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(54) **HYGRO FLAT WOVEN FABRICS, ARTICLES, AND RELATED PROCESSES**

(57) A woven fabric and related process that includes hygro yarn structures with hollow cores that formed into flat woven fabrics suitable for bedding applications.

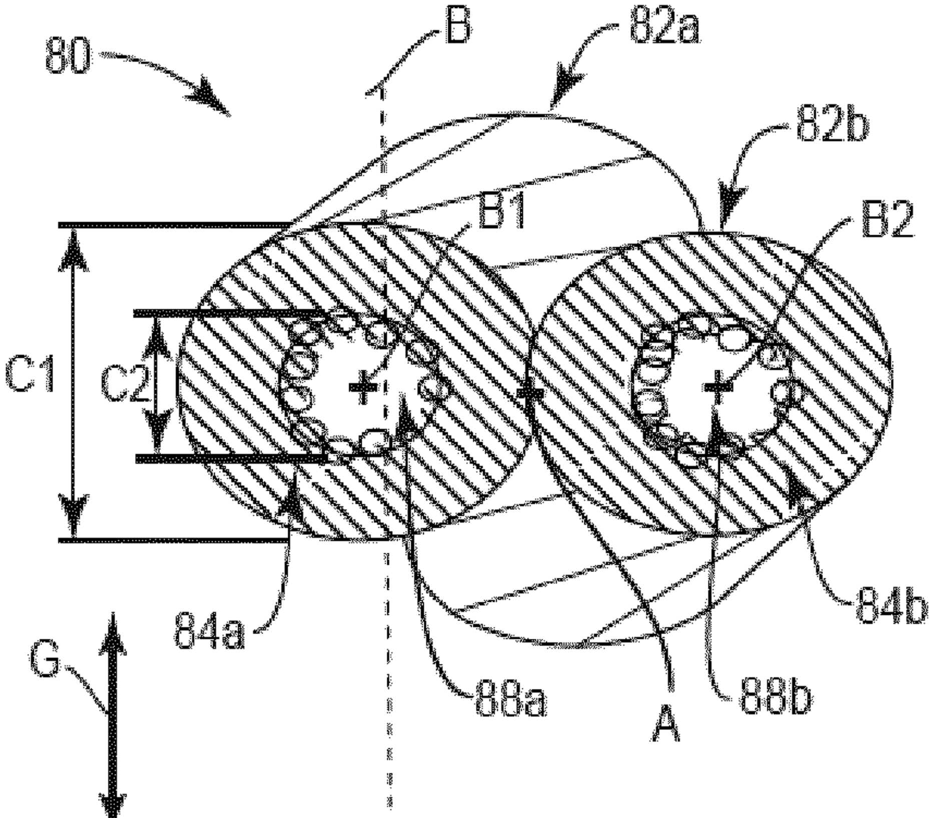

FIG. 4B

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Description

TECHNICAL FIELD

[0001] The present disclosure relates to hygro flat woven fabrics, articles, related processes for making same, and in particular to hygro flat woven fabrics and articles adapted for home textile uses, such as bedding.

BACKGROUND

[0002] Hygro materials can be used to describe materials, such as yarns and fabrics, which absorb water or moisture. Textile materials can absorb water through the fiber structure itself. For instance, cotton fibers are highly absorbent and textile materials that use cotton fibers can be absorbent materials. Textile materials can also be designed to absorb moisture through the specific yarn and woven fabric constructions. For example, lightly twisted yarn structure may absorb more moisture than highly twisted yarn structures. In another example, terry fabrics can typically absorb more moisture than flat fabrics due to the presence of piles and increased surface area available to absorb and transport moisture. It is challenging to balance the ability of a fabric structure to absorb moisture while also maintaining fabric durability and softness. This effort is further challenged by developing yarn structures that can readily withstand the rigors of weaving or other textile processes.

SUMMARY

[0003] A first embodiment of the disclosure is a woven fabric that includes plied staple yarns that include hollow cores. The woven fabric includes a warp component including warp yarns and a weft component including weft yarns interwoven with the warp yarns to define the woven fabric. At least one of a) the warp component, and b) the weft component includes a plurality of the plied staple yarns. Each plied staple yarn has a length and a plurality of separate package dyed staple yarns twisted together. Each package dyed staple yarn includes an outer sheath of staple fibers twisted together, and a hollow core within the outer sheath of staple fibers. The hollow core extends along the length of the plied staple yarn. One example of the first embodiment of the present disclosure is a bedding article that includes the woven fabric described above. The bedding articles formed from the first embodiment of the woven fabric includes one or more of a flat sheet, a fitted sheet, a pillow case, a comforter, and a pillow sham.

[0004] A second embodiment of the present disclosure is a process for manufacturing a flat woven fabric that includes the plied staple yarns that include separate package dyed yarns each having a hollow core. The process includes spinning a first staple yarn to include a first outer sheath of staple fibers twisted around a first inner core of water soluble fibers, and spinning a second staple yarn to include a second outer sheath of staple fibers twisted around a second inner core of water soluble fibers. The process includes plying the first staple yarn and the second staple into a plied staple yarn. The plied staple yarn is wound into a yarn package. With the plied staple yarn on the yarn package, the first and second inner core of the water soluble fibers are removed from each one of the first and second staple yarns in the plied staple yarn to form first and second hollow cores in the first and second staple yarns, respectively. After the removing step, the process includes weaving a plurality of the plied staple yarns into a flat woven fabric. In one example of the second embodiment, the weaving step includes weaving a flat woven fabric having warp yarns and weft yarns such that at least one of the warp yarns and the weft yarns include the plied staple yarns. In another example of the second embodiment, the removing step can also include dyeing the outer sheath of staple fibers.

[0005] A third embodiment of the present disclosure is a flat woven fabric that include multi-core staple yarns. The flat woven fabric includes a warp component including warp yarns, and a weft component including weft yarns interwoven with the warp yarns to define the woven fabric. At least one of a) the warp component and b) the weft component includes a plurality of multi-core staple yarns. Each multi-core staple yarn includes a length, an outer sheath of twisted staple fibers that extends along the length, a first hollow core that extends through the outer sheath of staple fibers along the length, and a second hollow core that extends through the outer sheath of staple fibers along the length. In one example of the third embodiment, the first hollow core and the second hollow core are twisted around and with respect to each other as each extends along the length. Another example of the third embodiment of the present disclosure is a bedding article that includes the woven fabric with multi-core staple yarns. The bedding article includes one or more of a flat sheet, a fitted sheet, a pillow case, a comforter, and a pillow sham.

[0006] A fourth embodiment of the present disclosure is process for manufacturing a woven fabric that includes multi-core staple yarns. The process includes spinning staple yarns to include an outer sheath of staple fibers twisted around a first core of water soluble fibers and a second core of water soluble fibers. The process further includes removing the first and second cores of water soluble fibers from each one of the staple yarns to from a multi-core staple yarn having the first and second hollow cores. The process includes weaving the multi-core staple yarns into a flat woven fabric. In one example of the fourth embodiment, the weaving step includes weaving warp yarns and weft yarns with each other to define the flat woven fabric such that at least one of a) the warp yarns, and b) the weft yarns include the multi-core staple yarns. In one example of the fourth embodiment, the weaving step occurs after the removing step. In another example, however, the weaving step occurs before the removing step. In yet another example of the fourth embodiment, the removing step includes dyeing the multi-core staple yarns.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] The foregoing summary, as well as the following detailed description of illustrative embodiments of the present application, will be better understood when read in conjunction with the appended drawings, which are described below. For the purposes of illustrating the present application, there is shown in the drawings illustrative embodiments of the disclosure. It should be understood, however, that the application is not limited to the precise arrangements and instrumentalities shown.

Figure 1A is a schematic view of a woven fabric formed with hygro yarns according to an embodiment of the present disclosure.

Figure 1B is a cross-sectional view of the woven fabric taken along line 1B-1B in Figure 1A.

Figure 2 is a sectional side view of a terry fabric woven including hygro yarns according to another embodiment of the present disclosure.

Figure 3A is a schematic side view of a hygro yarn used in to form the fabrics illustrated in Figures 1A-2B;

Figure 3B is cross-sectional view of the hygro yarn taken along line 3B-3B in Figure 3A, and illustrating the water soluble fiber core.

Figure 4A is a schematic side view of the plied hygro yarn illustrated in Figures 3A, after the water soluble fiber core has been removed.

Figure 4B is cross-sectional view of the plied hygro yarn, taken along line 4B-4B in Figure 4A, and illustrating the hollow core after the water soluble fiber core has been removed.

Figure 5 a process flow diagram for manufacturing the plied hygro yarn, according to an embodiment of the present disclosure.

Figure 6 a process flow diagram for manufacturing textile articles with the plied hygro yarns, according to an embodiment of the present disclosure.

Figure 7A is a schematic side view of the multi-core hygro yarn used in fabrics illustrated in Figures 1A-2B;

Figure 7B is cross-sectional view of the multi-core yarn, taken along line 7B-7B in Figure 7A, and illustrating the first and second water soluble fiber core.

Figure 8A is a schematic side view of the multi-core hygro yarn illustrated in Figure 7A, after the first and water soluble fiber cores have been removed.

Figure 8B is cross-sectional view of the multi-core yarn, taken along line 8B-8B in Figure 8A, and illustrating the first and second water soluble fiber core.

Figure 9 a process flow diagram for manufacturing the multi-core hygro yarn and related fabrics, according to an embodiment of the present disclosure.

Figure 10 a process flow diagram for manufacturing textile articles with the multi-core hygro yarns, according to an embodiment of the present disclosure.

Figure 11 is schematic of an apparatus using in yarn spinning according to an embodiment of the present disclosure.

Figures 12A and 12B illustrate data related heat loss for certain flat woven fabrics.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

[0008] Embodiments of the present disclosure include unique "hygro" textile structures, such as yarns, fabrics, and related articles that are highly absorbent, hydrophilic, soft, and adapted for home textile applications. The hygro textile structures may be suitable for bedding articles, such as sheeting products. Also described herein are processes and devices used to manufacture hygro textile structures. The hygro textile structures as described herein are formed with yarn configurations that include an outer sheath of fibers that surround inner, multiple, hollow core(s). The multiple hollow cores are formed by the removal of soluble fibers, e.g. water soluble fibers, during the manufacturing process, as will be further explained below.

[0009] The yarn configurations described in the present disclosure can have one of several different structures. In one embodiment, the yarn configuration is a plied yarn formed from single end yarns that include a core of soluble fibers, as shown Figures 3A and 3B. After the soluble fibers are removed, the resulting structure is a plied hygro yarn 80 of multiple single end yarns, each of which have a hollow core, as shown Figures 4A and 4B. The process used to form the yarn structures illustrated in Figures 3A to 4B will be described in detail below. In another embodiment, the yarn configuration is a single end yarn formed to include multiple cores of soluble fibers, as shown Figures 7A and 7B. After the soluble fibers are removed, the resulting structure is a single end, multi-core yarn 180 that includes multiple hollow cores, as shown Figures 8A and 8B. The process used to form the yarn multi-core yarn 180 illustrated in Figures 7A-8B will also be described in further below. The yarn structures that include soluble fibers as illustrated in the Figures 3A and 3B and in Figures 7A and 7B are referred to in the present disclosure as "intermediate yarns." The yarn structures where the soluble fibers have been removed as illustrated in the Figures 4A and 4B and in Figures 8A and 8B are referred to in the present disclosure as "hygro yarns."

[0010] The resulting hygro yarn configurations as described herein in many circumstances boost manufacturing efficiency and improve end-product quality. For instance, the plied yarn yarns 80 as shown Figures 4A and 4B may result in fewer end breaks during weaving, increasing weaving efficiency. The plied yarns 80shown in Figures 4A and 4B are also packaged dyed yarns, which can result in better color fastness in the finished product, among other benefits discussed below. For multi-core yarns 180 shown in Figures 8A and 8B, the process used to form the yarns 180 results in increased productivity, which in turn, increases overall efficiency along the yarn-to-textile article supply chain. Embodiments of the present disclosure thus improve upon existing technologies used to form hygro yarns that include an outer sheath of cotton fibers and a single hollow core, such as those described in U.S. Patent No. 8,733,075, entitled, "Hygro Materials For Use In Making Yarns And Fabrics," (the "075 patent"). The disclosure of the 075 patent which is not inconsistent with the present disclosure is herein incorporated by reference.

[0011] Embodiments of the present disclosure also include flat woven fabric 10 formed using the hygro yarns as described herein. An exemplary flat woven fabric 10 is shown in Figures 1A and 1B. In one example, the flat woven fabric 10 may be formed to include the plied staple hygro yarns 80 (see Figures 4A, 4B). In another example, the flat woven fabric 10 may be formed to multi-core staple hygro yarns 180 (see Figures 8A, 8B).

[0012] Referring to Figures 1A and 1B, the flat woven fabric 10 includes a warp component having warp yarns 20, and a weft component including weft yarns 40 that are interwoven with the warp yarns 20 to define the woven fabric. The warp yarns 20 extends along a warp direction 4 and the weft yarns 40 extend along a weft or fill direction 6 that is perpendicular to the warp direction 4. The woven fabric 10 includes a face 12, and back 14 opposite the face 12 along a thickness direction 8 that is perpendicular to the warp direction 4 and the weft direction 6. As illustrated, either or both of the warp component and the weft component may include the various hygro yarn configurations described herein. In one example, either or both of the warp component and the weft component the plied hygro yarn 80 as described herein. In another example, either or both of the warp component and the weft component may include the multi-core yarns 180 as describe herein. The flat woven fabrics 10 as described herein are suitable for bedding applications, such as sheeting fabrics. Accordingly, the flat woven fabric 10 can be converted into a sheeting article.

