% of the end sliver (e.g., the sliver comprising a blend of primary and soluble fiber). Low blend ratios are preferred, such as 3% to 10% because these ranges are the most cost viable. It would be further preferred to have a 3.5% to 7% ratio of soluble fiber. Generally, the resulting sliver should have a count of 0.100 to 0.180 Ne (cotton count).

[0111] In step **565**, the soluble fibers may undergo drawing to ensure the unity of the fibers in the stream. After step **565**, drawn slivers are finisher drawn in step **540**. Generally, in during finisher drawing, 6 to 8 slivers are fed through the drawing machine to produce one blended sliver. The fibers may be blended in such a way as to create bundles or tufts of wool and/or silk dispersed throughout the primary fiber in the resulting blended sliver. These tufts, when dissolved, leave pores in yarn cross-sections. These pores are desirable in certain applications where their unique absorbency and wicking properties are desirable. Alternatively, the wool and/or cotton may be evenly distributed throughout the cotton-blend sliver. Where the soluble fiber is evenly distributed, the pores left after dissolving are smaller than the pores

that result from tufts of wool and/or silk. These pores are desirable in certain applications where their unique absorbency and wicking properties are desired.

[0112] In step **570**, the blended slivers produced through any combination of the forgoing processes undergo speed frame roving. A person of skill in the art will understand that roving is required for ring spinning. During roving, slivers are further drafted to reduce the weight per length and a low amount of twist is inserted.

[0113] In step **575**, the roving created in step **570** undergoes ring spinning. Ring spinning is desirable for applications, such as terry toweling, rugs, bedding, and leisure fabrics, where softness is desired. Further, yarn spinning produces yarns with desirable elasticity. During ring spinning roving is fed into the ring spinning machine and bobbins of yarn are output. Generally, the resulting yarn should have a count of 6 Ne to 120 Ne. Additionally, a new attachment in the ring spinning system was utilized to eliminate the spinning triangle formed in a conventional ring system. This attachment provides multiple benefits, including reducing yarn hairiness and yarn breakage during spinning, and increasing yarn strength (making lower twist ratios possible) and yarn evenness (lower coefficient of variation). These yarn benefits also provide greater weaving efficiency (i.e., enables higher picks per minute and decreases downtime due to broken yarns). Additionally, a finer yarn count may be obtained by changing the blend ratios. In place of Ring Spinning, a Rotor Spinning, Friction Spinning, Air Jet Spinning or Compact Spinning may also be used in the alternate.

[0114] In step **580**, after spinning the bobbins of yarn may be combined onto a cone using an autoconer. Cones are required to convert the bobbins to larger packages suitable for textile processing.

[0115] In step **585**, the yarns may undergo plying. During this step, yarns of the same or different counts may be plied together. Similarly, yarns with the same fiber and blend content, or yarns with differing fiber and blend contents may be plied. The number of yarns plied may be two or more.

[0116] In step **590**, the yarns may be wound onto suitable packages. For example, yarns may be wound off of tapered cones onto cylindrical tubes or other forms of packaging more suitable for warping and weaving.

[0117] **Figure 3B** is a flowchart of a fabric manufacturing method that comprises a continuous fabric dyeing process. Illustrating an exemplary method **600** of processing yarns into fabrics.

[0118] In step **605**, yarn is received from a supplier or the spinning room.

[0119] In step **610**, the yarn may be stored. When stored, the yarns may be conditioned to a certain temperature or relative humidity to prepare the yarns for weaving. As one of skill in the art would understand, the desired temperature and humidity would be dependent, in part, upon the type of fiber and type of processing that will occur.

[0120] In step **615**, the yarn undergoes warping. Any

known process for warping, including high speed/direct warping, sectional/indirect warping, and/or ball warping, may be utilized in this step.

[0121] In step **620**, the yarn undergoes sizing. Any known process for sizing, including wet sizing, solvent sizing, cold sizing, and/or hot melt sizing, may be utilized in this step.

[0122] In step **625**, the yarn undergoes weaving. Any known process for weaving, including terry weaving, may be utilized. For example, in terry weaving, two warp beams are prepared (one for the ground warp and one for the pile warp). These two warps are fed through the loom at different speeds to create loops on the pile warp. The weft and ground warp form a ground weave that supports the pile loops.

[0123] In step **630**, the fabric may undergo inspection. Any known process for inspection may be utilized. For example, terry fabric may be manually inspected by a trained employee using a light board (sometimes called a light box) or automatically inspected using a camera-based visual inspection system.

[0124] In step **635**, the resulting fabric may be treated using a plasma treatment. Effect of plasma treatment: Plasma treatment is a dry state treatment on to any textile surface before any wet processing. Essentially, four main effects can be obtained depending on the treatment conditions: surface cleaning, etching, surface activation, and polymerization. Thus, plasma treatments find their application in the textile field for a variety of purposes including modification of surface energy, modification of surface topography, improvement of adhesion, and surface cleaning. References, R. Abd. Jelil, A review of low-temperature plasma treatment of textile materials, 50 J. MATER SCI. 5913 (2015); Sheila Shahidi et al., Study of Surface Modification of Wool Fabrics Using Low Temperature Plasma, PROC. OF THE 3RD INT'L CONF. ON THE FRONTIERS OF PLASMA PHYSICS AND TECH. 1 (2008); Amelia Sparavigna, Plasma treatment advantages for textiles. ARXIV: POPULAR PHYSICS. 1-16.; describe the plasma treatment process in detail and are incorporated herein by reference. In certain embodiments, a plasma treatment is used for surface etching and the creation of micro cracks on the wool fiber. Thus, absorbency of the wool fiber will increase, resulting in faster dissolution of wool fiber with various manufacturing benefits (e.g., reduces the volume of chemicals, water, and power required to treat the fabric). Hence, plasma treated fabrics are more sustainable. More specifically, in certain embodiments, plasma treatment occurs at ambient conditions (temperature and pressure are normal) at a speed of 20 to 40 meters per minute at a power of 16 Kw. A variety of plasma systems may be utilized. For example, atmospheric/air plasma (dry), or N₂, Argon, or a combination thereof.

[0125] In step **640**, the plasma treated fabric is subjected to a continuous process pretreatment. The pretreatment stage comprises desizing, scouring, and/or bleaching, where the soluble fibers may be dissolved.

For example, the wool and/or silk fibers may be dissolved in NaOH, an enzyme, or a combination thereof. As the fabric undergoes desizing, desizing agents aid in the removal of added impurities the form of starch and synthetic sizes without having any effect on the fabric. It is important that these impurities are removed to ensure better realization of further processing. After desizing, the fabric then undergoes scouring and bleaching. In this pretreatment process, the fabric may be loaded into a machine where they are placed in a water bath. The temperature of the water bath may be increased to 70 °C. When the temperature reaches 70 °C, a wetting agent (e.g., a commercially available wetting agent 1.25 ± 0.20 g/l) and a desizing agent (e.g., a commercially available desizing agent 0.40 ± 0.20 g/l) are added. These chemicals are used to wet and desize the fabric over twenty minutes while the bath is maintained at 70 °C. After desizing, a peroxide stabilizer (e.g., a commercially available peroxide stabilizer 0.50 ± 0.20 g/l), caustic soda (5.50 ± 0.50 g/l), and a lubricant (e.g., a commercially available lubricant 0.50 ± 0.20 g/l) are added and the bath temperature is increased to 75 °C over the course of five minutes. Once the bath reaches 75 °C, hydrogen peroxide (4.75 ± 0.50 g/l) is introduced to the bath. The fabric dwells at 75 °C for approximately ten minutes before the temperature is increased to 100 °C over the course of five minutes. Once the temperature reaches 100 °C, the bath is maintained at that temperature for 25 minutes. The bath is then drained and the fabric is subjected to a hot water (90 °C) rinse. After the hot water rinse, the bath is once again drained. The bath is then refilled with 45 °C water and a core alkali neutralizer or buffer (e.g., a commercially core alkali neutralizer or buffer 0.35 ± 0.20 g/l) and an acid to maintain the bath pH (e.g., acetic acid or Green Acid (1.00 ± 0.20 g/l)) are introduced. The fabric dwells in this bath at 45 °C for 29 minutes before a lubricating agent (e.g., a commercially available lubricating agent 0.50 ± 0.20 g/l) and a peroxide stabilizer (e.g., a commercially available peroxide stabilizer 0.50 ± 0.20 g/l) are introduced. The fabric dwells in the modified bath for an additional five minutes before the bath is drained. The entire cycle may take 119 minutes. Alternatively, the bleaching process may start out with a loading step where the fabric is placed in a water bath and the temperature of the bath is increased to 70 °C. When the bath reaches 70 °C, non-ionic wetting agent (e.g., a commercially available wetting agent (1.25 ± 0.20 g/l)) and enzymatic desizing agent (e.g., a commercially available desizing agent 0.40 ± 0.20 g/l) are added. The non-ionic wetting agent and enzymatic desizing agent are used to desize the fabric over twenty minutes while the bath is maintained at 70 °C. After desizing, enzymatic desizing agent (e.g., a commercially available enzymatic desizing agent 0.50 ± 0.20 g/l), caustic soda (10.00 ± 2.00 g/l), and lubricating agent (e.g., a commercially available lubricating agent 0.50 ± 0.20 g/l) are added and the bath temperature is increased to 75 °C over the course of five minutes. Once the bath reaches 75 °C, a peroxide sta-

bilizer (e.g., a commercially available peroxide stabilizer 7.50 ± 1.00 g/l) is introduced to the bath. The fabric dwells at 75 °C for approximately ten minutes before the temperature is increased to 100 °C over the course of five minutes. Once the temperature reaches 100 °C, the bath is maintained at that temperature for 25 minutes. The bath is then drained and the fabric is subjected to a hot water (90 °C) rinse. After the hot water rinse, the bath is once again drained. The bath is then refilled with 45 °C water and core neutralizer (e.g., a commercially available core neutralizer 0.35 ± 0.20 g/l) and an acid to maintain the bath pH, such as acetic acid or Green Acid (1.50 ± 0.20 g/l) are introduced. The fabric dwells in this bath at 45 °C for 29 minutes before a lubricating agent (e.g., a commercially available lubricating agent 0.50 ± 0.20 g/l) and a levelling agent (e.g., a commercially available leveling agent 0.40 to 0.60 g/l) are introduced. The fabric dwells in the modified bath for an additional five minutes before the bath is drained. The entire cycle may take 119 minutes.

[0126] In step 645, the fabric is dyed or printed. One of skill in the art would understand that the dyeing process depends upon the fiber being dyed. In certain applications, printing may be desirable. Printing may be achieved using any technical method. For example, printing may be achieved with screen printing, block printing, or digital printing.

[0127] In step 650, the fabric is finished using a stenter. During this step the fabric is pulled taught in the weft direction and subjected to finishing treatments. This step ensures that the yarns are properly oriented prior to cutting and sewing.

[0128] In step 655, the finished fabric undergoes a second inspection.

[0129] In step 660, the fabric is cut a part.

[0130] In optional step 665, if the resulting textile is intended for use as a terry towel, then length hemming occurs to finish the raw edges of the towel. After length hemming, partially finished towel may undergo cross-cutting 670 and cross hemming 675.

[0131] In optional step 680, where the resulting textile article is not a terry towel, the fabric may be stitched or sewn in the manner required.

[0132] In step 685, the resulting article is subjected to a final inspection.

[0133] In step 690, the textile is packed into bags.

[0134] In step 695, the bagged textile is carton packaged.

[0135] Figure 4A is a flowchart of a yarn manufacturing method that comprises a batch fabric dyeing process illustrating an exemplary method 700 of processing fibers to form yarn for use in the preparation of fabrics. In one embodiment, method 700 starts with step 705, in which primary fiber (e.g., the fiber that remains after dissolution) is received from a supplier. The primary fibers may be a variety of fibers or a blend of different fibers. For example, the primary fibers may be one or more of cotton, linen, hemp, kapok, nettle, bamboo, lyocell, viscose, polyester

(sustainable or recycled), PLA, PBT, nylon, acrylic, etc. More specifically, the primary fiber may be cotton fibers. Where a finer yarn is desired, finer fibers may be preferred (e.g., fibers with smaller diameters). Likewise, for coarser yarn, coarser fibers may be preferred (e.g., fibers with larger diameters).

[0136] In step **710**, the primary fiber may be stored. When stored, the primary fibers may be conditioned to a certain temperature or relative humidity to prepare the fibers for spinning.

[0137] As one of skill in the art would understand, the desired temperature and humidity would be dependent, in part, upon the type of fiber and type of processing that will occur.

[0138] In step **715**, the fibers may be processed in a blow room. A person of skill in the art would recognize that a blow room is where fiber is processed to prepare the fiber for yarn manufacturing. In the blow room, fibers are selected for opening, cleaning, and blending.

[0139] In step **720**, the fibers undergo carding. At this stage, the fibers are passed through carding machines to remove short fibers and trash (e.g., vegetable matter and other undesirable particulate), and individualize and align the fibers into slivers. After carding, the slivers are subjected to a drawing process to further align the fibers. During drawing, a number of carded slivers are fed through a drawing frame where they are drafted to create a more uniform sliver. At this stage, the slivers made of the primary fiber may be drafted with wool, silk, or wool/silk blended slivers to create a blended sliver with soluble fibers. In slivers comprised of a wool and silk blend, the ratio may be anywhere from 99:1 to 1:99. The content of the soluble fiber may make up 3% to 40% of the end sliver. Low blend ratios are preferred, such as 3% to 10% because these ranges are the most cost viable. It would be further preferred to have a 3.5% to 7% ratio of soluble fiber. Generally, the resulting sliver should have a count of 0.100 to 0.180 Ne (cotton count).

[0140] In optional step **725**, the fibers may undergo lapping and followed by combing operation to remove shorter fibers and produce a more lustrous resulting yarn. Generally, lapping is done where a longer fiber is required (for example, to form a low twist yarn). In this step, 20 to 24 slivers are fed into the lapping machine to produce one lap. A person of skill in the art would understand that laps then input into a combing machine (thus, if optional step **725** is performed, optional step **730** is also performed). Generally, the resulting lap should have a count of 0.0079 to 0.0091 Ne. These steps are generally used where a premium quality product is desired.

[0141] In optional step **730** (which is performed if optional step **725** is performed), the fibers undergo combing. During combing, the laps are passed through a set of combs that further orient the fiber, as well as removing additional short fibers and noils. Generally, in this step, 6 to 8 laps are input into the combing machine to produce one sliver. As previously discussed, lapping and combing are not required. These steps are generally used where

a premium quality product is desired.

[0142] In step **735**, the resulting slivers undergo breaker drawing. Breaker drawing may be done whether or not the fibers were combed. In certain embodiments, the fibers may proceed from carding in step **720** directly to step **735** to undergo breaker drawing. Generally, in this step, 6 to 8 slivers are fed through the drawing frame together. These slivers are subjected to drafting, most commonly: a breaker draft and a main draft. During each of the drafting stages, a set of rollers (appropriately spaced to minimize fiber breakage) is calibrated to ensure that the resulting weight per length is appropriately sized.

[0143] In some embodiments, the fibers which underwent combing in step **730**, may be combined with the fibers that underwent carding and breaker drawing to undergo a finisher drawing in step **740**. Generally, in this step, 6 to 8 slivers are fed through the drawing machine to produce one blended sliver. The fibers may be blended in such a way as to create bundles or tufts of wool and/or silk dispersed throughout the primary fiber in the resulting blended sliver. These tufts, when dissolved, leave pores in yarn cross-sections. These pores are desirable in certain applications where their unique absorbency and wicking properties are desirable. Alternatively, the wool and/or cotton may be evenly distributed throughout the cotton-blend sliver. Where the soluble fiber is evenly distributed, the pores left after dissolving are smaller than the pores that result from tufts of wool and/or silk. These pores are desirable in certain applications where their unique absorbency and wicking properties are desired.

[0144] In a parallel process, in step **745**, the soluble fibers may be received. Desirable soluble fibers include wool, silk, and suitable combinations thereof. As a person of skill in the art would understand, wool and silk fibers have varying properties. For example, wool may be fine (i.e., possess a small diameter) or coarse (i.e., possess a large diameter). When engineering a fabric, the fiber properties of the variety of soluble fiber must be considered, as well as other factors such as ratio of primary to soluble fiber, and blend characteristics (e.g., if the soluble fiber is dispersed in tufts or as single fibers).

[0145] In step **750**, the soluble fibers may be stored. When stored, the processed fibers may be conditioned to a certain temperature or relative humidity to prepare the fibers for spinning. As one of skill in the art would understand, the desired temperature and humidity would be dependent, in part, upon the type of fiber and type of processing that will occur.