[0013] The woven fabric 10 as described herein may be defined by a number of different woven structures or woven design repeats. As used herein, a woven design repeat includes at least a first warp yarn 20a, a second warp yarn 20b, and at least one weft yarn 40. For example, a plain weave fabric has a woven design repeat that includes two adjacent warp yarns 20 and two adjacent weft yarns 40. Depending on the particular design, woven design repeats may repeat along: a) the weft direction 4; b) the warp direction 6; or both the weft direction 4 and warp directions 6. However, the design of the woven fabric 10 is not limited to a plain weave. For example, the woven fabric can have a number of exemplary woven structures including, but are not limited to: plain weaves; basket weaves, rib weaves (e.g. 2x1 rib weave; 2x2 rib weave; or 3x1 rib weave) twill weaves; oxford weaves; percale weaves, satin weaves (e.g. satin dobby base, satin stripe satin 5/1, satin 4/1 satin; 4/1 satin base strip; 4/1 stain swiss dot; 4/1 down jacquard;5/1 satins), or sateen weaves. In one example, the woven fabric is a plain weave. In another example, the woven fabric is a basket weave. In another example, the woven fabric is a rib weave. In another example, the woven fabric is a twill. In another example, the woven fabric is an oxford weave. In another example, the woven fabric is a satin weave. Furthermore, a number of exemplary satin constructions are possible. For instance, in one satin weave example, the woven fabric is a

4/1 satin. In another example, the woven fabric is a 4/1 satin dobby diamond weave. In another example, the woven fabric is a 4/1 satin dobby stripe. In yet another example, the woven fabric is a 4/1 satin jacquard weave. In another example, the woven fabric is a 5/1 satin. In still another example, the woven fabric may be a 6/1 satin. In another example, the woven fabric is a 7/1 satin. In yet another example, the woven fabric is a 8/1 satin. In another example, the woven fabric is a 9/1 satin. And in another example, the woven fabric is a 10/1 satin.

[0014] The present disclosure can utilize co-insertion techniques to insert multiple weft yarns 40 along a weft insertion path 19 in a single weft insertion event during weaving, as will be further detailed below. The weft insertion path 19 of weft yarn 40 is shown in dashed lines in Figures 1B. As used herein, the weft insertion path 19 extends along the weft direction 4 around the warp yarns 20 across an entirety of the width of the woven fabric 10. As illustrated, the weft insertion path extends under (with respect to the sheet) warp 20a, over warp yarn 20b, under warp yarn 20c, and over warp yarn 20d. A person of skill in the art will appreciate that the weft insertion path 19 varies from one woven design to another woven design. By inserting groups of multiple weft yarns into the shed during a weft insertion event, it is possible to attain increased weft (or pick or fill) densities and therefore higher thread counts. Thus, the woven fabric 10 as described herein may be constructed to have higher weft yarn densities than what is otherwise possible, and thus higher thread counts, yet the woven fabric 10 exhibits desirable fabric quality, softness, hand, and drape suitable for bedding applications. The thread count of the woven fabrics made in accordance with present disclosure is typically greater than about 100 and can be as high as about 1000 (or even higher). The thread count as used herein is the total number of yarns in square inch of fabric. The thread count in this context is based on total number of yarn ends. In other words, plied yarns are considered one yarn for the purpose of determining thread count.

[0015] The present disclosure can utilize co-insertion techniques to insert multiple weft yarn 40 along a weft insertion path 19 in a single weft insertion event during weaving, as will be further detailed below. A "co-insertion" technique is where multiple pick or weft yarns are inserted into the warp shed at one time during weaving. In co-insertion, two pick yarns supplied from two different yarn packages are inserted at one time through the shed during weaving. Co-insertion may also include inserting three or more yarns supplied from the three or more different yarn packages into the shed during weaving. In one example, the woven fabric 10 has between one (1) weft yarn and seven (7) weft yarns inserted during a single insertion event, i.e. along the weft insertion path 19.

[0016] The warp yarns and weft yarns are arranged to achieve desired warp and weft end densities, respectively, and thus desired thread count, for bedding applications. In accordance with an embodiment of the present disclosure, the woven fabric has a warp end density between about 50 warp ends per inch and about 350 warp ends per inch. In one example, the warp end density is between about 50 and 150 warp ends per inch. In another example, the warp end density is between about 150 and 250 warp ends per inch. In another example, the warp end density is between about 250 and 350 warp ends per inch. Furthermore, the weft yarns are arranged to define a weft end density between about 50 weft yarns per inch and about 700 weft yarns per inch (or more). In one example, the weft yarn density is between about 100 and about 700 weft yarns per inch. In one example, the weft yarn density is between about 100 and about 300 weft yarns per inch. In another example, the weft yarn density is between about 300 and about 500 weft yarns per inch. In another example, the weft yarn density is between about 500 and about 700 weft yarns per inch. The weft yarn density has used herein refers to the total number of separate weft yarns along a length of the woven fabric. For example, a weft yarn density of about 50 picks per inch refers the 50 total weft yarns per inch of woven fabric. If the weft yarn groups are inserted during a single weft insertion event and each group includes three (3) weft yarns, then there would be about 16 total weft yarn groups per inch of fabric and 48 picks per inch.

[0017] The yarns can have a range of counts for the different fibers and woven constructions as described herein. The yarn count as used in this paragraph refers to the yarn count for each single end in the plied hygro yarn 80, and the yarn count of the multi-core yarn 180. The yarn count can range between about 8 Ne (664 denier) to about 120 Ne (44.3 denier). In one example, the yarns can have a count in a range between about 8 Ne (664 denier). In one example, the yarns can have a count in a range between about 20 Ne (266 denier). In one example, the yarns can have a count in a range between about 30 Ne (177 denier). In one example, the yarns can have count in a range between about 40 Ne (133 denier). In another example, the yarns have a count of about 60 Ne (88.6 denier). In another example, the yarns have a count of about 70 Ne (75.9 denier). In another example, the yarns have a count of about 80 Ne (66.4 denier). In another example, the yarns have a count of about 100 Ne (53.1 denier). In another example, the yarns have a count of about 120 Ne (44.3 denier). For flat woven fabrics, the warp yarn counts may range from 20 Ne (266 denier) to about 100 Ne (53.1 denier). The weft yarn counts may range from 20 Ne (266 denier) to about 120 Ne (44.3.1 denier).

[0018] The flat woven fabric 10 can use different yarn constructions in the warp and weft components. In one example, the warp yarns are typical staple spun yarns (cotton or any fiber blends) and the weft yarns include plied hygro yarns 80 or multi-core hygro yarns 180. In one example, the warp yarns are typical continuous filament yarns and the weft yarns are plied hygro yarns 80 or multi-core hygro yarns 180. In another example, the weft yarns are typical staple spun yarns and the warp yarns are plied hygro yarns 80 or multi-core hygro yarns 180. In one example, the weft yarns are typical continuous filament yarns and the warp yarns are plied hygro yarns 80 or a multi-core hygro yarns 180. In one preferred embodiment, the warp yarns are typical staple spun yarns and the weft yarns include plied hygro yarns 80 or multi-core hygro yarns 180.

[0019] In accordance with an alternative embodiment of the present disclosure, the hygro yarns can be used to form other types of woven fabrics, for example, a terry fabric 110 as shown in Figure 2. As can be seen in Figure 2, in accordance with an alternative embodiment, a terry woven fabric 110 is illustrated that includes a ground component 130 that includes warp yarns 120 and weft yarns 140 interwoven with the warp yarns 120. The terry woven fabric 110 also includes one or more pile components 150a, 150b. The ground component 130 includes a first side 32 and a second side 34 opposite the first side. The pile component 150a and 150b extend away from opposite sides 32 and 34 of the ground component 130 along a thickness direction 8. The warp yarns 120 extend along a warp direction 4, which is perpendicular to the weft direction 6 and the thickness direction 9. The weft yarns 140 extend along a weft or fill direction 6 that is perpendicular to the warp direction 4. The woven fabric 110 includes a face 12, and back 14 opposite the face 12 along a thickness direction 8 that is perpendicular to the warp direction 4 and the weft direction 6. The terminal ends of the pile components 150a and 150b can define the face 12 and back 14 of the woven fabric 110. The piles have a pile height H that extends from the ground component to the terminal ends of the piles.

[0020] As illustrated in Figure 2, the terry woven fabric 110 includes a first pile component 150a and a second pile component 150b. However, the terry fabric may include only the one pile component. Each pile component 150a, 150b includes a plurality of piles 152a, 152b that project in a direction away from the ground component 130. The piles 152a, 152b are defined by pile yarns 154a, 154b interwoven with the ground component 130. The terry woven fabric 110 can be formed using any of the hygro yarn configurations described in the present disclosure. In one example, the pile yarns 154a, 154b may include the plied hygro yarns 80. Furthermore, one or both of the warp yarns 120 and the weft yarns 140 may include the plied hygro yarns 80. In another example, however, the pile yarns 154a, 154b may include the multi-core yarns 180. In such an example, one or both of the warp yarns 120 and the weft yarns 140 may include the multi-core yarns 180. The terry woven fabrics 110 may be converted bath and/or kitchen products, such as towel articles. Terry articles include a towel, a hand towel, a wash cloth, a bath robe, a rug, a kitchen towel, and the like.

[0021] Figures 3A-6 illustrate the intermediate plied yarns 60, plied hygro yarns 80, and processes used form textile articles with the plied hygro yarns 80. Each of the yarns shown in Figures 3A-4B is a plied yarn structure made of a plurality of separate, packaged dyed yarns twisted together into a plied yarn configuration. The yarn structures before and after removal of the soluble fibers is illustrated in Figures 3A-3B and 4A-4B, respectively. Figures 3A and 3B illustrates a plied yarn 60 with two staple yarns 62a and 62b, each having an outer sheath 84a,84b of staple fibers and a core 66a, 66b of soluble fibers. A plied yarn with cores of soluble fibers may be referred to as an intermediate plied yarn 60. Figures 4A and 4B illustrate the plied yarn 80 after the soluble fibers have been removed, for instance via yarn or packaging dyeing. The plied yarn 80 has a plurality of separate packaged dyed staple yarns 82a, 82b twisted together into the plied yarn configuration. Each package dyed staple yarn has a hollow core 88a, 88b surrounded by the outer sheath 84a, 84b of staple fibers. As illustrated, the plied staple yarn 80 is a two-ply yarn that includes a first staple yarn 82a and a second staple yarn 82b twisted with the first staple yarn 82a to define the two-ply yarn 80. However, the plied staple yarn can have more than two separate yarns. A plied yarn with cores of soluble fibers removed is referred to as a plied hygro yarn 60 or plied yarn 60. Both the intermediate yarn 60 and the plied hygro yarn will be described in more detail next.

[0022] Referring to Figures 3A-4B, the intermediate yarn 60 includes an outer sheath of staple fibers and an inner core of soluble fibers. The outer sheath 84a, 84b of staple fibers may by cotton fibers. Alternatively, for example, in place of cotton, the outer sheath may contain viscose fibers, modal fibers, silk fibers, modal fibers, linen fibers, bamboo fibers, acrylic fibers, polyethylene terephthalate (PET) fibers, polyamide fibers, or blends of fibers. Fiber blends, for example, may include, but are not limited to: cotton and viscose fiber blends; cotton and modal fiber blends; cotton and silk fiber blends; cotton and modal fibers, cotton and linen fiber blends; cotton and bamboo fiber blends; cotton and acrylic fiber blends; cotton and PET fiber blends; cotton and polyamide fiber blends; viscose and modal fiber blends; viscose and silk fiber blends; viscose and modal fibers, viscose and linen fiber blends; viscose and bamboo fiber blends; viscose and acrylic fiber blends; viscose and PET fiber blends; viscose and polyamide fiber blends; PET and viscose fiber blends; PET and modal fiber blends; PET and silk fiber blends; PET and modal fibers, PET and linen fiber blends; PET and bamboo fiber blends; PET and acrylic fiber blends; and PET and polyamide fiber blends. The sheath may, for example, be 100% cotton or a combination of any of the foregoing blends.

[0023] The inner core of soluble fibers may be water soluble fibers. In one example, the water soluble fibers are polyvinyl alcohol (PVA) fibers. PVA fibers are synthetic fibers available in the form of filaments and cut staple fibers. PVA fibers are preferably easily dissolved in warm or hot water at about 50 degrees Celsius to about 110 degrees Celsius without the aid of any chemical agents. However, it should be appreciated that other fibers that can be removed and/or dissolved with water or other specific agents that can leave an outer sheath of fibers intact may be used. The description here refers to use of PVA fibers and water soluble fibers interchangeably for ease of illustrating embodiments of the present disclosure. The present disclosure is not limited to PVA fibers unless the claims recite PVA fibers. The amount of soluble fibers dissolved depends, in part, on the count of the yarn or yarns used. The amount of soluble fibers present can vary from about 5% to about 40% of the weight of the yarn. The balance of the weight is comprised of the outer sheath of staple fibers. In one example, the soluble fibers may vary from about 10% to about 30 % of the weight of the yarn. In one example, the soluble fibers may vary from about 15% to about 25 % of the weight of the yarn. In one example, the soluble fibers may vary from about 17% to about 23 % of the weight of the yarn. In one example, the soluble fibers may be about 20 % of the weight of the yarn. However, it should be appreciated that the amount of soluble fibers can be any specific amount between 5% to about 40%. Each intermediate yarns 62a, 62b may include similar soluble fiber content. In other embodiments, however, the weight content of the water soluble fibers between the first intermediate yarn 62a and the second intermediate yarn 62b can vary with respect to each other.

[0024] In accordance with illustrated embodiment, the intermediate plied yarns 60 (or separate intermediate yarns 62a, 62b) are dyed prior to fabric formation to remove the core 66a, 66b of soluble fibers and apply color to the staple fibers in the outer sheath 84a, 84b. Following removal of the core 66a, 66b of soluble fibers, each yarn has an outer sheath 84a, 84b of staple fibers twisted around a hollow core to define the plied yarn 80 as illustrated in Figures 4A and 4B. By dissolving the soluble fibers, e.g. PVA fibers, hollow air spaces are formed throughout the yarns, corresponding to an increase in the air space in the yarn. By increasing the air space in the yarn, the textile articles formed therefrom are softer and bulkier than textile articles made without the hygro yarns as described herein.

[0025] Turning to Figures 4A and 4B, removal of the soluble fibers from the intermediate yarn 60 results in a plied staple yarn 80 having a plurality of separate, package dyed staple yarns 82a, 82b that each include a hollow core. As illustrated in Figures 4A and 4B, the plied staple yarn 80 includes a first package dyed staple yarn 82a and a second package dyed staple yarn 82b twisted with the first staple yarn 82a to define a two-ply yarn. Each separate dyed staple yarn 82a, 82b includes an outer sheath 84a, 84b of staple fibers (which were previously dyed) twisted together around a hollow core 88a, 88b. The plied yarn 80 extends along a length L that is aligned with a plied yarn central axis A. Accordingly, it can be said that the first and second staple yarns 82a, 82b extend along the length L of the plied yarn 80. However, as can be seen in the figures, the first dyed staple yarn 82a and the second dyed staple yarn 82b are twisted with respect to each other and about the central axis A. As can be seen in Figures 4A and 4B, the first staple yarn 82a has a first central axis B1. The outer sheath 84a of fibers in the first dyed staple yarn 82a is twisted about the first central axis B1 such that the hollow core 88a extends along the first central axis B1. Likewise, the second dyed staple yarn 82b has a second central axis B2. The outer sheath 84b of fibers in the second dyed staple yarn 82a are twisted about the second central axis B2 such that the hollow core 88b extends along the second central axis B2. The plied yarn 80 defines a helical type structure whereby the first and second central axes B1 and B2 twist around the plied yarn central axis A and with respect to each other.

[0026] The hollow cores 88a, 88b comprise a predefined portion of separate, dyed staple yarns 82a and 82b. The predefined portion may be described in terms of a percentage of yarn cross-sectional dimension (e.g. distance) and/or volume of the dyed staple yarn 82a, 82b or plied yarn 80. For instance, each dyed staple yarn 82a, 82b defines a yarn cross-sectional dimension C1 that is perpendicular to the yarn central axis A and the respective yarn central axis B1, B2 (Figure 4B). The hollow core 88a, 88b defines a cross-sectional dimension C2 that is perpendicular to the respective yarn central axis B1, B2 (Figure 4B). In this instance, the cross-sectional dimension C2 of the hollow core is aligned with the yarn cross-sectional dimension C1 of separate staple yarn 82a, 82b along a direction G. In other words, the cross-sectional dimensions C1 and C2 are defined along a similar direction G. The phrase "cross-sectional dimension" is the longest distance across a point of reference in the yarn structure. For instance, an idealized yarn structure has a circular cross section. In that case the cross-sectional dimension would be referred to as the diameter of the yarn. However, yarn structures may not have a perfectly circular cross-section. Furthermore, in practice, it is believed the collapse of the yarn structure, fiber migration, and twist variances along the length could distort the cross-sectional shape of the hollow core. The cross-sectional dimension may be measured using image analysis techniques to obtain relative measurements of the yarn dimensions. In accordance with the illustrated embodiment, the hollow core 88a, 88b defines between about 8% to about 40 % of the cross-sectional dimension C1 of the dyed staple yarn 82a, 82b. In other words, the hollow core has a cross-sectional dimension C2 that is between about 8% to about 40% of the cross-sectional dimension C1 of the staple yarn 82a, 82b. This percentage corresponds to the approximate weight percentage of water soluble fibers in the intermediate staple yarns 62a, 62b before remove of the water soluble fibers. In one example, the hollow core defines between about 10% to about 30% of the cross-sectional dimension C1. In another example, the hollow core defines between about 15% to about 25% of the cross-sectional dimension C1.

[0027] Similarly, the hollow core 88a, 88b comprises a defined volume percentage of the dyed staple yarns. Volume percentage is determined assuming that the dyed staple yarns 82a, 82b are cylindrical. A person of skill would appreciate the use of volume percentage based on this assumption. The yarn volume V1 is equal to $[\pi(C1/2)^2]*h$, where C1 is the cross-sectional dimension C1 defined above and h is a given length L of the yarn 82a, 82b. The hollow core volume V2 is equal to $[\pi(C2/2)^2]*h$, where C2 is the cross-sectional dimension C2 of the hollow care defined above and h is a given length L of the yarn 82a, 82b. The volume percentage of the hollow core is equal to (V2/V1)*100. In accordance with the illustrated embodiment, the hollow core 88a, 88b comprises between about 8% to about 40% of the volume of the dyed staple yarn 82a,82b. In one example, the hollow core 88a, 88b defines between about 10% to about 30% of the volume of the dyed staple yarn 82a, 82b. In another example, the hollow core 88a,88b defines between about 15% to about 25% of the volume of the dyed staple yarn. The volume percentage of the hollow core 88a, 88b also corresponds to the approximate weight percentage of water soluble fibers in the intermediate staple yarns 62a, 62b before remove of the water soluble fibers.

[0028] The plied yarn 80 can be twisted to have ether a z-twist or a s-twist. Each yarn in the plied yarn can have a twist direction that is opposite to the twist direction of the plied yarn. For instance, if the plied yarn has a Z-twist, each yarn end will have an s-twist and vice versa. Furthermore, while a two-ply yarn is illustrated in the figures, the plied yarn 80 as described herein is not limited to two-plies. The plied yarns can be 3-ply or 4 ply yarns. In one example, the plied yarn is a three-ply yarn that includes a first package dyed staple yarn, a second package dyed staple yarn, and a third package dyed staple yarn twisted into a plied structure.

[0029] The plied yarns 80 are formed to have strength sufficient for formation into the woven fabrics 10 and 110. In conventional hygro yarns, such as those disclosed in the 075 patent, the water soluble fibers are removed after fabric formation. Hence, during manufacturing, the hygro yarns have a weight and strength that is suitable to withstand the rigors of the weaving process. In present disclosure, however, the water soluble fibers are removed before weaving, as will be further explained below. This results in a generally lower mass of yarn, if for example, single end yarns are used during weaving. The loss of mass in the yarn due to the removal of water soluble fibers decreases yarn strength. The present embodiment balances this decrease in strength by plying the singled end yarns together prior to removal of the water soluble fibers. Accordingly, each package dyed staple yarn 82a, 82b has a strength that is less than the tensile strength of the plied yarns 80. In certain exemplary cases, each package dyed staple yarn 82a, 82b may not be well suited to withstand the rigors of the weaving cycle, whether used as warp or weft yarns, due to the hollow core. Plied yarns 80, however, can be woven into fabrics 10 and 110 due to the increased strength and are suitable for withstanding the weaving motions and forces applied the yarn structures during weaving.

[0030] Forming the plied yarn 80 illustrated in Figures 4A-4B into textile articles will be described next. Figures 5 and 6 illustrate a method 200 for manufacturing hygro textile articles with the plied yarns 80 according to an embodiment of the present disclosure. The method 200 described below refers to use of cotton fiber in the outer sheath and of PVA fibers used to form the inner core. However, it should be appreciated that other fibers can be used in the outer sheath and an inner core, as described above.

[0031] The method 200 illustrated includes two preliminary phases: outer sheath sliver formation 202 and soluble fiber sliver formation 204. Outer sheath sliver formation 202 creates slivers used to form the outer sheath 84as, 84b, of fibers in the intermediate yarns 62a, 62b while soluble fiber sliver formation 204 creates slivers used to form the inner core of soluble fibers 66a,66b in the intermediate yarns 62a, 62b.

[0032] Outer sheath fiber formation phase 202 forms slivers of staple fibers for roving. Outer fiber sliver formation initiates with fiber receiving 206 and storage 208. In one example, the outer fibers are cotton fibers. The outer cover sliver (or outer sheath) may be made from, for example, cotton fibers or blends of cotton fiber or other fibers blends as described above. Described below is an exemplary process of forming a cotton slivers. The 075 patent includes properties of exemplary cotton fibers suitable for processing as described herein. For clarity of description the outer sheath sliver formation phase 202 will be referred to as outer fiber sliver formation.

[0033] Next, the outer sheath fibers (or cotton fibers) are subject to an opening step 210 in a blow room. In the blow room, the cotton fibers are processed with a bale plucker, opener, multi-mixer, beater and a dustex machine. After opening 201, the fibers are carded 212 on card machines to deliver card slivers. The sliver from carding 212 is then processed through a breaker drawing step 214 to draw out the slivers. In one example of the breaker drawing step 214, the number of doublings at the feed end can be 6 and the hank delivered is maintained at about 0.12. In case of blended slivers, each component is separately processed through carding and the individual carded slivers are subsequently blended together on draw frames. From breaker drawing 214, the slivers can follow one of two processing step: a lapping step 216 or fed directly roving step 232.

[0034] In instances where combing is needed, processing proceeds from the breaker drawing 214 to the lapping step 216. As should be appreciated, combing is used to remove short fibers during cotton processing. In the lapping step 216, a unilap machine converts doublings into a lap of fibers. The lap is processed in a combing step 218 using a comber. The combed cotton sliver is then passed through another finisher drawing step 220 using a finisher draw frame. In one example, the finisher draw frame has a feed hank of 0.12 and a delivery hank of 0.75 and at speeds up to about 400 meters per minute. The sliver hank exiting the drawing step 220 is kept relatively coarse (e.g. at 0.075) in order enable covering of the soluble fiber sliver during roving step.

[0035] Referring back to step 214, in certain instances, the slivers produced at breaker drawing step 214 are fed directly to the roving step 232, further explained below.

[0036] The formation of the soluble slivers is described next. Soluble fiber sliver formation initiates with fiber receiving 222 and storage 224. The description below refers to PVA fibers. But it should be understood that the description below is not limiting and other soluble fibers could be used in place of or in addition to PVA fibers. In one example, the denier of the PVA fibers may be range from about 0.9 denier to about 2.2 denier. The soluble fibers have a cut length that is equal to or more than 32 mm and equal to or shorter than 51 mm. However, other cut lengths can be used with modifications in the machine parameters during spinning. In an exemplary embodiment, the PVA fiber is 38 mm staple length and 1.4

denier. The 075 patent includes properties of exemplary PVA fibers suitable for processing as described herein.

[0037] Next, the soluble fibers are subject to an opening step 226 in a blow room in a "cotton" type spinning system. Here, the PVA fibers are first passed through a blow room having a feeder and a mono cylinder beater only. Because PVA fibers are synthetic, the PVA fibers are clean and have minimal impurities. Thus, less aggressive cleaning steps are needed during soluble sliver formation phase 204 compared to similar phases of processing cotton.

[0038] After opening 226, the PVA fibers are conveyed from the blow room to carding 228 to form card slivers, which are coiled into sliver cans. In one example, the carding machines are run between 100 and 120 meters per minute delivery speed and to yield a hank that can range between 0.05 to 0.40. The carded slivers are then further drawn via drawing step 230 to yield the PVA sliver. During the drawing step 230, the carded slivers are passed through one or more draw frames to further orient the fibers along the length of the sliver, i.e. to impart more parallelization, of the fibers. For instance, during drawing 230, the PVA slivers are initially processed with a breaker draw frame. A second pass of drawing in a finisher draw frame is used to further arrange the PVA fibers in parallel form with respect to each other. The delivery hank from the finisher draw frame is kept fine (e.g. at about 0.3 although it could be higher than 0.3) to enable the PVA sliver to be inserted into a central or middle portion on the cotton fiber sliver upon entry into the speed frame. An exemplary delivery speed at the finishing frame can be between 250 to 300 meters per minute. The output of the drawing step 220 are cans of PVA slivers.

[0039] After outer fiber sliver formation 202 and soluble fiber sliver formation 204, the cotton and PVA slivers are combined during roving 232. During roving 232, the PVA sliver is inserted into a middle or central portion of the cotton sliver at a speed frame. Specifically, the sliver cans of both cotton slivers and PVA slivers are positioned at a feed end of the speed frame. Suitable arrangements, such as guide pulleys on a roving machine creel, are made for guiding the PVA sliver and the cotton sliver from the sliver cans at the creel side of the speed frame.

[0040] The speed frame as described herein includes an inlet condenser, a middle condenser, a main feed condenser, multiple sets of drafting rollers, and a flyer. Typically, slivers are processed through an inlet zone, back drafting zone, middle drafting zone, and a forward drafting zone. The condensers are disposed along these different zones at or near their respective drafting rollers. The cotton sliver follows a normal path from the back to the front of the speed frame through at least the main feed condenser. The inlet and middle condensers are incorporated for feeding PVA slivers at the inlet, the back and middle drafting zones on the speed frame, to ensure that the PVA sliver stays in the middle of the cotton sliver. The PVA sliver, however, passes through the inlet condenser before occupying the middle portion on the cotton sliver in the main feed condenser. The middle condenser is incorporated in the back zone of the drafting system to retain the PVA sliver in the middle of the cotton sliver, as mentioned above. As the cotton and PVA slivers emerge out of the drafting zone on the speed frame, the twist flowing from the flyer to the nip of the front rollers of the speed frame causes the cotton fibers to wrap around the inner PVA sliver, thus forcing the PVA sliver into the core. The twisting and winding on to the bobbin on the speed frame is typical as with any other cotton roving system. For example, clock-wise rotation of the flyer can give "Z" twist. Alternatively, the roving can have an "S" twist, by reversing the direction of the rotation of the flyer to a counter-clockwise direction. The roving hank ranges from about 0.5 to about 5.0 hanks. In one example, the hank of roving can be about 0.58.

[0041] The roving step 232 described above feeds the PVA fiber roving into the path of the cotton roving in the drafting zone of a speed frame. However, placing PVA fibers in a core of staple fibers can be accomplished in a variety of ways. In one embodiment, the PVA fibers can be added via core-spinning machine. In another variation, the PVA roving is introduced in the path of cotton roving on the roving machine. Alternatively, the PVA can be added to the middle of the cotton roving by reversing the rotation of flyer in the counter-clock-wise direction, which is opposite the direction of the normal flyer rotation. In both situations, the PVA fibers are placed in the middle of the cotton sliver during the roving process to yield a roving with a core of PVA fibers.

[0042] After the roving step 232, a yarn spinning step 234 converts the rovings into single end intermediate yarns 62a, 62b. In accordance with illustrated embodiment, yarn spinning 234 is accomplished on a ring spinning frame using typical settings for forming ring spun yarns. The spinning parameters on the ring frame are set based on the type of fibers in the outer sheath and type and content of the PVA fibers in the inner core. The result of yarn spinning 234 is a single intermediate staple yarn 62a as illustrated in Figure 3A and 3B. The ring spinning frame can produce single end yarns with a count that ranges from about 8 Ne to about 100 Ne. Yarns used for flat woven fabric 10 (Figures 1A & 1B) may have a count that ranges from 10 Ne to about 120 Ne. Yarns used for terry fabrics 110 (Figure 2) may have a count that ranges from about 8 Ne to about 50 Ne. After yarn spinning 234, the intermediate plied yarns 62a, 62b are further packaged 236 into suitable yarn packages using auto-coners. Those packages are then used in a plying step 238.

[0043] In plying step 238, the yarns plied into intermediate plied yarn 60 as shown in Figures 3A and 3B. In accordance with the illustrated embodiment, the plying step 238 uses two-for-one twisters to twist two single end yarns into a two-ply yarn. Accordingly, as shown, the intermediate plied staple yarn 60 is a two-ply yarn that includes a first intermediate staple yarn 62a and a second intermediate staple yarn 62b twisted with the first intermediate staple yarn 62a to define the intermediate plied yarn 60. The intermediate plied yarn 60 can have an overall twist per inch (TPI) from about 6.5 to about 14.5 TPI in an "S" direction. The twist direction can, however, be in a "Z" direction. Furthermore, the twist configuration can be either Z over S or Z over Z. The resultant yarn counts would be about 2/8s to about 2/50s for terry fabrics. Similarly the doubled yarns for flat fabrics may be from about 2/10s to about 2/100s. In alternative embodiments, the intermediate plied yarn 60 can be 3-ply yarn. Such a 3-ply intermediate yarn includes a first intermediate staple yarn, a second intermediate staple yarn, and a third intermediate staple yarn twisted into a plied structure. More plies than 3 can be used as needed. After yarn plying 238, the intermediate plied yarns 60 are wound 240 onto suitable yarn packages for further processing. For example, the plied yarn 60 can be cross-wound onto a yarn package. The yarn package may include a core and the plied yarn 60 wound onto the core. The core may be perforated to aid in dyeing the cross-wound package.