[0146] In step **755**, the soluble fibers may be processed in a blow room. A person of skill in the art would recognize that a blow room is where fiber is processed to prepare the fiber for yarn manufacturing. In the blow room, fibers are selected for opening, cleaning, and blending. In the blow room, the soluble fibers may be blended together to achieve the desired ratio.

[0147] In step **760**, the soluble fibers may undergo carding and become sliver. At this stage, the fibers are passed through carding machines to remove short fibers,

and trash (e.g., vegetable matter and other undesirable particulate), and individualization and align the fibers into slivers. After carding, the slivers are subjected to a drawing process to further align the fibers. During drawing, a number of carded slivers are fed through a drawing frame where they are drafted to create a more uniform sliver. In slivers comprised of a wool and silk blend, the ratio may be anywhere from 99:1 to 1:99. The content of the soluble fiber may make up 3% to 40% of the end sliver (e.g., the sliver comprising a blend of primary and soluble fiber). Low blend ratios are preferred, such as 3% to 10% because these ranges are the most cost viable. It would be further preferred to have a 3.5% to 7% ratio of soluble fiber. Generally, the resulting sliver should have a count of 0.100 to 0.180 Ne (cotton count).

[0148] In step **765**, the soluble fibers may undergo drawing to ensure the unity of the fibers in the stream. After step **765**, drawn slivers are finisher drawn in step **740**. Generally, in during finisher drawing, 6 to 8 slivers are fed through the drawing machine to produce one blended sliver. The fibers may be blended in such a way as to create bundles or tufts of wool and/or silk dispersed throughout the primary fiber in the resulting blended sliver. These tufts, when dissolved, leave pores in yarn cross-sections. These pores are desirable in certain applications where their unique absorbency and wicking properties are desirable. Alternatively, the wool and/or cotton may be evenly distributed throughout the cotton-blend sliver. Where the soluble fiber is evenly distributed, the pores left after dissolving are smaller than the pores that result from tufts of wool and/or silk. These pores are desirable in certain applications where their unique absorbency and wicking properties are desired.

[0149] In step **770**, the blended slivers produced through any combination of the forgoing processes undergo speed frame roving. A person of skill in the art will understand that roving is required for ring spinning. During roving, slivers are further drafted to reduce the weight per length and a low amount of twist is inserted.

[0150] In step **775**, the roving created in step **770** undergoes ring spinning. Ring spinning is desirable for applications, such as terry toweling, rugs, bedding, and leisure fabrics, where softness is desired. Further, yarn spinning produces yarns with desirable elasticity. During ring spinning roving is fed into the ring spinning machine and bobbins of yarn is output. Generally, the resulting yarn should have a count of 6 Ne to 120 Ne. Additionally, a new attachment in the ring spinning system was utilized to eliminate the spinning triangle formed in a conventional ring system. This attachment provides multiple benefits, including reducing yarn hairiness and yarn breakage during spinning, and increasing yarn strength (making lower twist ratios possible) and yarn evenness (lower coefficient of variation). These yarn benefits also provide greater weaving efficiency (i.e., enables higher picks per minute and decreases downtime due to broken yarns). Additionally, a finer yarn count may be obtained by changing the blend ratios. In place of Ring Spinning, a

Rotor Spinning, Friction Spinning, Air Jet Spinning or Compact Spinning may also be used in the alternate.

[0151] In step **780**, after spinning the bobbins of yarn may be combined onto a cone using an autoconer. Cones are required to convert the bobbins to larger packages suitable for textile processing.

[0152] In step **785**, the yarns may undergo plying. During this step, yarns of the same or different counts may be plied together. Similarly, yarns with the same fiber and blend content, or yarns with differing fiber and blend contents may be plied. The number of yarns plied may be two or more.

[0153] In step **790**, the yarns may be wound onto suitable packages. For example, yarns may be wound off of tapered cones onto cylindrical tubes or other forms of packaging more suitable for warping and weaving.

[0154] Figure 4B is a flowchart of a fabric manufacturing method that comprises a batch dyeing process illustrating exemplary method **800** of processing yarns into fabrics.

[0155] In step **805**, yarn is received from a supplier or the spinning room.

[0156] In step **810**, the yarn may be stored. When stored, the yarns may be conditioned to a certain temperature or relative humidity to prepare the yarns for weaving. As one of skill in the art would understand, the desired temperature and humidity would be dependent, in part, upon the type of fiber and type of processing that will occur.

[0157] In step **815**, the yarn undergoes warping. Any known process for warping, including high speed/direct warping, sectional/indirect warping, and/or ball warping, may be utilized in this step.

[0158] In step **820**, the yarn undergoes sizing. Any known process for sizing, including wet sizing, solvent sizing, cold sizing, and/or hot melt sizing, may be utilized in this step.

[0159] In step **825**, the yarn undergoes weaving. Any known process for weaving, including terry weaving, may be utilized. For example, in terry weaving, two warp beams are prepared (one for the ground warp and one for the pile warp). These two warps are fed through the loom at different speeds to create loops on the pile warp. The weft and ground warp form a ground weave that supports the pile loops.

[0160] In step **830**, the fabric may undergo inspection. Any known process for inspection may be utilized. For example, terry fabric may be manually inspected by a trained employee using a light board (sometimes called a light box) or automatically inspected using a camera-based visual inspection system.

[0161] In step **835**, the fabric is treated using a plasma treatment. Effect of plasma treatment: Plasma treatment is a dry state treatment on to any textile surface before any wet processing. Essentially, four main effects can be obtained depending on the treatment conditions: surface cleaning, etching, surface activation, and polymerization. Thus, plasma treatments find their application in the tex-

tile field for a variety of purposes including modification of surface energy, modification of surface topography, improvement of adhesion, and surface cleaning. References, R. Abd. Jelil, A review of low-temperature plasma treatment of textile materials, 50 J. MATER SCI. 5913 (2015); Sheila Shahidi et al., Study of Surface Modification of Wool Fabrics Using Low Temperature Plasma, PROC. OF THE 3RD INT'L CONF. ON THE FRONTIERS OF PLASMA PHYSICS AND TECH. 1 (2008); Amelia Sparavigna, Plasma treatment advantages for textiles. ARXIV: POPULAR PHYSICS. 1-16.; describe the plasma treatment process in detail and are incorporated herein by reference. In certain embodiments, a plasma treatment is used for surface etching and the creation of micro cracks on the wool fiber. Thus, absorbency of the wool fiber will increase, resulting in faster dissolution of wool fiber with various manufacturing benefits (e.g., reduces the volume of chemicals, water, and power required to treat the fabric). Hence, plasma treated fabrics are more sustainable. More specifically, in certain embodiments, plasma treatment occurs at ambient conditions (temperature and pressure are normal) at a speed of 20 to 40 meters per minute at a power of 16 Kw. A variety of plasma systems may be utilized. For example, atmospheric/air plasma (dry), or N₂, Argon, or a combination thereof.

[0162] In step 840, during pretreatment, the fabric undergoes a dissolving treatment. During this step, the fabric may optionally be dyed and finished in rope form. For example, the wool and/or silk fibers may be dissolved in NaOH, an enzyme, or a combination thereof. The pretreatment stage comprises desizing, scouring, and/or bleaching, where the soluble fibers may be dissolved. For example, the wool and/or silk fibers may be dissolved in NaOH, an enzyme, or a combination thereof. As the fabric undergoes desizing, desizing agents aid in the removal of added impurities the form of starch and synthetic sizes without having any effect on the fabric. It is important that these impurities are removed to ensure better realization of further processing. After desizing, the fabric then undergoes scouring and bleaching. In this pretreatment process, the fabric may be loaded into a machine where they are placed in a water bath. The temperature of the water bath may be increased to 70 °C. When the temperature reaches 70 °C, a wetting agent (e.g., a commercially available wetting agent 1.25±0.20 g/l) and a desizing agent (e.g., a commercially available desizing agent 0.40±0.20 g/l) are added. These chemicals are used to wet and desize the fabric over twenty minutes while the bath is maintained at 70 °C. After desizing, a peroxide stabilizer (e.g., a commercially available peroxide stabilizer 0.50±0.20 g/l), caustic soda (5.50 ± 0.50 g/l), and a lubricant (e.g., a commercially available lubricant 0.50±0.20 g/l) are added and the bath temperature is increased to 75 °C over the course of five minutes. Once the bath reaches 75 °C, hydrogen peroxide (4.75 ± 0.50 g/l) is introduced to the bath. The fabric dwells at 75 °C for approximately ten minutes before the temper-

ature is increased to 100 °C over the course of five minutes. Once the temperature reaches 100 °C, the bath is maintained at that temperature for 25 minutes. The bath is then drained and the fabric is subjected to a hot water (90 °C) rinse. After the hot water rinse, the bath is once again drained. The bath is then refilled with 45 °C water and a core alkali neutralizer or buffer (e.g., a commercially core alkali neutralizer or buffer 0.35 ± 0.20 g/l) and an acid to maintain the bath pH (e.g., acetic acid or Green Acid (1.00 ± 0.20 g/l)) are introduced. The fabric dwells in this bath at 45 °C for 29 minutes before a lubricating agent (e.g., a commercially available lubricating agent 0.50 ± 0.20 g/l) and a peroxide stabilizer (e.g., a commercially available peroxide stabilizer 0.50 ± 0.20 g/l) are introduced. The fabric dwells in the modified bath for an additional five minutes before the bath is drained. For example, the bleaching process may start out with a loading step where the fabric is placed in a water bath and the temperature of the bath is increased to 70 °C. When the bath reaches 70 °C, a wetting agent (e.g., a commercially available wetting agent (1.25 ± 0.20 g/l)) and a desizing agent (e.g., a commercially available desizing agent (0.20 ± 0.20 g/l)) are added. These chemicals are used to wet and desize the fabric over twenty minutes while the bath is maintained at 70 °C. After desizing, a peroxide stabilizer (e.g., a commercially available peroxide stabilizer (0.50 ± 0.20 g/l)), caustic soda (5.5 ± 1.0 g/l), and a lubricant (e.g., a commercially available lubricant (0.50 ± 0.20 g/l)) are added and the bath temperature is increased to 75 °C over the course of five minutes. Once the bath reaches 75 °C, hydrogen peroxide (4.75 ± 1.00 g/l) is introduced to the bath. The fabric dwells at 75 °C for approximately ten minutes before the temperature is increased to 100 °C over the course of five minutes.

[0163] Once the temperature reaches 100 °C, the bath is maintained at that temperature for 25 minutes. The bath is then drained and the fabric is subjected to a hot water (90 °C) rinse. After the hot water rinse, the bath is once again drained. The bath is then refilled with 45 °C water and a core neutralizer or buffer (e.g., a commercially available core neutralizer or buffer (0.35 ± 0.20 g/l)) and an acid to maintain the bath pH (e.g., acetic acid or Green Acid (1.00 ± 0.20 g/l)) are introduced. The fabric dwells in this bath at 45 °C for 29 minutes before a lubricating agent (e.g., a commercially available lubricating agent (0.50 ± 0.20 g/l)) and a leveling agent (e.g., a commercially available leveling agent (0.50 ± 0.20 g/l)) are introduced. The yarn dwells in the modified bath for an additional five minutes before the bath is drained. The entire cycle may take 119 minutes.

[0164] Alternatively, where wool fibers are being dissolved, the bleaching process may start out with a loading step where the fabric is placed in a water bath and the temperature of the bath is increased to 70 °C. When the bath reaches 70 °C, a wetting agent (e.g., a commercially available wetting agent (1.25 ± 0.20 g/l)) and a desizing agent (e.g., a commercially available desizing agent

(0.20 ± 0.20 g/l) are added. The wetting agent and desizing agent are used to desize the yarns over twenty minutes while the bath is maintained at 70°C . After desizing, a leveling agent (e.g., a commercially available leveling agent (0.50 ± 0.20 g/l)), caustic soda (10 ± 2.00 g/l), and a lubricating agent (e.g., a commercially available lubricating agent (0.50 ± 0.20 g/l)) are added and the bath temperature is increased to 75°C over the course of five minutes. Once the bath reaches 75°C , hydrogen peroxide (7.50 ± 2.00 g/l) is introduced to the bath. The fabric dwells at 75°C for approximately ten minutes before the temperature is increased to 100°C over the course of five minutes. Once the temperature reaches 100°C , the bath is maintained at that temperature for 25 minutes. The bath is then drained and the fabric is subjected to a hot water (90°C) rinse. After the hot water rinse, the bath is once again drained. The bath is then refilled with 45°C water, and a core neutralizer (e.g., a commercially available core neutralizer (0.30 ± 0.05 g/l)) and an acid to maintain the bath pH (e.g., acetic acid or Green Acid (1.50 ± 0.20 g/l)) are introduced. The fabric dwells in this bath at 45°C for 29 minutes before a lubricating agent (e.g., a commercially available lubricating agent (0.50 ± 0.20 g/l)) and leveling agent (e.g., a commercially available leveling agent (0.50 ± 0.20 g/l)) are introduced. The fabric dwells in the modified bath for an additional five minutes before the bath is drained. The entire cycle may take 119 minutes.

[0165] In step **845**, if terry toweling or similar fabric is being manufactured, the washed "rope" of fabric is opened.

1. In step **850**, the fabric is optionally finished and dried using a stenter. During this step the fabric is pulled taught in the weft direction and subjected to finishing treatments. This step ensures that the yarns are properly oriented prior to cutting and sewing.
2. In step **855**, the finished fabric undergoes a second inspection.
3. In step **860**, the fabric is cut apart.

In step optional **865**, if the resulting textile is intended for use as a terry towel or similar product, then length hemming occurs to finish the raw edges of the towel. After length hemming, partially finished towel may undergo cross-cutting **870** and cross hemming **875**.

4. In optional step **880**, where the resulting textile article is not a terry towel, the fabric may be stitched or sewn in the manner required.
5. In step **885**, the resulting article is subjected to a final inspection.
6. In step **890**, the textiles are packed into bags.
7. In step **895**, the bagged textiles are carton packaged.

[0166] Also disclosed herein are the following clauses:

1. A method of creating a sustainable engineered fabric comprising:

- a. creating an engineered yarn with primary and soluble fibers;
- b. dissolving the soluble fibers during yarn dyeing with a process involving a wetting agent, hydrogen peroxide, alkali and/ or enzyme or combination thereof, peroxide stabilizer, lubricant, core alkali neutralizer/buffer, a leveling agent and dye; and
- c. weaving the engineered yarn into fabric.

2. The method of clause 1, wherein the primary fibers comprise one or more of cotton, linen, hemp, kapok, nettle, bamboo, lyocell, viscose, polyester (sustainable or recycled), PLA, PBT, nylon, acrylic, etc., and suitable combinations thereof.

3. The method of clause 1, wherein the soluble fibers comprise one or more of: wool, or silk, or a combination thereof.

4. The method of clause 1, wherein the primary fibers comprise cotton.

5. The method of clause 1, wherein the soluble fibers comprise recycled wool, virgin wool, or a combination thereof.

6. The method of clause 1, wherein the soluble fibers comprise recycled silk, virgin silk, or a combination thereof.

7. The method of clause 1, wherein the primary fibers comprise cotton and the soluble fibers comprise virgin or recycled wool or combination thereof.

8. The method of clause 1, wherein the primary fibers comprise cotton and the soluble fibers comprise virgin or recycled silk or combination thereof.

9. The method of clause 1, wherein the primary fiber is cotton, and the soluble fiber is virgin wool or virgin silk or recycled wool or recycled silk or combination thereof.

10. The method of clause 1, wherein the soluble fibers are dissolved during yarn dyeing process.

11. The method of clause 1, wherein the wetting agent is an-ionic or non-ionic wetting agent.

12. The method of clause 1, wherein the desizing agent is a group of enzymes.

13. The method of clause 1, wherein the hydrogen peroxide stabilizer is anionic in nature.

14. The method of clause 1, wherein the lubricant is cryptanionic in nature.

15. The method of clause 1, wherein the core alkali neutralizer/buffer is anionic in nature.

16. The method of clause 1, wherein the leveling agent is anionic in nature.

17. A method of creating an engineered fabric comprising:

- a. creating a yarn with primary and soluble fibers wherein the soluble fibers are comprised of wool

and/or silk fibers;
 b. weaving the yarn into a fabric; and
 c. dissolving the soluble fibers using a process involving a wetting agent, desizing agent, hydrogen peroxide, alkali and/ or enzyme or combination thereof, peroxide stabilizer, lubricant, core alkali neutralizer/buffer, and a leveling agent.

18. An engineered fabric created using a method as described in clause 17, wherein the primary fiber includes cotton, linen, hemp, kapok, nettle, bamboo, lyocell, viscose, polyester (sustainable or recycled), PLA, PBT, nylon, acrylic, etc., and suitable combinations thereof.