[0044] Turning to Figure 6, the next phase in the production of hygro textile articles is soluble fiber removal, yarn dyeing, followed by fabric formation and article formation. As illustrated, the plied yarn packages formed during the packaging step 240 are received 242 and stored 244 for later processing in the fiber removal and coloration step 246. In step 246, the soluble fibers are removed from the inner core and color is applied to the fibers in the outer sheaths 84a, 84b with the plied yarns 80 wound onto the yarn packages. The process step 246 may occur in two phases where the soluble fibers are removed first followed by application of coloring agents. Alternatively, soluble fiber removal and color application can overlap. In accordance with the illustrated embodiment, the yarn packages are placed within a package dyeing machine and exposed to elevated water temperatures under pressure for a predetermined period of time, as will be understood by persons familiar with convention package dyeing machines and processes. In one example, the water temperatures range from at least about 95 degrees Celsius to about 120 degrees Celsius. In one preferred example, the temperature of water in the package dyeing machine during PVA removal is about 120 degrees Celsius, which can ensure that all the PVA dissolves leaving the hollow inner cores in each yarn of the plied yarn structure. The result of process step 240 is the plied yarn 80 with two yarns, each having an outer sheath of fibers and a hollow core, as illustrated in Figures 4A and 4B.

[0045] After process step 246, the plied yarns 80 proceed to a warping step 248. The warping step 248 includes typical warping operations for flat woven fabrics 10 and/or typical warping operations for terry fabrics 110. For instance, for terry fabrics 110, warping includes both ground yarn warping and pile yarn warping.

[0046] A weaving step 250 follows warping 248. The weaving step converts the yarns into woven fabrics. One or more looms, e.g. air-jet looms, rapier looms, water-jet looms (or others) can be use during the weaving step. Each loom may utilize typical shedding mechanism, such as a dobby or jacquard type shedding mechanism. During the weaving step for the woven fabric 10 (Figure 1A, 1B), the warp and weft yarns can be arranged into a number of different weaving constructions and designs as is known by persons of skill in the art and that detailed above. For instance, the flat woven fabrics may include a plain weave, twills, rib weaves, basket weaves, percale, satins, sateens, other woven designs. In accordance with an embodiment of the present disclosure, the weaving step forms a woven fabric to have a) a warp end density between about 50 warp ends per inch and about 350 warp ends per inch; and b) a weft end density between about 50 weft yarns per inch and about 700 weft yarns per inch (or more). In one example, the weft yarn density is between about 100 and about 700 weft yarns per inch. Furthermore, the flat woven fabrics may have thread counts ranging from 100 TC to about 1000C. The weaving step may include co-insertion or insertion of multiple picks during a single pick insertion event. In one example, the weaving step includes inserting between one (1) weft yarn and seven (7) weft yarns during a single insertion event along the weft insertion path 19 (Fig. 1A). Furthermore, for woven fabrics 10, the weft yarns, warp yarns, or both the warp and weft yarns can include the plied hygro yarns 80. The flat woven fabrics are formed to have constructions that are suitable for bedding applications in both consumer, hospitality and /or healthcare markets.

[0047] In accordance with an alternative embodiment, the weaving step may include weaving a terry fabrics 110. In such an embodiment, the ground, weft, and pile yarns are woven together using a loom configured for terry production. The terry fabric 110 can be 3-pick, 4-pick, 5-pick, 6-pick, or 7-pick terry. In the one example, the terry fabric 110 is a 3-pick terry. The pile component 150a, 150b can define a pile height H that extends from the ground component 130 to a top of a pile154, 154b along the thickness direction 8. The pile height can range from about 2.0 to 10 mm.

[0048] The weaving step 250 results in "greige fabrics" that are further processed into textile articles. After the weaving step 250, the griege fabrics are inspected 252 and washed 254 in a washing vessel. After unloading the woven fabrics from the washing vessel, the water is extracted in an extractor in the typical manner to reduce the moisture content. Next, an opening step 256 untwists the fabric using a rope opener, similar to the rope opener as described in the 075 patent. A drying step 258 may use a hot air dryer to further dry the fabrics and expose the fabrics to the desired temperature, as is typical in the art. The dried fabric is expanded to full width and then passed through a stentering step 260. The stentering step 260 can help straighten the fabric.

[0049] In certain alternative embodiments for processing terry fabrics, a shearing step is used, whereby both sides of the terry fabric are passed through a shearing machine. The shearing machine has cutting devices, such as blades and/or a laser, which are set such that only protruding fibers are cut and the piles are not cut. The shearing step reduced linting during subsequent washing in use by the consumer.

[0050] After the stentering 260 (or optional shearing step), a cutting step 262 cuts the woven fabrics to the desired length and width depending on the particular end use. The next phase of processing can proceed based on particular end-used and fabric type. Process steps 272, 274 and 276 may be used to form articles based on a flat woven fabric 10. For flat woven fabrics 10, after cutting 262, the cut woven fabric is stitched 272, inspected 274, and a packaged 276. Packaging 276 may include folding the formed articles and packing them into packages or containers for shipment. In an alternative embodiments, after the cutting 262, processing steps 266, 268, 276 and 278 are used to form textile articles based on terry fabrics 110. For terry fabrics 110, after cutting 262, the cut terry fabrics are hemmed 266, cross-cut 268, cross-hemmed 278, inspected 276, and packaged 278. A carton package step 278 follows to prepare the packages for transport to customers.

[0051] The process 200 described above utilizes a plied yarn 80 that has been package dyed prior to fabric formation. Next will be described an alternative process used to manufacture the multi-core hygro yarn 180 and various textile structures that include the multi-core hygro yarn 180.

[0052] Figures 7A-11 illustrate an intermediate multi-core yarn 160, multi-core hygro yarn 180, a processes 300 used form textile articles with the hygro yarns 180, and an apparatus 400 used during process 300 to form the hygro yarn 180. The yarn structures during and after removal of the water soluble fibers according to process 300 are illustrated in Figures 7A-8B. Figures 7A and 7B illustrates an intermediate yarn 160 with two yarns with pair of water soluble fiber cores 166aa and 166b. Figures 8A and 8B illustrates the resulting the hygro yarn 180 after the water soluble fibers have been removed resulting in a pair of hollow cores 188a, 188b surround by the outer sheath 184 of staple fibers. As illustrated, the hygro yarn 180 is a single ply two-ply yarn that includes a first hollow core 188a and a second hollow core 188b twisted with the first hollow core 188a about a yarn central axis A to define a multi-core hygro yarn 180.

[0053] As can be seen in Figures 7A-8B, the intermediate yarn 160 is formed to include an outer sheath of fibers 184 and an inner core 166a, 166a of water soluble fibers 168. The outer sheath 184 of fibers may be cotton fibers, similar to the embodiment described above and illustrated In Figures 3A-3B. Accordingly, the outer sheath of fibers 180 may include, in place of cotton, viscose fibers, modal fibers, silk fibers, modal fibers, acrylic fibers, polyethylene terephthalate (PET) fibers, polyamide fibers, are fibers blends. Fiber blends may, for example, include: blends of cotton and bamboo; blends of cotton and sea weed fibers; blends of cotton and silver fibers; blends of cotton and charcoal fibers; blends of PET fibers and cotton; blends of PET and viscose; blends of cotton and modal; blends of cotton; silk and modal; and any combinations thereof. The sheath may be 100% cotton or a combination of any of the foregoing blends.

[0054] The soluble fibers may be water soluble fibers as described above in the yarns 60 and 80 illustrated in Figures 3A-4B. In one example, the soluble fibers are polyvinyl alcohol (PVA) fibers. The present embodiment, however, is not limited to PVA fibers unless the claims recite PVA fibers. The amount of soluble fibers present in the intermediate yarn 160 can vary from about 5% to about 40% of the weight of the yarn 160. The balance of the weight is comprised of the outer sheath of staple fibers. In one example, the soluble fibers may vary from about 10% to about 30 % of the weight of the yarn. In one example, the soluble fibers may vary from about 15% to about 25 % of the weight of the yarn. In one example, the soluble fibers may vary from about 17% to about 23 % of the weight of the yarn. In one example, the soluble fibers may be about 20 % of the weight of the yarn. However, it should be appreciated that the amount of soluble fibers can be any specific amount between 5% to about 40%.

[0055] The intermediate yarns 160 are processed to remove the water soluble fibers after fabric formation, which is similar to the process as described in the 075 patent. In alternative embodiments, however, the intermediate yarns 160 can be died prior to fabric formation to remove the water soluble fiber core 166a, 66b of water soluble fibers and apply color to the fibers in the outer sheath 184. After removal of the first and second water soluble fiber cores 166a and 166b, each yarn has an outer sheath 184 of staple fibers twisted around a first and second hollow core 188a and 188b to define the multi-core yarn 180 as illustrated in Figures 8A and 8B. As discussed above, by dissolving the PVA fibers, hollow air spaces are formed throughout the yarns, corresponding to an increase in the air space in the yarns. By increasing the air space in the yarn, the textile articles formed therefrom are softer and bulkier than textile articles made without the hygro yarns as described herein.

[0056] Turning to Figures 7A and 7B, removal of the water soluble fibers from the intermediate yarn 160 results in a multi-core yarn 180 having a plurality hollow cores 188a, 188b. The multi-core yarn 180 extends along a length L that is aligned with a yarn central axis A. As illustrated the multi-core yarn 180 includes a first hollow core 188a and a second hollow core 188b. The first and second hollow cores 188a and 188b twist about each other along the length L. Furthermore, the first and second hollow cores 188a and 188b twist about the central yarn axis A as they extend along the length L.

[0057] The first and second hollow cores 188a and 188b comprise a predefined portion of the yarn 180. The predefined portion may be described in terms of a percentage of yarn cross-sectional dimension (e.g. distance) and/or percentage of a volume of the yarn 180. For instance, the multi-core yarn 180 defines a yarn cross-sectional dimension D1 that is perpendicular to the yarn central axis A. The first hollow core 188a can define a first core cross-sectional dimension F1. The second hollow core 188b can define a second cross-sectional dimension F2. The yarn cross-sectional dimension D1, the first cross-sectional dimension F1, the second cross-sectional dimension F2 are aligned along the same direction G. As discussed above, the phrase "cross-sectional dimension" is the longest distance across a point of reference in the yarn structure. The cross-sectional dimension may be measured using image analysis techniques, as noted above.

In accordance with the illustrated embodiment, each hollow core defines between about 4 % to about 20 % of the yarn cross-sectional dimension D1. For instance, the combined extent of the first core cross-sectional dimension F1 and the second core cross-sectional dimension F2 is between about 8% to about 40 % of the yarn cross-sectional dimension D1 of the multi-core yarn 180. In other words, F1 plus F2 is between about 8% to about 40 % of the yarn cross-sectional dimension D1 of the multi-core yarn 180. In one example, the first and second hollow cores 188a and 188b together define between about 10% to about 30 % of the cross-sectional dimension D1. In another example, the first and second hollow cores 188a and 188b together define between about 15% to about 25 % of the yarn cross-sectional dimension D1. The percentages described above correspond to the approximate weight percentage of water soluble fibers in the intermediate yarn 160 before their removal from the yarn.

[0058] Similarly, the first and second hollow cores 188a, 188b comprise a defined volume percentage of the multi-core yarn 180. As described above, the volume percentage is determined assuming that the multi-core yarn 180 is cylindrical. The yarn volume V1 is equal to $[\pi(D1/2)^2]*h$, where D1 is the yarn cross-sectional dimension D1 defined above and h is a given length L of the yarn 180. The first hollow core volume V2 is equal to $[\pi(F1/2)]*h$, where F1 is the cross-sectional dimension F1 of the first hollow core 188a. The second hollow core volume V3 is equal to $[\pi(F2/2)^2]*h$, where F2 is the cross-sectional dimension F2 of the second hollow core 188a. The volume percentage of the hollow core is equal to $[(V2+V3)/V1]*100$. In accordance with the illustrated embodiment, the first and second hollow cores 188a and188b comprises between about 8% to about 40% of the volume of the multi-core yarn 180. In one example, the first and second hollow cores 188a and188b define between about 10% to about 30% of the volume of the multi-core yarn 180. In another example, the first and second hollow cores 188a and188b defines between about 15% to about 25% of the volume of the multi-core yarn 180. The volume percentage of the first and second hollow cores 188a, 188b also correspond to the approximate weight percentage of water soluble fibers in the intermediate yarn 160 before remove of the water soluble fibers.

[0059] The multi-core yarn 180 can be twisted to have ether a z-twist or a s-twist. Furthermore, the multi-core yarn 180 can be plied into a plied yarn structure. Each yarn in the multi-core yarn in such a plied structure can have a twist direction that is opposite to the twist direction of the multi-core yarn. For instance, if the plied multi-core yarn has a Z-twist, each multi-core yarn 180 end will have an s-twist and vice versa.

[0060] Forming the multi-core yarn 180 illustrated in Figures 8A-8B into textile articles will be described next. Figures 9 and 10 illustrate a method 300 for manufacturing hygro textile articles with the multi-core yarns 180 according to an embodiment of the present disclosure. Figure 11 illustrates an apparatus 400 used during spinning to help form the multi-core yarn 180. The method 300 described below refers to use of cotton fiber in the outer sheath and of PVA fibers used to form the inner fiber cores 166a and 166b. However, it should be appreciated that other fibers can be used in the outer sheath and the inner cores, as described above.

[0061] The method 300 illustrated includes two preliminary phases: outer sheath sliver formation 302 and soluble fiber sliver formation 304. Outer sheath sliver formation 302 creates slivers used to form the outer sheath of fibers 184 in the intermediate yarn 160 while soluble fiber sliver formation 304 creates slivers used to form the inner cores 166a and 166b of soluble fibers in the intermediate yarn 160.

[0062] Outer sheath fiber formation phase 302 forms slivers of staple fibers for roving. Outer fiber sliver formation initiates with fiber receiving 306 and storage 308. The outer sheath fiber formation phase 302 is similar to the outer sheath formation phase 202 illustrated in Figure 5. For instance, the outer sheath fibers (or cotton fibers) are subject to an opening step 310 in a blow room. In the blow room, the cotton fibers are processed with a bale plucker, opener, multi-mixer, beater and a dustex machine. After opening 310, the fibers are carded 312 on card machines to deliver card slivers. The sliver from carding is then processed through a breaker drawing step 314 to draw out the slivers. In case of blended slivers, each component is separately processed through carding and the individual carded slivers are subsequently blended together on draw frames. After breaker drawing 314, the slivers can be fed to the speeding frame 332 or inter a lapping step 316 and combing step 318.

[0063] For combed yarns, the draw frame slivers are processed via lapping 216. In lapping, a unilap machine convers doublings into a lap of fibers. The lap is processed in a combing step 318 using a comber. The combed cotton sliver is then passed through another drawing step 320 using a finisher draw frame. The output of the finisher draw frame is fed into the speed frame to make roving for later yarn spinning.

[0064] Soluble fiber sliver formation will be described next. Soluble fiber sliver formation phase 304 is substantially similar the soluble fiber formation phase 204 described above and illustrated in Figure 5. Accordingly, similar soluble fiber configurations, e.g. cut length, denier, etc., as described with respect to the sliver formation phase 204 shown in Figure 5 are used during the soluble fiber formation phase 304. The soluble fiber formation phase 304 includes a receiving step 322, and a storage step 324. Next, the soluble fibers are subject to an opening step 226 in a blow room in a "cotton" type spinning system. After opening 326, the PVA fibers are conveyed from the blow room to carding 328 to form card slivers, which are coiled into sliver cans. The carded slivers are then further drawn via drawing step 330 to yield the PVA sliver. During the drawing step 330, the carded slivers are passed through one or more draw frames to further orient the fibers. For instance, during drawing 330, the PVA slivers are initially processed with a breaker draw frame and a second pass of drawing uses a finisher draw frame. The output of the drawing 330 are cans of PVA slivers that fed into the roving step 332.

[0065] After outer fiber sliver formation 302 and soluble fiber sliver formation 304, the staple fibers (or outer fibers) and soluble fiber slivers are combined during roving 332. Roving 332 is substantially similar to the roving 232 illustrated in Figure 5 and described above. For example, during roving 332, the soluble fiber sliver is inserted into a middle or central portion of the cotton sliver at a speed frame to yield a single roving 140 (Fig. 11) with a water soluble fiber core. As described above, the speed frame used in the roving step 332 includes an inlet condenser, a middle condenser, a main feed condenser, multiple sets of drafting rollers, and a flyer. The cotton sliver follows a normal path from the back to the front of the speed frame through at least the main feed condenser. The inlet and middle condensers are incorporated for feeding PVA slivers at the inlet, the back and middle drafting zones on the speed frame, to ensure that the PVA sliver stays in the middle of the cotton sliver. The PVA sliver, however, passes through the inlet condenser before occupying the middle portion on the cotton sliver in the main feed condenser, similar to roving step 232 described above. Alternative mechanisms for feeding PVA fiber roving into the path of the cotton roving in the drafting zone of a speed frame can be used as well. In one embodiment, the PVA fibers can be added via core-spinning machine. In another variation, the PVA roving is introduced in the path of cotton roving on the roving machine. Alternatively, the PVA can be added to the middle of the cotton roving by reversing the rotation of flyer in the counter-clock-wise direction, which is opposite the direction of the normal flyer rotation. In both situations, the PVA fibers are placed in the middle of the cotton sliver during the roving process to yield a roving with a core of PVA fibers.

[0066] Continuing with Figures 9 and 11, a multi-core spinning step 334 converts two rovings 140 and 142 into an intermediate multi-core yarn 160 using an apparatus 400 of a spinning frame. Turning to Figure 11, the apparatus 400 includes a roving guide 404, rear rollers 408, and pre-drafting zone condensers that exit side of the rear rollers 408. The apparatus includes a middle roller and apron assembly 416, main drafting zone condense 420, and front rollers 424, and a yarn guide 430. In operation, the roving ends 140 and 142 are fed separately through the drafting zones and converge at the yarn guide 430. Between rollers 428 and yarn guide 430, the ends 140 and 142 are twisted about each other into a single end yarn structure, or intermediate yarn 160. The intermediate yarns 160 exit the rollers 428 and are wound into suitable bobbins. In step 334, subsequent spinning following exit from the apparatus 400 is accomplished using typical settings for forming ring spun yarns. The spinning parameters, however, on the ring frame are set based on the type of fibers in the outer sheath and type and content of the PVA fibers in the inner cores 166a and 166b. Because the input of the apparatus 400 are two ends 140 and 142 each having a water soluble fiber core, the intermediate yarn 160 exiting will be wound onto the bobbins as a single yarn 160 having first water soluble fiber core 166a and a second water soluble fibers core 166b, as illustrated in Figure 7A and 7B.

[0067] The spinning step 334 can produce single end yarns 160 with a count that ranges from about 8 Ne to about 120 Ne. Yarns used for a flat woven fabric 10 (Figures 1A & 1B) may have a count that ranges from 20 Ne to about 120 Ne. Yarns used for terry fabrics 110 (Figure 2) may have a count that ranges from about 8 Ne to about 50 Ne. After yarn spinning 334, the intermediate multi-core yarn 160 can be further packaged 340 into a suitable yarn packages. Alternative, the intermediate multi-core yarn 160 can be plied into a plied yarn configuration as needed.

[0068] Turning to Figure 10, the next phase in the production of hygro textile articles is fabric formation, soluble fiber removal and dyeing, followed by article formation. The multi-core yarn packages formed during packaging 340 are received 342 and stored 344 for warping 348. The warping step 348 includes typical warping operations for flat woven fabrics 10. In alternative embodiment for terry production, the warping operations includes steps typical for terry fabrics 110: ground yarn warping and pile yarn warping. After warping 348, a sizing step 349 can be used to applying sizing composition to the warp ends.

[0069] A weaving step 350 follows sizing 349 and warping 348. The weaving step 350converts the yarns into woven fabrics. The weaving step 350 converts the yarns into woven fabrics. One or more looms, e.g. air-jet looms, rapier looms, water-jet looms (or others) can be use during the weaving step. Each loom may utilize typical shedding mechanism, such as a dobby or jacquard type shedding mechanism. During the weaving step for the woven fabric 10 (Figure 1A, 1B), the warp and weft yarns can be arranged into a number of different weaving constructions and designs as is known by persons of skill in the art and that detailed above. For instance, the flat woven fabrics may include a plain weave, twills, rib weaves, basket weaves, percale, satins, sateens, other woven designs. In accordance with an embodiment of the present disclosure, the weaving step forms a woven fabric to have a) a warp end density between about 50 warp ends per inch and about 350 warp ends per inch; and b) a weft end density between about 50 weft yarns per inch and about 700 weft yarns per inch (or more). In one example, the weft yarn density is between about 100 and about 700 weft yarns per inch. Furthermore, the flat woven fabrics may have thread counts ranging from 100 TC to about 1000C. The weaving step may include co-insertion or insertion of multiple picks during a single pick insertion event. In one example, the weaving step includes inserting between one (1) weft yarn and seven (7) weft yarns during a single insertion event along the weft insertion path 19 (Fig. 1A). Furthermore, for woven fabrics 10, the weft yarns, warp yarns, or both the warp and weft yarns can include the multi-core hygro yarns 180. The flat woven fabrics are formed to have constructions that are suitable for bedding applications in both consumer, hospitality and /or healthcare markets.

[0070] In alternative embodiments, during the weaving step for terry fabrics 110, the ground, weft, and pile yarns are woven together using a loom configured for terry production. The terry fabric 110 can be 3-pick, 4-pick, 5-pick, 6-pick, or 7-pick terry. In the one example, the terry fabric 110 is a 3-pick terry. The pile component 150a, 150b can define a pile height H that extends from the ground component 130 to a top of a pile 154, 154b along the thickness direction 8. The pile height can range from about 2.0 to 10 mm.

[0071] The weaving step 350 results in "greige fabrics" that are further processed into textile articles. After the weaving step 350, the griege fabrics are inspected 352. Following inspection 352, the fabrics can either undergo a batch dyeing and soluble fiber dissolving step 346a or a continuous dyeing and fiber dissolving step 356a.

[0072] The batch dyeing and soluble fiber dissolving step 346a includes scouring, bleaching, and dyeing dyed in a typical fashion in a fabric dyeing machine. The operating temperature is maintained in a range from about 95 degrees Celsius to about 120 degrees Celsius. In one example, the temperature is about 120 degrees Celsius, which can help ensure that all the PVA fibers are dissolved in the water. The batch dyeing step 346a utilizes a liquor ratio sufficient to facilitate prompt dissolution of the PVA fibers, while allowing free movement of the fabric in the dyeing machine. The liquor ratio may range from about 1:5 to about 1:30. For example, the liquor ratio may be 1:10, 1:12, 1:15, 1:20, 1:25, 1:22, or 1:28.

[0073] During step 346a, the fabrics are typically wound into the shape of a rope prior to entering the fabric-dyeing machine. The rotation of the fabric in rope form aids in promoting rapid dissolution of the PVA fibers. The dissolution step 346a also includes washing and rinsing the fabric. After washing, the liquor is drained and fresh water is injected into the machine for rinsing the fabric and to remove all the dissolved PVA from the fabric and machine. During the washing and rinse phase, the water is at a temperature ranging from about 55 degrees Celsius to about 100 degrees Celsius Preferably, the water is at a high temperature, such as 100 degrees Celsius. The fabric can be rinsed in hot water after draining to wash away any PVA residue. After unloading the woven fabrics from the vessel, the water is extracted material in an extractor in the typical manner to reduce the moisture content. Next, an opening step 256 untwists the fabric using a rope opener, similar to the rope opener as described in the 075 patent. Following the rope opening step, a drying step 358 dries the fabric further.

[0074] As described above, after the inspection step 352, the griege fabric can processed using continuous dyeing range in a continuous dyeing step 346b using similar process temperatures as used in the batch step 346a. After the continuous dyeing step 346b, the woven fabric is dried 358. The drying step 358 utilizes a hot air dryer to further dry the fabrics at the desired temperature. The dried fabric is expanded to full width and then passed through a stentering step 360. The stentering step 360 can help straighten the fabric.

[0075] In certain alternative embodiments for processing terry fabrics, a shearing step is used, whereby both sides of the terry fabric are passed through a shearing machine. The shearing machine has cutting devices, such as blades and/or a laser, which are set such that only protruding fibers are cut and the piles are not cut. The shearing step reduced linting during subsequent washing in use by the consumer.

[0076] The result of process 300 is a textile article formed from a woven fabric, such as a flat woven fabric 10 or terry fabric 110, which include multi-core hygro yarns 180, as illustrated in Figures 8A and 8B.

[0077] Following the stentering step 360 (or optional shearing step), a cutting step 362 cuts the woven fabrics to the desired length and width depending on the particular end use. Steps 372, 374 and 376 may be used to form textile articles based on a flat woven fabric 10. For flat woven fabrics 10, after cutting 362, the cut woven fabric is stitched 372, inspected 376, and a packaged 376. Packaging step 376 may include folding and packing the textile articles into packages or containers for shipment. Alternatively, after the cutting step 362, processing steps 366, 368, 376 and 378 may be used to form textile articles with terry fabrics 110. For terry fabrics 110, after the cutting step 362, the cut terry fabrics length hemmed 366, cross-cut 368, cross-hemmed 378, inspected 376, and the packaged 376. A carton package step 378 follows to prepare the packages for transport to customers.

[0078] The flat woven fabric 10 formed as described includes either plied hygro yarn 80 and the multi-core hygro yarn 180 has better comfort profiles comparted to typical flat woven fabrics. The comfort profile may be related to the flat woven fabrics ability to absorb moisture in combination with the desirable heat and moisture transfer properties. The comfort profile as described herein related to the ability of the flat woven fabric to keep a user cool in warmer environmental conditions and warm in cooler environmental conditions. While not being bound to any particular theory, it is believed that flat woven fabrics as described herein that include either plied hygro yarn 80 or multi-core hygro yarn 180 are more comfortable to the user compared to sheeting products made with typical yarn constructions.

[0079] The comfort profile in this context relates to heat transfer and moisture properties of the flat woven fabrics. The heat and moisture transfer properties can be determined in accordance with ASTM F 1868, *Standard Test Method for Thermal and Evaporative Resistance of Clothing Materials Using a Sweating Hot Plate,* Part C, the entirety of which is expressly incorporated herein by reference in its entirety. This test is referred to herein as the *"Thermal and Evaporative Resistance"* test). Two exemplary flat woven fabrics were constructed and included the attributes illustrated in Table 1.

Table 1 Example Flat Woven Fabrics for Thermal and Evaporative Resistance Test

Example	A	B
Fiber Content	100% Cotton	100% Hygro Cotton
Thread Count	400	400
Warp Ne	80	80
Weft Ne	80	80
EPI	196	196
PPI	201	201
Weave Design	Satin	Satin
Weight(oz/yd2)	3.61	3.997
Thickness (mm)	0.23	0.23

[0080] The "Thermal and Evaporative Resistance" test is a measure of heat flow from the calibrated test plate (heated to a skin surface temperature of 35 degrees Celsius) through the flat woven fabric into the test environment (25 degrees Celsius, 65%RH). Heat flow is determined for both simulated dry and wet skin conditions. Heat loss parameters can be calculated from the following thermal transport measurements.

[0081] The total thermal resistance (Rct), [(Δ°C)(m^2)/W], is the total resistance to dry heat transfer (insulation) for a fabric including the surface air layer. Total thermal resistance (Rct) is given by the following equation:

$$Rct = [(TS\text{-}\ Ta)\cdot A]/[H],$$

where Ts is the temperature of the plate surface (35°C), Ta is the temperature in the local environment (25°C), A is the area of the test plate (0.01 m^2), and W is the power input (W).

[0082] The intrinsic thermal resistance (Rcf), [(Δ°C)(m^2)/W], is the resistance to dry heat transfer provided by the fabric alone. Intrinsic thermal resistance (Rcf), is determined by subtracting the average dry bare plate resistance (Rcbp) from the average of the total thermal resistance (Rct) of the specimens.

[0083] The bare plate thermal resistance (Rcbp), [(Δ°C)(m^2)/W], is the resistance to dry heat provided by the surface air layer as measured on the bare plate. Bare plate thermal resistance values are shown in table 3 below.