19. An engineered fabric as created using a method as described in clause 17, wherein the primary fiber is cotton, and the soluble fiber is virgin or recycled wool or combination thereof.

20. An engineered fabric as created using a method as described in clause 17, wherein the primary fiber is cotton, and the soluble fiber is virgin or recycled silk or combination thereof.

21. An engineered fabric as created using a method as described in clause 17, wherein the primary fiber is cotton, and the soluble fiber is virgin wool or virgin silk or recycled wool or recycled silk or combination thereof.

22. An engineered fabric as created using a method as described in clause 17, wherein the fabric may undergo plasma treatment.

23. The method of clause 17, wherein the wetting agent is an-ionic or non-ionic wetting agent.

24. The method of clause 17, wherein the desizing agent is a group of enzymes.

25. The method of clause 17, wherein the hydrogen peroxide stabilizer is anionic in nature.

26. The method of clause 17, wherein the lubricant is cryptanionic in nature.

27. The method of clause 17, wherein the core alkali neutralizer/buffer is anionic in nature.

28. The method of clause 17, wherein the leveling agent is anionic in nature.

29. The method of clause 17, wherein after the soluble fibers are dissolved during yarn dyeing process.

Claims

1. A method of creating a sustainable engineered fabric, the method comprising:

creating a yarn with primary and soluble fibers;
 dissolving the soluble fibers using a process involving:

a wetting agent, hydrogen peroxide, alkali, and/or enzyme, or combination thereof,

peroxide stabilizer,
 lubricant,
 core alkali neutralizer/buffer, and
 a leveling agent,; and

weaving the yarn into fabric.

2. The method of claim 1, wherein the step of dissolving the soluble fibers is performed after the step of weaving the yarn into fabric.

3. The method of claim 1 or 2, wherein the soluble fibers are dissolved during a yarn dyeing process involving dye.

4. The method of any of claims 1 to 3, wherein the soluble fibers comprise one or more of: wool, or silk, or a combination thereof.

5. The method of any of claims 1 to 4, wherein the soluble fibers comprise recycled wool, virgin wool, or a combination thereof.

6. The method of any of claims 1 to 5, wherein the soluble fibers comprise recycled silk, virgin silk, or a combination thereof.

7. The method of any of claims 1 to 6, wherein the primary fibers comprise one or more of cotton, linen, hemp, kapok, nettle, bamboo, lyocell, viscose, polyester (sustainable or recycled), PLA, PBT, nylon, acrylic, etc., and suitable combinations thereof.

8. The method of any of claims 1 to 7, wherein the primary fibers comprise cotton.

9. The method of any of claims 1 to 8,

wherein the primary fibers comprise cotton; and
 wherein the soluble fibers comprise:

virgin or recycled wool or combination thereof; or virgin or recycled silk or combination thereof; or
 virgin wool, or virgin silk, or recycled wool, or recycled silk, or combination thereof.

10. The method of any of claims 1 to 9, wherein the wetting agent is an-ionic or non-ionic wetting agent.

11. The method of any of claims 1 to 10, wherein one or more of: the hydrogen peroxide stabilizer the core alkali neutralizer/buffer, and the leveling agent is anionic in nature.

12. The method of any of claims 1 to 11, wherein the lubricant is cryptanionic in nature.

13. The method of claim 1, wherein the process of dissolving the soluble fibers involves a desizing agent from a group of enzymes.

14. in the method of any of claims 1 to 13, comprising the fabric applying plasma treatment to the fabric.

15. An engineered fabric manufactured using the method of any of claims 1 to 13.

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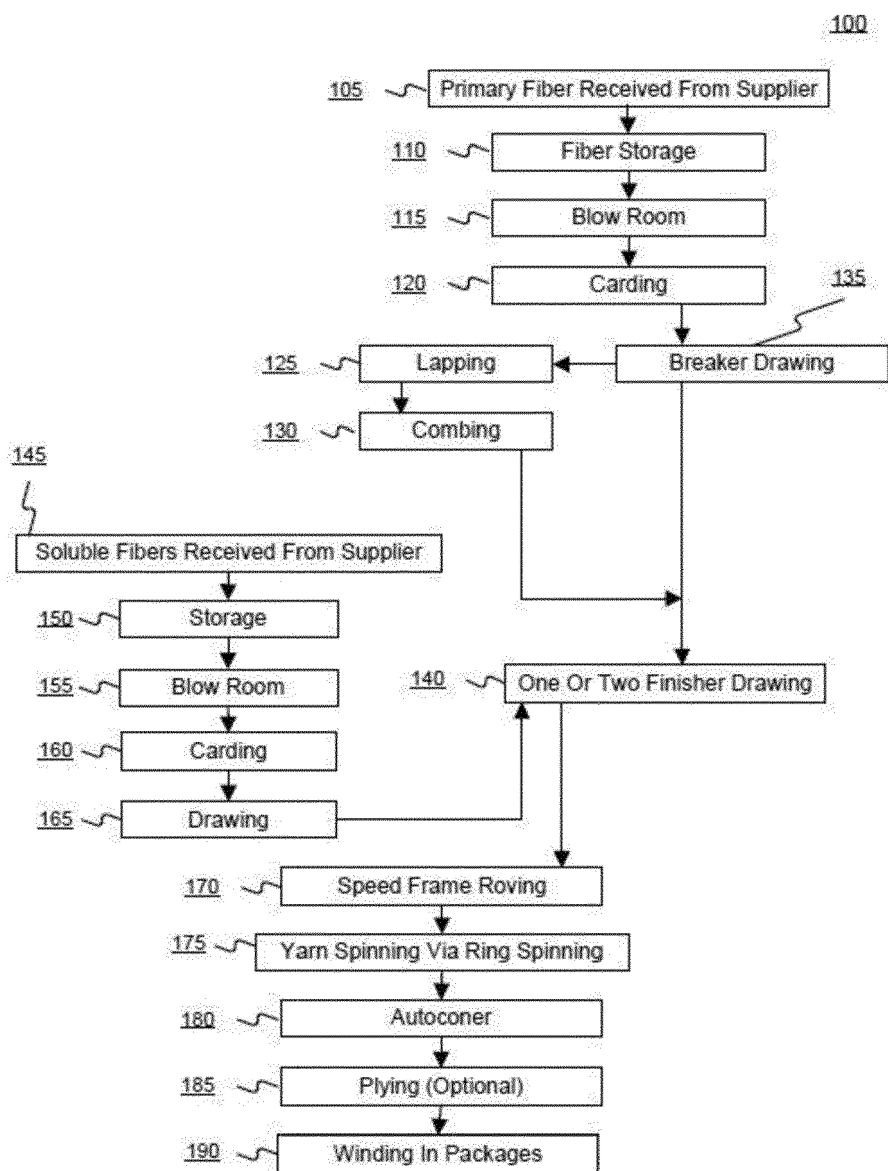