[0084] The apparent total evaporative resistance(RetA), [(ΔkPa)(m^2)/W], is the total resistance to evaporative heat transfer for a fabric including the surface air layer and liquid barrier (the descriptor term 'apparent' is added to account for the fact that heat transfer may have an added condensation component in nonisothermal conditions). Apparent total evaporative resistance (RetA) is given by the following equation:

$$RetA = [(Ps\text{-}\ Pa)\cdot A/H - (Ts\text{-}\ Ta)\cdot A]/Rct,$$

where Ps is the water vapor pressure at the surface plate (kPa), Pa is the water vapor pressure in the local environment (kPa), A is the area of the test plate (0.01 m^2), H is power input (W), Ts is temperature at the plate surface (35°C), Ta is temperature at the local environment (25°C), and Rct is the total thermal resistance as defined above.

[0085] The apparent intrinsic evaporative resistance (RefA), [([(ΔkPa)(m^2)/W], is the resistance to evaporative heat transfer provided by the fabric alone. The apparent intrinsic evaporative resistance (RefA), is determined by the apparent total evaporative resistance (RetA) minus the average bare plate evaporative resistance (Rebp).

[0086] The bare plate thermal resistance (Rebp), [(ΔkPa)(m^2)/W], is the resistance to evaporative heat transfer provided by the liquid barrier and surface air layer as measured on the bare plate (with liquid barrier attached).

[0087] Total heat loss (Qt), [W/m^2],is an indicator of the heat transferred through the fabric material by the combined dry and evaporative heat loss, from a fully sweating test plate surface into the test environment. Total heat loss, measured at a 100% wet skin condition, indicates the highest predicted metabolic activity level that a user may sustain and still maintain body thermal comfort while in a highly stressed state in a test environment. Total heat loss (Qt) is calculated using the following equation:

$$Q_t = \frac{10°C}{R_{cf} + .04} + \frac{3.57\ kPa}{R_{et}^{A} + .0035}$$

[0088] The total insulation value (It),[clo], is the thermal resistance measured in units of clo, which indicates the insulating ability of the fabric material. Materials with higher clo values provide more thermal insulation. The clo value includes the insulation provided by the air layer above the fabric and does not subtract it out as with Rcf discussed above. It (clo) values are derived using dry plate test results, from the formula It = Rct*6.45.

[0089] The im value, or permeability index, indicates moisture-heat permeability through the fabric on a scale of 0 (totally impermeable) to 1 (totally permeable) normalized for the permeability of still air (naked skin). This comfort parameter indicates the effect of skin moisture on heat loss as in the case of a sweating skin condition. This value includes the evaporative resistance provided by the air layer above the sample and does not subtract it out as with RefA discussed above. The Im value (permeability index) is calculated, using both dry and sweating plate test results,from the formula Im = 0.060 * (Rct/RetA).

[0090] The average values for Rct, RetA, Rcf, RefA, It, im, and Qt of the Examples A and B are shown in Table 2 below. The average bare plate values are shown in Table 3. Weights and thicknesses for each sample are given in Table 1 above.

Table 2 Sweating Hot Plate Data

Example	Rct	RetA	Rcf	RefA	It	Im	Qt
A	0.080	0.00849	0.012	0.00327	0.518	0.568	720.12
B	0.080	0.00737	0.012	0.00214	0.518	0.655	825.06

Table 3 Bare Plate Test Data

	Rcbp	Rebp
Average	0.068	0.005220

Heat transfer makes it possible to predict the body heat that will flow from the skin surface through the flat woven fabric into the surrounding atmosphere. As illustrated in table 2 above, example B, which included the hygro yarn configuration, had greater heat loss in humid and sweat conditions and increased ability to transport moistures, e.g. sweat. Table 3 indicates that Evaporative Resistance(RetA) for example A is greater than the Evaporative Resistance(RetA) for example A, indicating that example B allows moisture transfer more quickly to the atmosphere. The total heat loss (Qt) for example B is higher than the total heat loss for example A, indicating example B can transfer heat more quickly to the atmosphere, which indicates the example B fabrics would keep a user more cool.

[0091] The comfort profile also relates thermal insulation properties of flat woven fabrics used to form sheeting products. The thermal insulation properties can be determined in terms of thermal resistance and can be measured accordance with ASTM F 1291 *Standard Method for Measuring the Thermal Insulation of Clothing Using a Heated Manikin,* the entirety of the which is incorporated by reference into the present disclosure. Exemplary flat woven fabrics were constructed and included the attributes illustrated in Table 4.

Table 4 Examples for Thermal and Evaporative Resistance Test

Example	C	D	E
Fiber Content	100 % Cotton	100% Hygro Cotton	100% Hygro Cotton
Thread Count	400	400	400
Warp Ne	80	80	80
Weft Ne	80	70	60
EPI	196	196	196
PPI	201	201	201
Weave Design	Satin	Satin	Satin

Tests for thermal resistance should occur in non-isothermal conditions, such as those shown in Table 5. Prior to testing the manikin was stabilized in the 20°C environment within the chamber. After the bed was made, the test session was started and the manikin was placed on the mattress/fitted sheet and was covered with the accompanying top-sheet. After which the manikin was left to stabilize for 20 minutes. After the 20 minute mark the conditions of the chamber would be changed from 20°C to 25°C. Once 25°C was reached the manikin was allowed to stabilize at which point the test session was stopped. One repetition was completed for each sheet set, as specified by the above referenced test standard.

Table 5 Testing Conditions

	Thermal Resistance
Air Temperature (°C)	20-25
RH (%) ~60	
Air Speed (m/s)	0.2-0.4
Skin Temperature (°C)	35

Thermal resistance measurements were taken from all sections (Whole Body) as well as the front of manikin (the area completely covered by the test sheets and not in contact with a mattress). Thermal resistance values were converted to units of clo. The measurement of heat transfer is a measure of heat flow from the manikin surface (heated to a skin surface temperature of 35°C) through an ensemble into the test environment and is determined for both simulated dry and wet skin conditions. Heat loss parameters in this context, calculated from thermal transport measurements, include;a) the total thermal resistance (Rct) provided by the manikin, fabric ensemble, and air layers; b) the total evaporative resistance *(Ret),* [kPa·m2/W], which is the total evaporative resistance provided by the manikin, fabric ensemble, and air layers; c) the intrinsic thermal resistance *(Rcl),* [°C·m2/W], total thermal resistance provided by the garment ensemble only; d) the intrinsic evaporative resistance, [kPa·m2/W] is the intrinsic evaporative resistance provided by the fabric ensemble only; e) the total insulation value (It), [clo]; f) the Im value, or permeability index; and g) the predicted heat loss potential (Qt), [W/m2], is a predicted level of the total amount of heat that could be transferred from the manikin to the ambient environment for a specified condition. It uses the thermal and evaporative resistance values to calculate predicted levels of evaporative and dry heat transfer components for a specific environmental condition. In this case the specified environment is 25°C, 65% RH. Table 6 provides predicted heat loss values for the "Front Body" test for examples C, D and E. Table 7 provides predicted heat loss values for the "Whole Body" test for examples C, D and E.

Table 6 Predicted Heat Loss Data for Front Body Manikin

Degrees(°C)	Example C	Example D	Example E
20	49.1	47.7	48.4
20.5	47.3	45.7	47.2
21	46.8	44.4	46.4
21.5	46.7	43.6	46.1
22	46.7	43	45.8
22.5	47	42.3	45.8
23	47	42.3	45.6
23.5	46.8	42.4	45.3
24	46.6	42.1	45
24.5	47.4	42.8	45.3
25	47	43.2	45.7

Table 7 Text Data for Whole Body Manikin

Degrees(°C)	Example C	Example D	Example E
20	48.4	47.5	46.6

(continued)

Degrees(°C)	Example C	Example D	Example E
20.5	46.6	45.4	45.4
21	46.1	44.1	44.7
21.5	46	43.3	44.4
22	46.1	42.9	44.1
22.5	46.3	42.4	44
23	46.3	42.4	43
23.5	46.4	42.4	43.6
24	46.3	42.2	43.6
24.5	47	42.6	43.3
25	46.7	42.7	44.1

[0092] Data listed in tables 6 and 7 are also illustrated graphically in Figures 12A and 12B. The "front" and "whole body" data indicate that examples D and E, which include hygro materials, have lower heat loss values compared to a typical flat woven fabrics that do not include any hygro materials. The data indicates that sheeting products made from examples D and E will tend to keep a user more cool compared to sheeting products made from example C.

[0093] The present application includes the following embodiments, each of which are consistent with the inventive concepts as disclosed herein.

1. A woven fabric, comprising:

   a warp component including warp yarns; and
   a weft component including weft yarns interwoven with the warp yarns to define the woven fabric, wherein at least one of a) the warp component, and b) the weft component include a plurality of plied staple yarns,
   each plied staple yarn having a length and a plurality of separate package dyed staple yarns twisted together, each package dyed staple yarn including an outer sheath of staple fibers twisted together, and a hollow core within the outer sheath of staple fibers, wherein the hollow core extends along the length of the plied staple yarn.

2. The woven fabric of embodiment 1, wherein the plurality of plied staple yarns has a first tensile strength adapted for formation into the woven fabric, and each package dyed staple yarn has a second tensile strength that is less than the first tensile strength.
3. The woven fabric of embodiment 1 or embodiment 2, wherein the at least one plied yarn is a two-ply yarn, and the plurality of separate package dyed staple yarns include a first package dyed staple yarn and a second package dyed staple yarn twisted with the first package dyed staple yarn to define the two-ply yarn.
4. The woven fabric of embodiment 3, wherein the two-ply yarn has one of a z-twist or a s-twist and each package dyed staple yarn has the other of the z-twist or the s-twist.
5. The woven fabric of embodiment 1 or embodiment 2, wherein each plied yarn is a three-ply yarn, and the plurality of separate package dyed staple yarns is a first package dyed staple yarn, a second package dyed staple yarn, and a third package dyed staple yarn.
6. The woven fabric of any of embodiments 1 to 5, wherein each package dyed staple yarn defines a yarn cross-sectional dimension and the hollow core defines a core cross-sectional dimension that is aligned with the yarn cross-sectional dimension along a direction, wherein the core cross-sectional dimension is between about 5% to about 40% of the yarn cross-sectional dimension.
7. The woven fabric of embodiment 6, wherein the core cross-sectional dimension is between about 15% to about 25% of the yarn cross-sectional dimension.
8. The woven fabric of any of embodiments 1 to 7, wherein the staple fibers are a) cotton fibers, or b) blends of cotton fibers with one or more other fibers.
9. The woven fabric of any of embodiments 1 to 8, wherein the warp and weft yarns are arranged to define a thread count between about 100 and about 1000.
10. The woven fabric of any of embodiments 1 to 9, wherein the weft yarns are co-inserted along weft insertion path through the warp yarns.

11. The woven fabric of any of embodiments 1 to 10, wherein the warp end density is between about 50 warp ends per inch and about 350 warp ends per inch.
12. The woven fabric of any of embodiments 1 to 11, wherein the weft yarn density is between about 100 and about 700 weft yarns per inch.
13. The woven fabric of any of embodiments 1 to 12, wherein each package dyed staple yarn has a count between about 20 Ne and about 120 Ne.
14. The woven fabric of any of embodiments 1 to 12, wherein the weft component includes the plurality of plied staple yarns, and wherein each package dyed staple yarn has a count between about 20 Ne and about 120 Ne.
15. The woven fabric of any of embodiments 1 to 12, wherein the warp component includes the plurality of staple yarns, and wherein each staple yarn has a count between about 20 Ne and about 120 Ne.
16. The woven fabric of any of embodiments 1 to 10, wherein the weft component includes the plurality of plied staple yarns, wherein each package dyed staple yarn has a count between about 20 Ne and about 120 Ne, wherein the warp end density is between about 50 warp ends per inch and about 350 warp ends per inch, and wherein the weft yarn density is between about 100 and about 700 weft yarns per inch.
17. A bedding article that includes the woven fabric of any of embodiments 1 to 16, wherein the bedding article is one or more of: a flat sheet, a fitted sheet, a pillow case, a comforter, and a pillow sham.
18. A process for manufacturing a flat woven fabric, comprising:

spinning a first staple yarn to include a first outer sheath of staple fibers twisted around a first inner core of water soluble fibers;
spinning a second staple yarn to include a second outer sheath of staple fibers twisted around a second inner core of water soluble fibers;
plying the first staple yarn and the second staple into a plied staple yarn; and
winding the plied staple yarn into a yarn package;
with the plied staple yarn on the yarn package, removing the first and second inner core of the water soluble fibers from each one of the first and second staple yarns in the plied staple yarn to form first and second hollow cores in the first and second staple yarns, respectively; and
after the removing step, weaving a plurality of the plied staple yarns into a flat woven fabric.

19. The process of embodiment 18, wherein the weaving step is weaving a flat woven fabric having warp yarns and weft yarns, wherein at least one of the warp yarns and the weft yarns include the plied staple yarns.
20. The process of embodiment 19, wherein the weft yarns include the plied staple yarns.
21. The process of embodiment 19, wherein the weaving step includes inserting one or more weft yarns into warp yarns during a single weft insertion event.
22. A woven fabric, comprising:

a warp component including warp yarns; and
a weft component including weft yarns interwoven with the warp yarns to define the woven fabric, and at least one of a) the warp component and b) the weft component includes a plurality of multi-core staple yarns,
each multi-core staple yarn including a length, an outer sheath of twisted staple fibers that extends along the length, a first hollow core that extends through the outer sheath of staple fibers along the length, and a second hollow core that extends through the outer sheath of staple fibers along the length.

23. The woven fabric of embodiment 22, wherein the first hollow core and the second hollow core are twisted around and with respect to each other as each extends along the length.
24. The woven fabric of embodiment 23, wherein the outer sheath of staple fibers and the first and second hollow cores have the same twist direction.
25. The woven fabric of embodiment 22, wherein each multi-core yarn defines a yarn cross-sectional dimension that is perpendicular to the length, wherein the first and second hollow cores each define a core cross-sectional dimension that is aligned with the yarn cross-sectional dimension, wherein the combined core-cross sectional dimension comprise between about 5% to about 40 % of the yarn cross-sectional dimension.
26. The woven fabric of embodiment 25, wherein the combined core-cross sectional dimensions comprise between about 15% to about 25 % of the yarn cross-sectional dimension.
27. The woven fabric of any of embodiments 22 to 26, wherein the staple fibers are a) cotton fibers, or b) blends of cotton fibers with one or more other fibers.
28. The woven fabric of any of embodiments 22 to 27, wherein the warp and weft yarns are arranged to define a thread count between about 100 and about 1000.
29. The woven fabric of any embodiments 22 to 28, wherein the weft yarns are co-inserted along weft insertion path

through the warp yarns.

30. The woven fabric of any of embodiments 22 to 29, wherein the warp end density is between about 50 warp ends per inch and about 350 warp ends per inch.