FIG. 1A

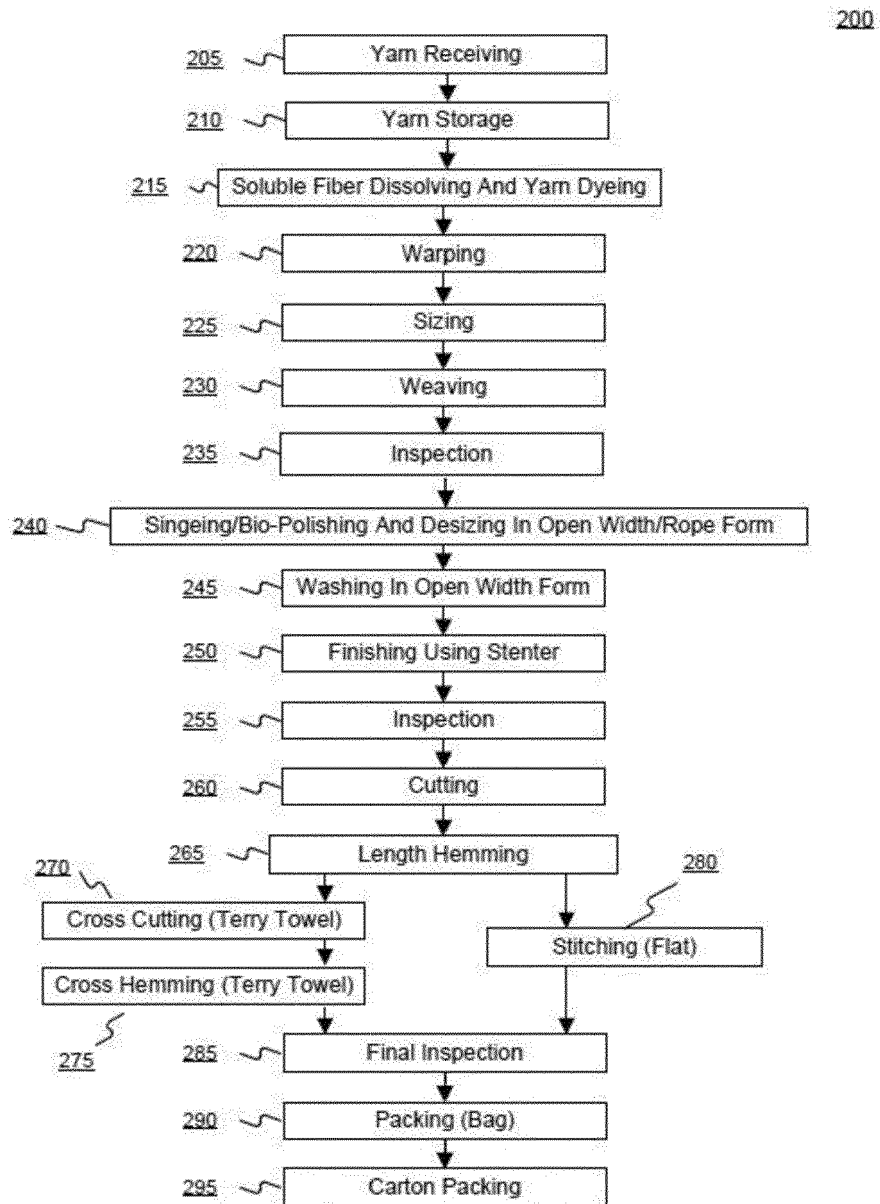


FIG. 1B

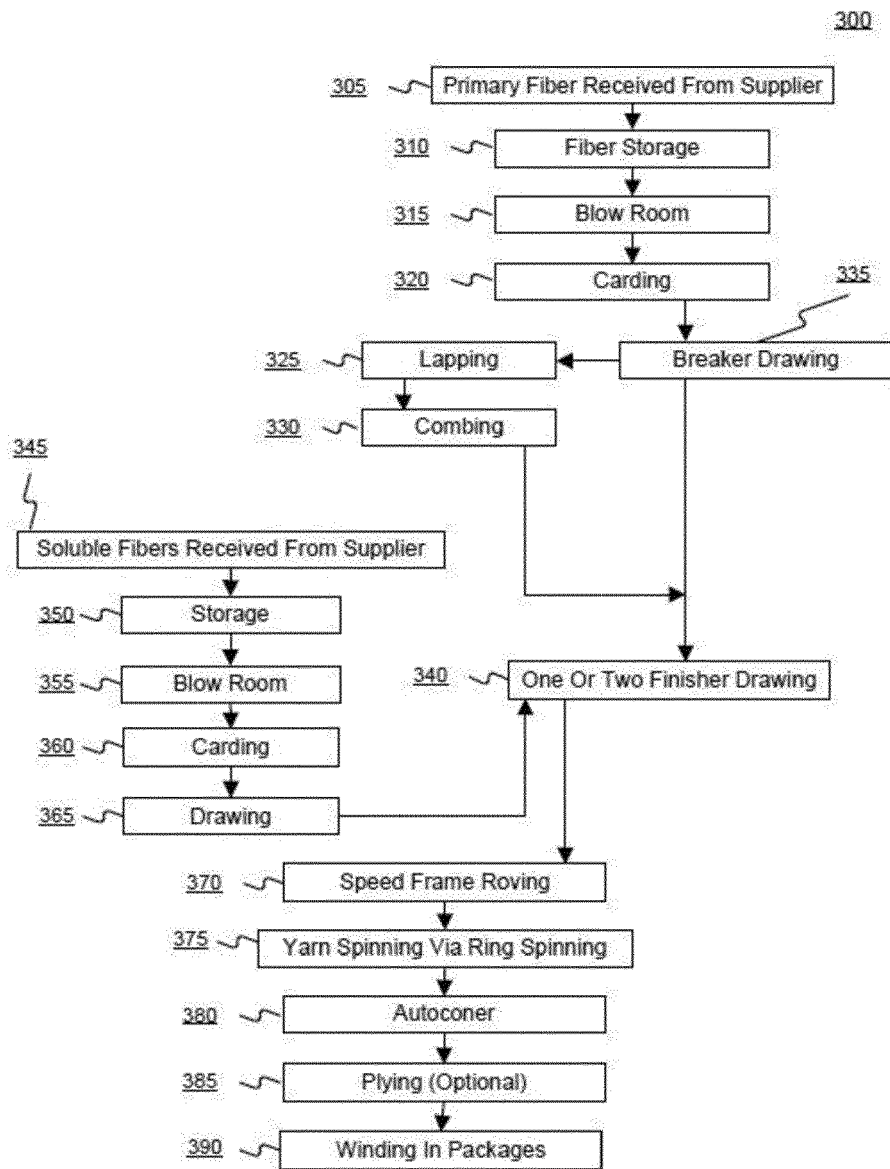


FIG. 2A

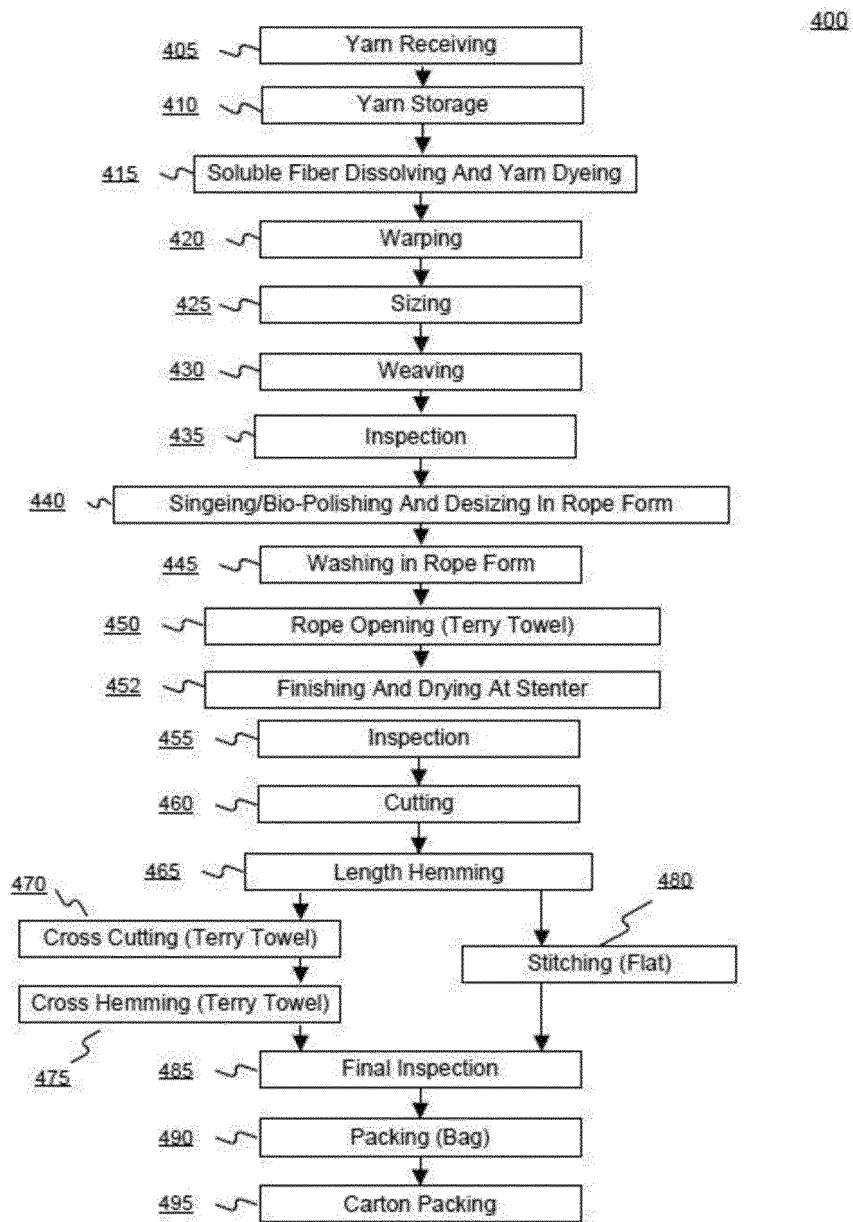


FIG. 2B

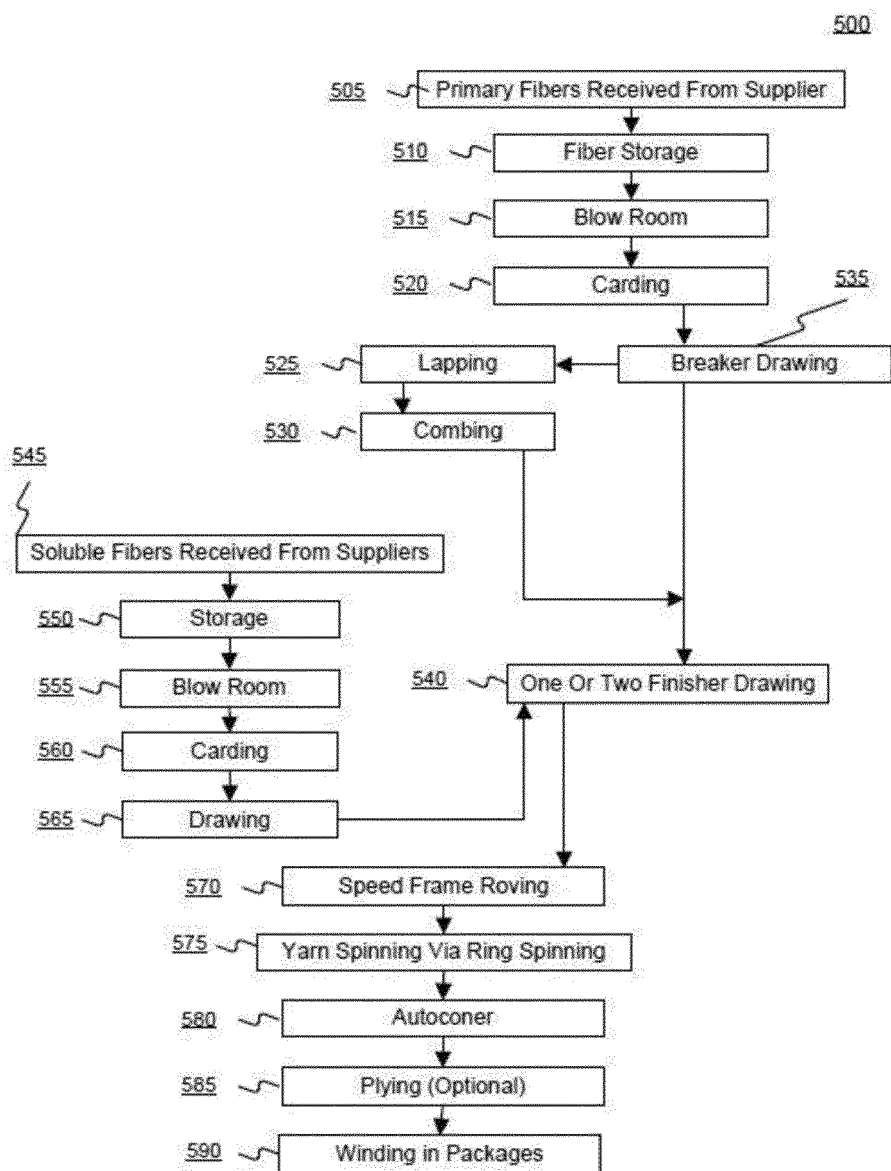


FIG. 3A

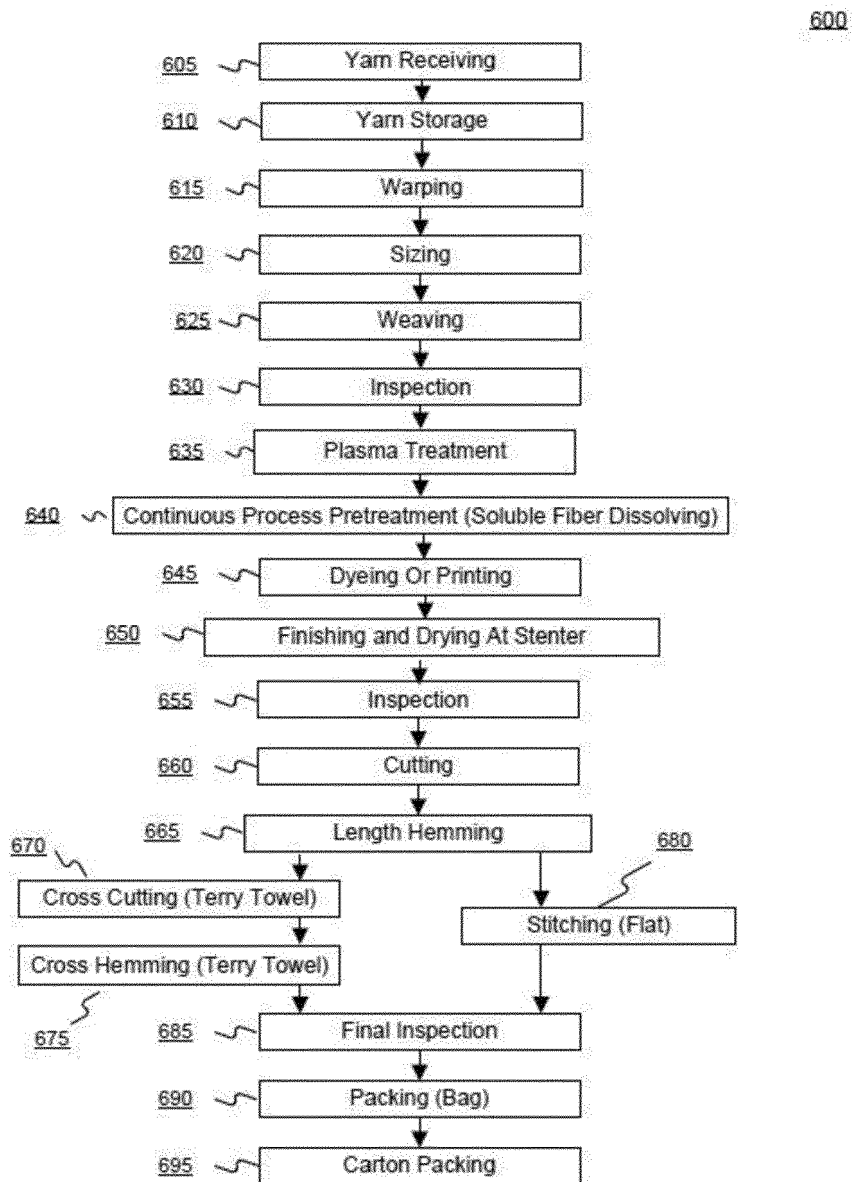


FIG. 3B

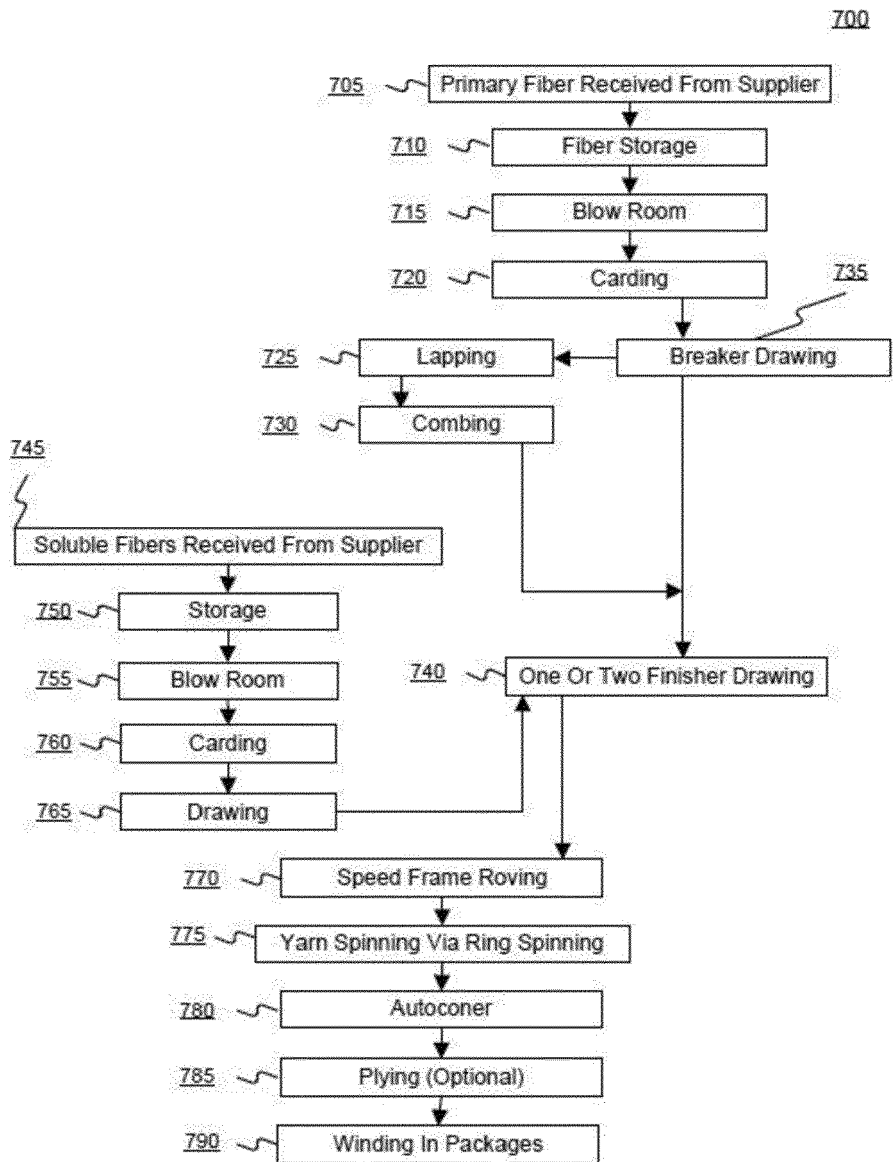


FIG. 4A

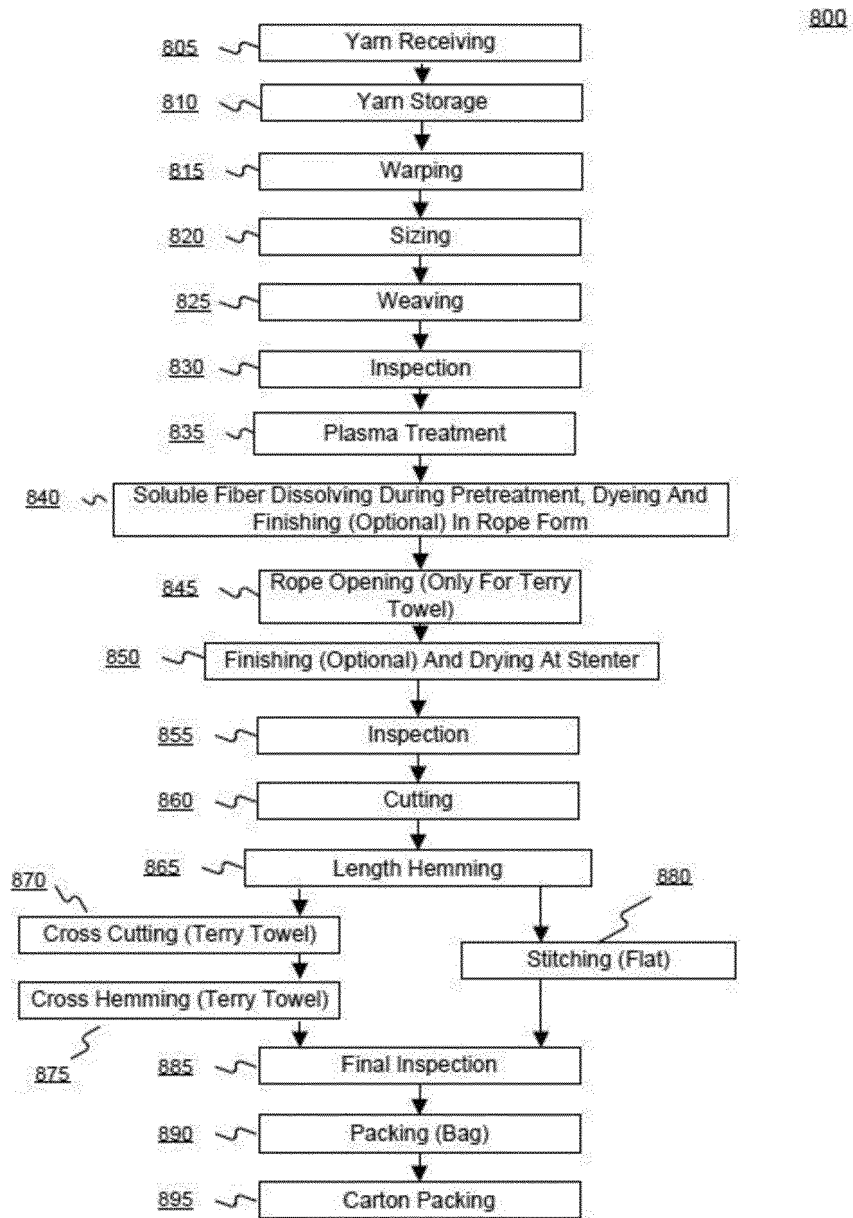


FIG. 4B



EUROPEAN SEARCH REPORT

Application Number

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EPO FORM 1503 03.82 (P04C01)

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	IN 50 MU 2010 A (WELSPUN GLOBAL BRANDS LIMITED)	1-5, 7-15	INV. D02G3/40
Y	* page 2, paragraph 1 - page 28, paragraph 4; claims 1-15; figure 1 *	6	D03D15/68 D03D15/47 D03D27/08
Y	US 3 169 557 A (HOLLAND VICTOR B ET AL) 16 February 1965 (1965-02-16) * column 1, line 10 - column 2, line 17; claim 6 *	6	D06P1/00 D06P3/60 D06P3/82 D06P1/673 D06M10/02 D06M11/38 D06M11/50 D06M16/00 D06Q1/02