31. The woven fabric of any of embodiments 22 to 30, wherein the weft yarn density is between about 100 and about 700 weft yarns per inch.

32. The woven fabric of any of embodiments 22 to 31, wherein each multi-core staple yarn has a count between about 20 Ne and about 120 Ne.

33. The woven fabric of any of embodiments 22 to 31, wherein the weft component includes the plurality of the multi-core staple yarns, wherein each multi-core staple yarn has a count between about 20 Ne and about 120 Ne.

34. The woven fabric of embodiment 33, wherein the warp component includes the plurality of staple yarns, wherein each staple yarn has a count between about 20 Ne and about 120 Ne.

35. The woven fabric of any of embodiments 22 to 29, wherein the weft component includes the plurality of multi-core staple yarns, wherein each multi-core staple yarn has a count between about 20 Ne and about 120 Ne, wherein the warp end density is between about 50 warp ends per inch and about 350 warp ends per inch, and wherein the weft yarn density is between about 100 and about 700 weft yarns per inch.

36. A bedding article that includes the woven fabric of any of embodiments 22 to 35, wherein the bedding article is one or more of: a flat sheet, a fitted sheet, a pillow case, a comforter, and a pillow sham.

37. A process for manufacturing a woven fabric, comprising:

spinning staple yarns to include an outer sheath of staple fibers twisted around a first core of water soluble fibers and a second core of water soluble fibers;

removing the first and second cores of water soluble fibers from each one of the staple yarns to from a multi-core staple yarn; and

weaving the multi-core staple yarns into a flat woven fabric.

38. The process of embodiment 37, wherein the weaving step includes weaving warp yarns and weft yarns with each other to define the flat woven fabrics, wherein at least one of a) the warp yarns, and b) the weft yarns include the multi-core staple yarns.

39. The process of embodiment 38, wherein the weft yarns include the multi-core staple yarns.

40. The process of any of embodiments 37 to 39, wherein the weaving step occurs after the removing step.

41. The process of any of embodiments 37 to 39, wherein the weaving step occurs before the removing step.

42. The process of any of embodiments 37 to 41, wherein the removing step includes dyeing the multi-core staple yarns.

43. The process of any of embodiments 37 to 42, wherein the weaving step includes inserting one or more weft yarns into warp yarns during a single weft insertion event.

[0094] While the disclosure is described herein using a limited number of embodiments, these specific embodiments are not intended to limit the scope of the disclosure as otherwise described and claimed herein. The precise arrangement of various elements and order of the steps of articles and methods described herein are not to be considered limiting. For instance, although the steps of the methods are described with reference to sequential series of reference signs and progression of the blocks in the figures, the method can be implemented in a particular order as desired.

Claims

1. A woven fabric, comprising:

a warp component including warp yarns; and

a weft component including weft yarns interwoven with the warp yarns to define the woven fabric, wherein at least one of a) the warp component, and b) the weft component includes a plurality of plied staple yarns, each plied staple yarn having a length and a plurality of separate package dyed staple yarns twisted together, each package dyed staple yarn including an outer sheath of staple fibers twisted together, and a hollow core within the outer sheath of staple fibers, wherein the hollow core extends along the length of the plied staple yarn.

2. The woven fabric of claim 1, wherein the plurality of plied staple yarns has a first tensile strength adapted for formation into the woven fabric, and each package dyed staple yarn has a second tensile strength that is less than the first tensile strength.

3. The woven fabric of claim 1 or claim 2, wherein the at least one plied yarn is a two-ply yarn, and the plurality of separate package dyed staple yarns include a first package dyed staple yarn and a second package dyed staple yarn twisted with the first package dyed staple yarn to define the two-ply yarn.

4. The woven fabric of any of claims 1 to 3, wherein each package dyed staple yarn defines a yarn cross-sectional dimension and the hollow core defines a core cross-sectional dimension that is aligned with the yarn cross-sectional dimension along a direction, wherein the core cross-sectional dimension is between about 5% to about 40% of the yarn cross-sectional dimension.

5. The woven fabric of any of claims 1 to 4, wherein the staple fibers are a) cotton fibers, or b) blends of cotton fibers with one or more other fibers.

6. The woven fabric of any of claims 1 to 5, wherein the warp and weft yarns are arranged to define a thread count between about 100 and about 1000.

7. The woven fabric of any of claims 1 to 6, wherein the warp end density is between about 50 warp ends per inch and about 350 warp ends per inch.

8. The woven fabric of any of claims 1 to 7, wherein the weft yarn density is between about 100 and about 700 weft yarns per inch.

9. The woven fabric of any of claims 1 to 8, wherein each package dyed staple yarn has a count between about 20 Ne and about 120 Ne.

10. The woven fabric of any of claims 1 to 9, wherein the weft component includes the plurality of plied staple yarns, and wherein each package dyed staple yarn has a count between about 20 Ne and about 120 Ne.

11. The woven fabric of any of claims 1 to 10, wherein the warp component includes the plurality of staple yarns, and wherein each staple yarn has a count between about 20 Ne and about 120 Ne.

12. A process for manufacturing a flat woven fabric, comprising:

spinning a first staple yarn to include a first outer sheath of staple fibers twisted around a first inner core of water soluble fibers;
spinning a second staple yarn to include a second outer sheath of staple fibers twisted around a second inner core of water soluble fibers;
plying the first staple yarn and the second staple into a plied staple yarn; and
winding the plied staple yarn into a yarn package;
with the plied staple yarn on the yarn package, removing the first and second inner core of the water soluble fibers from each one of the first and second staple yarns in the plied staple yarn to form first and second hollow cores in the first and second staple yarns, respectively; and
after the removing step, weaving a plurality of the plied staple yarns into a flat woven fabric.

13. The process of claim 12, wherein the weaving step is weaving a flat woven fabric having warp yarns and weft yarns, wherein at least one of the warp yarns and the weft yarns include the plied staple yarns.

14. The process of claim 12 or 13, wherein the weft yarns include the plied staple yarns.

15. The process of any of claims 12 to 14, wherein the weaving step includes inserting one or more weft yarns into warp yarns during a single weft insertion event.