A	MADHU AMIT ET AL: "Developments in application of enzymes for textile processing", JOURNAL OF CLEANER PRODUCTION, ELSEVIER, AMSTERDAM, NL, vol. 145, 6 January 2017 (2017-01-06), pages 114-133, XP029907059, ISSN: 0959-6526, DOI: 10.1016/J.JCLEPRO.2017.01.013 * paragraph [04.1] - paragraph [04.2] *	13	
A	ANDREA ZILLE ET AL: "Plasma Treatment in Textile Industry", PLASMA PROCESSES AND POLYMERS, vol. 12, no. 2, 25 February 2015 (2015-02-25), pages 98-131, XP055289873, DE ISSN: 1612-8850, DOI: 10.1002/ppap.201400052 * paragraph [0001] - paragraph [0002] *	14	TECHNICAL FIELDS SEARCHED (IPC) D02G D03D D06P D06M D06Q
The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 30 August 2023	Examiner Massella, Daniele
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.

EP 23 16 1056

5 This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

30-08-2023

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
IN 50MU2010 A	31-08-2023	-----	-----
US 3169557 A	16-02-1965	AT 245511 B	10-03-1966
		CH 419001 A	30-04-1966
		DK 129101 B	19-08-1974
		GB 977051 A	02-12-1964
		SE 304478 B	23-09-1968
		US 3169557 A	16-02-1965
		-----	-----

REFERENCES CITED IN THE DESCRIPTION

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Non-patent literature cited in the description

- **R. ABD. JELIL.** A review of low-temperature plasma treatment of textile materials. *J. MATER SCI.*, 2015, vol. 50, 5913 **[0124]**
- **SHEILA SHAHIDI et al.** Study of Surface Modification of Wool Fabrics Using Low Temperature Plasma. *PROC. OF THE 3RD INT'L CONF. ON THE FRONTIERS OF PLASMA PHYSICS AND TECH.*, 2008, 1 **[0124]**
- **AMELIA SPARAVIGNA.** Plasma treatment advantages for textiles. *ARXIV: POPULAR PHYSICS*, 1-16 **[0124]**
- **R. ABD. JELIL.** A review of low-temperature plasma treatment of textile materials. *J. MATER SCI.*, 2015, vol. 50, 5913 **[0161]**
- **SHEILA SHAHIDI et al.** Study of Surface Modification of Wool Fabrics Using Low Temperature Plasma. *PROC. OF THE 3RD INT'L CONF. ON THE FRONTIERS OF PLASMA PHYSICS AND TECH.*, 2008, 1 **[0161]**
- **AMELIA SPARAVIGNA.** Plasma treatment advantages for textiles. *ARXIV: POPULAR PHYSICS.*, 1-16 **[0161]**