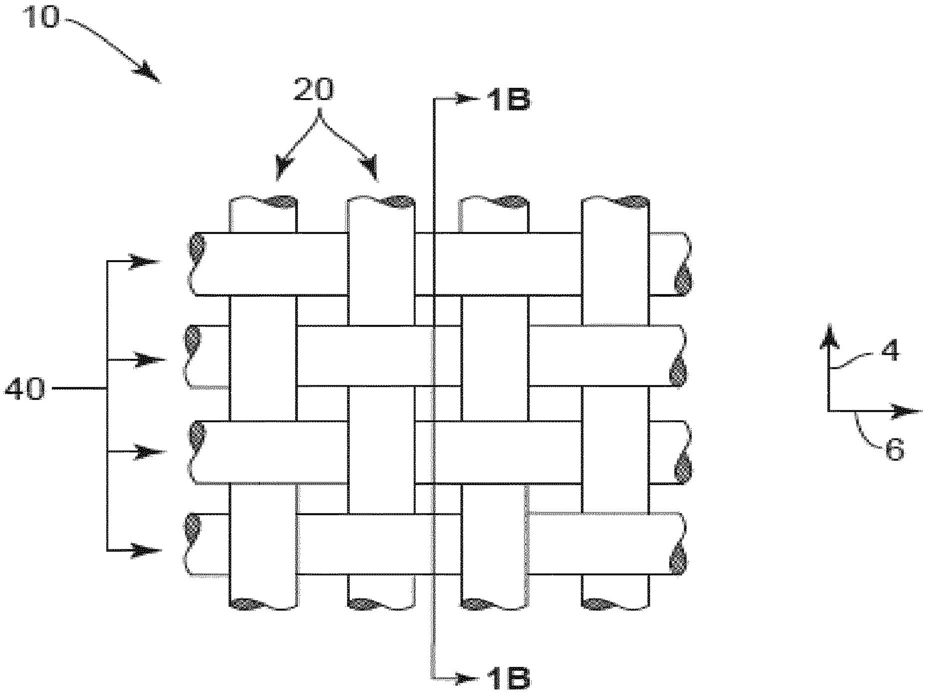


FIG. 1A

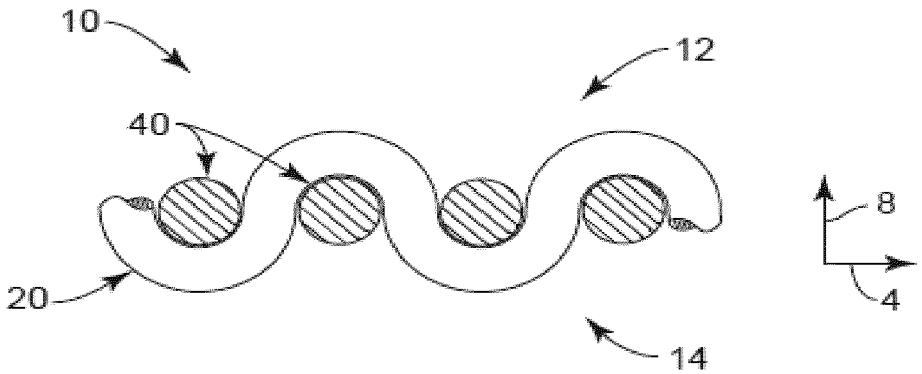


FIG. 1B

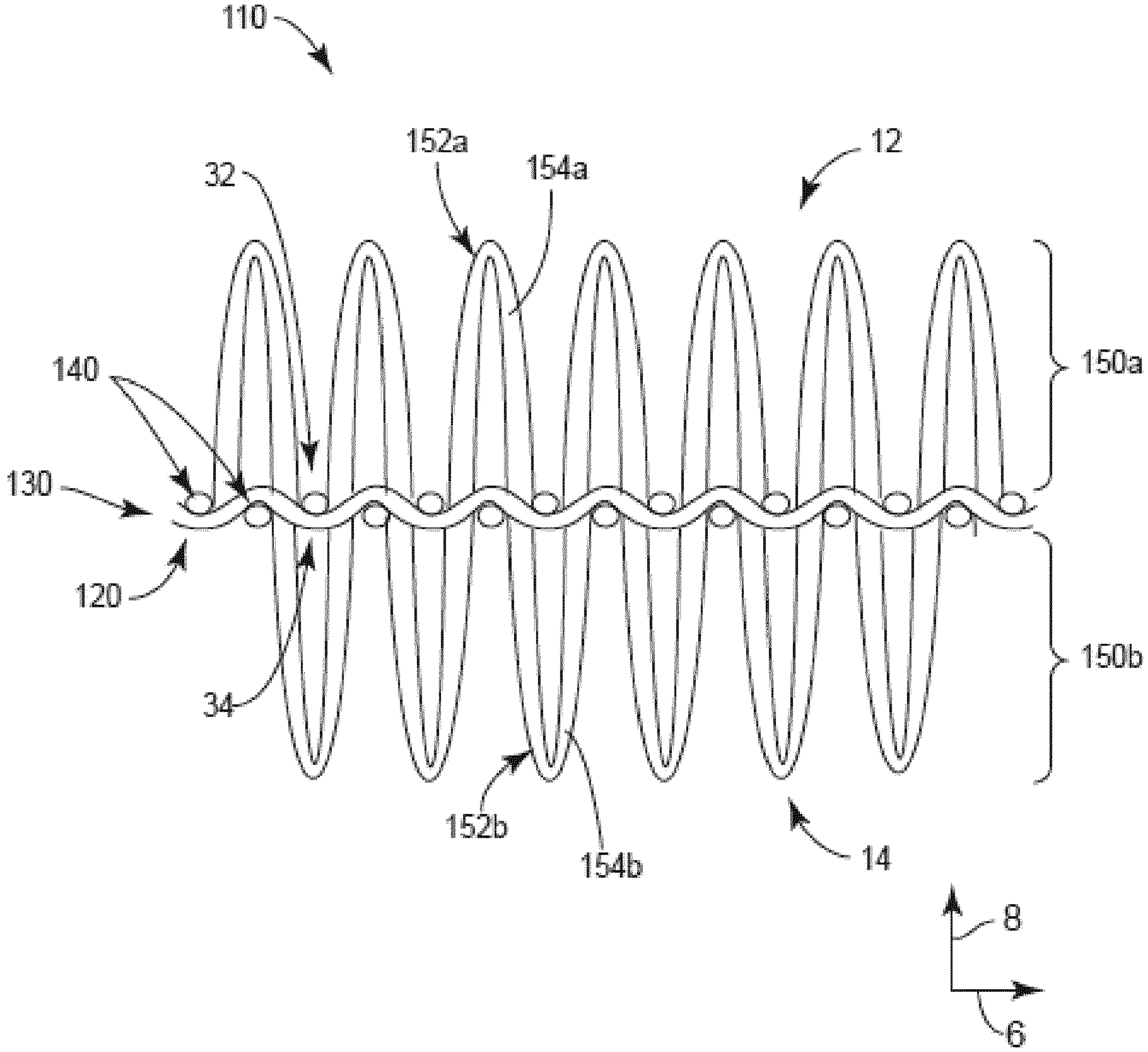


FIG. 2

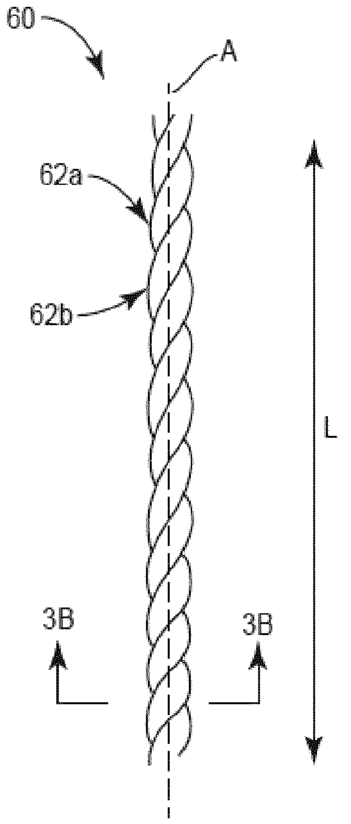


FIG. 3A

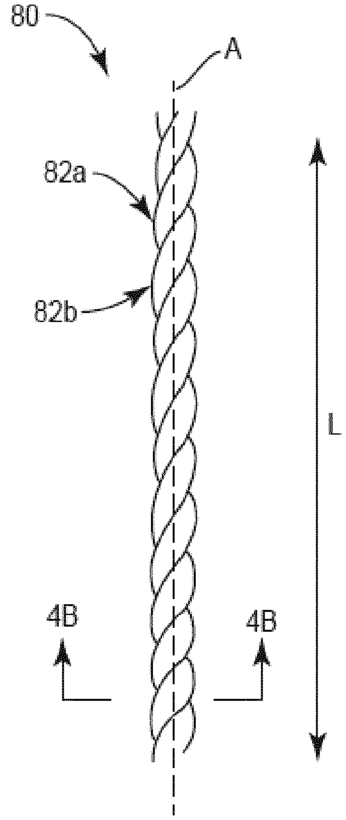


FIG. 4A

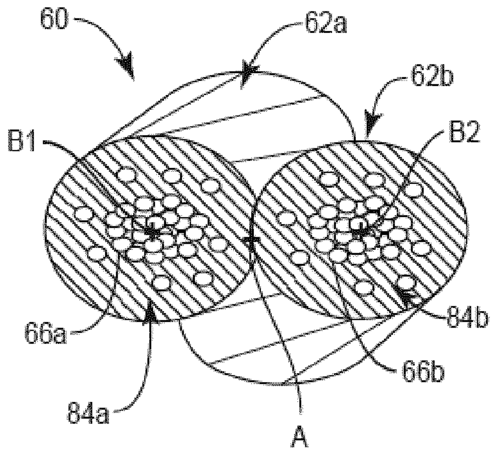


FIG. 3B

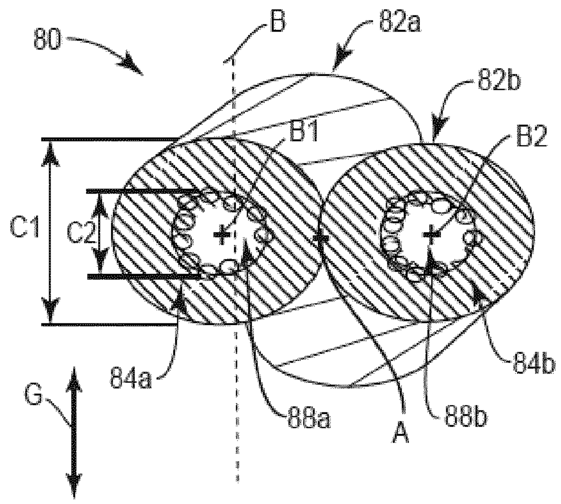
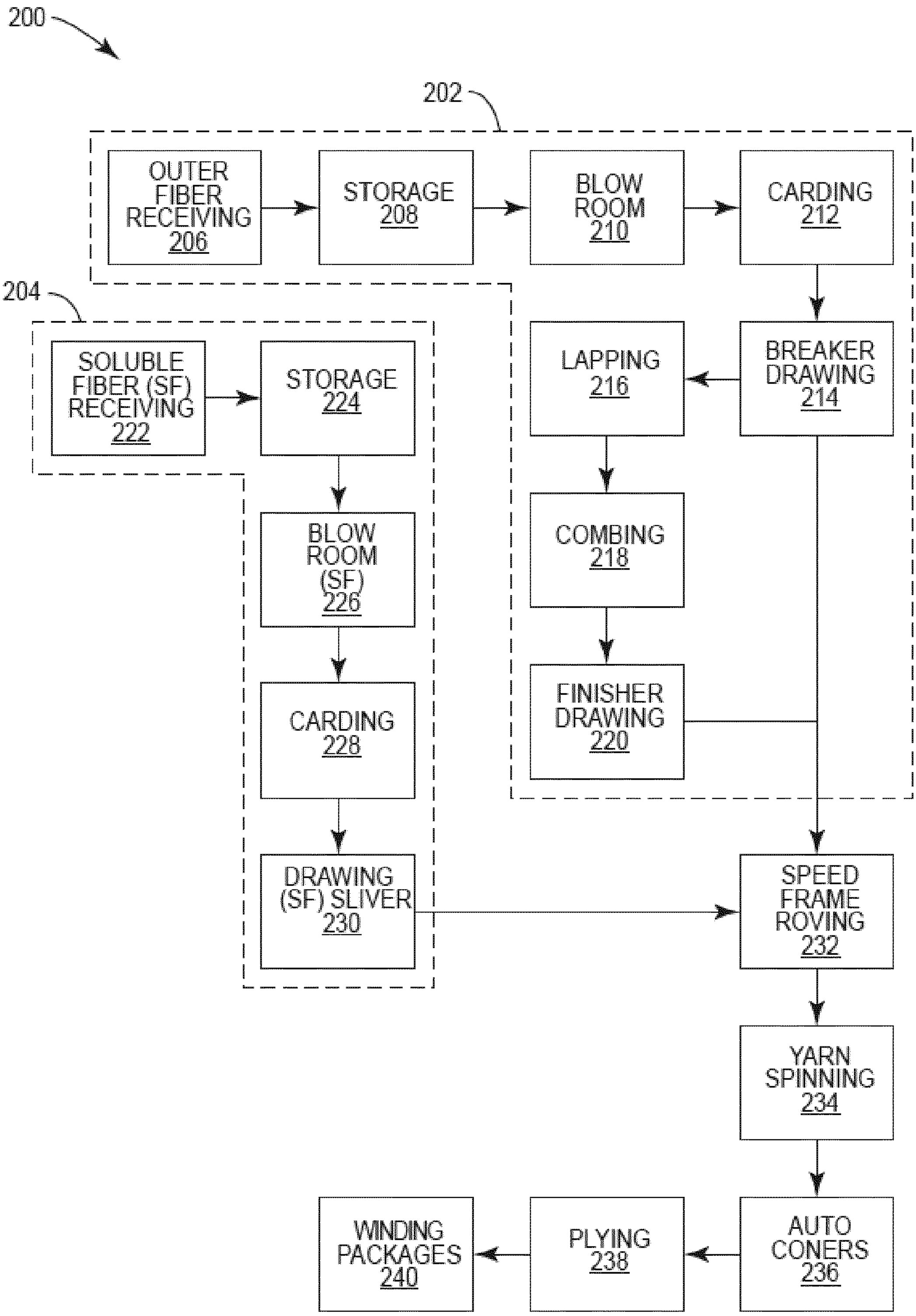


FIG. 4B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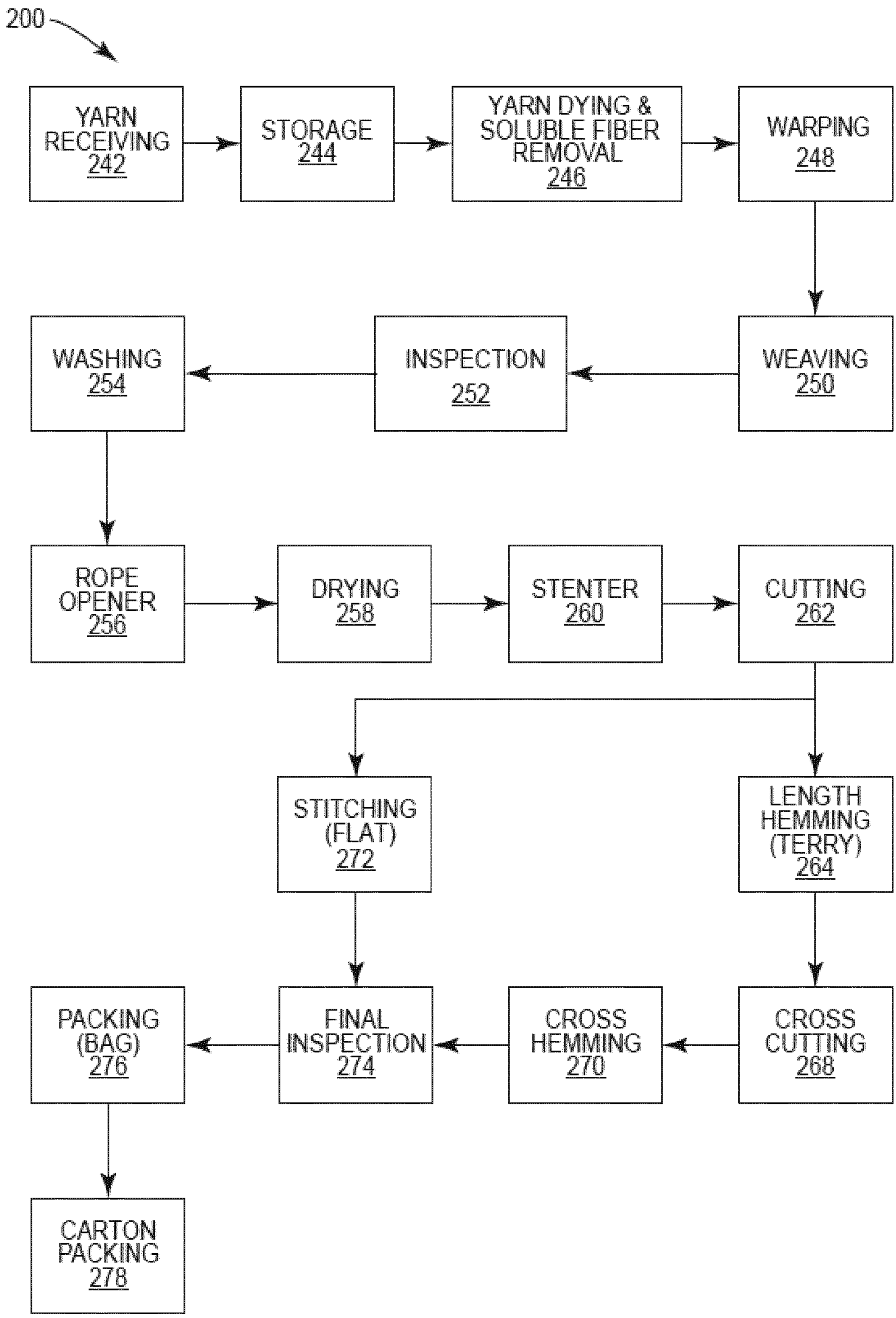
CARDING 212
BREAKER DRAWING 214
LAPPING 216
COMBING 218
FINISHER DRAWING 220
SOLUBLE FIBER (SF) RECEIVING 222
STORAGE 224
BLOW ROOM (SF) 226
CARDING 228
DRAWING (SF) SLIVER 230
SPEED FRAME ROVING 232
YARN SPINNING 234
AUTO CONERS 236
PLYING 238
WINDING PACKAGES 240

FIG. 5



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WARPING 248
WEAVING 250
INSPECTION 252
WASHING 254
ROPE OPENER 256
DRYING 258
STENTER 260
CUTTING 262
STITCHING (FLAT) 272
LENGTH HEMMING (TERRY) 264
CROSS CUTTING 268
CROSS HEMMING 270
FINAL INSPECTION 274
PACKING (BAG) 276
CARTON PACKING 278

FIG. 6

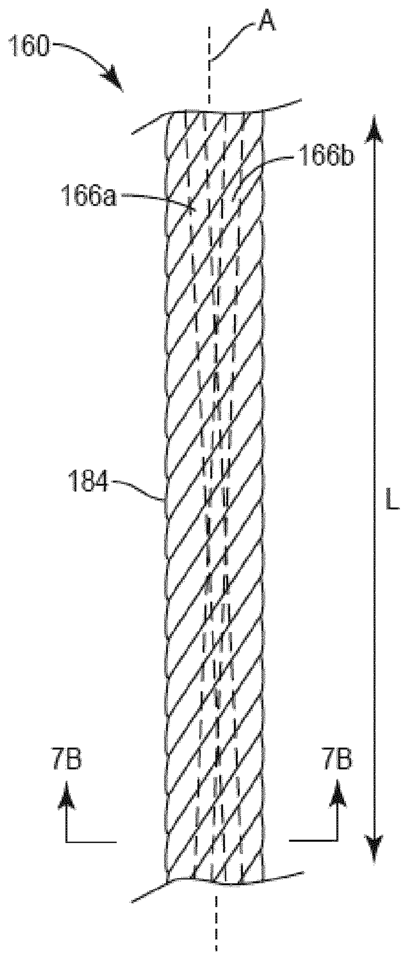


FIG. 7A

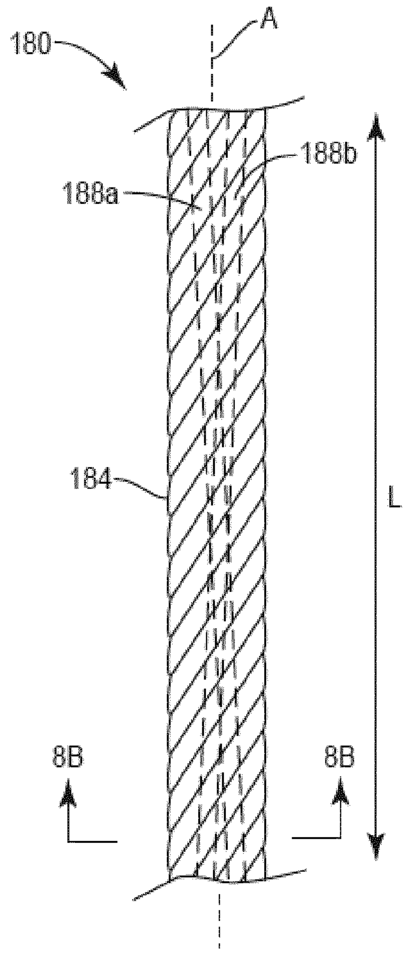


FIG. 8A

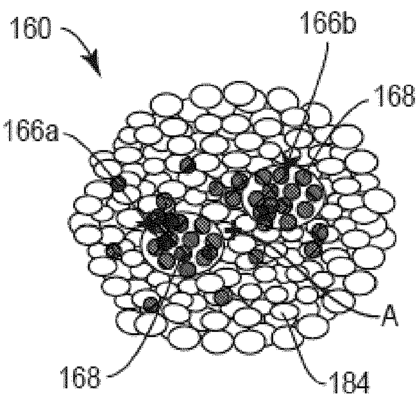


FIG. 7B

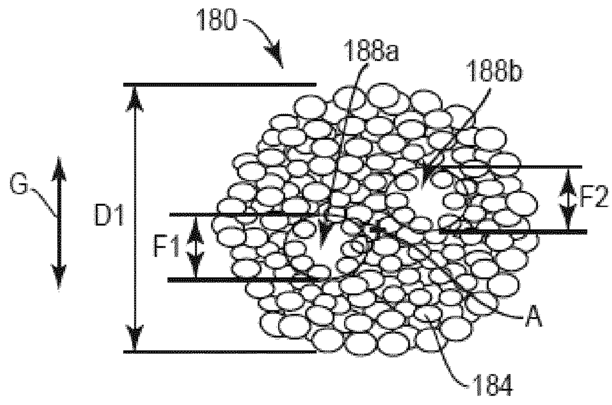
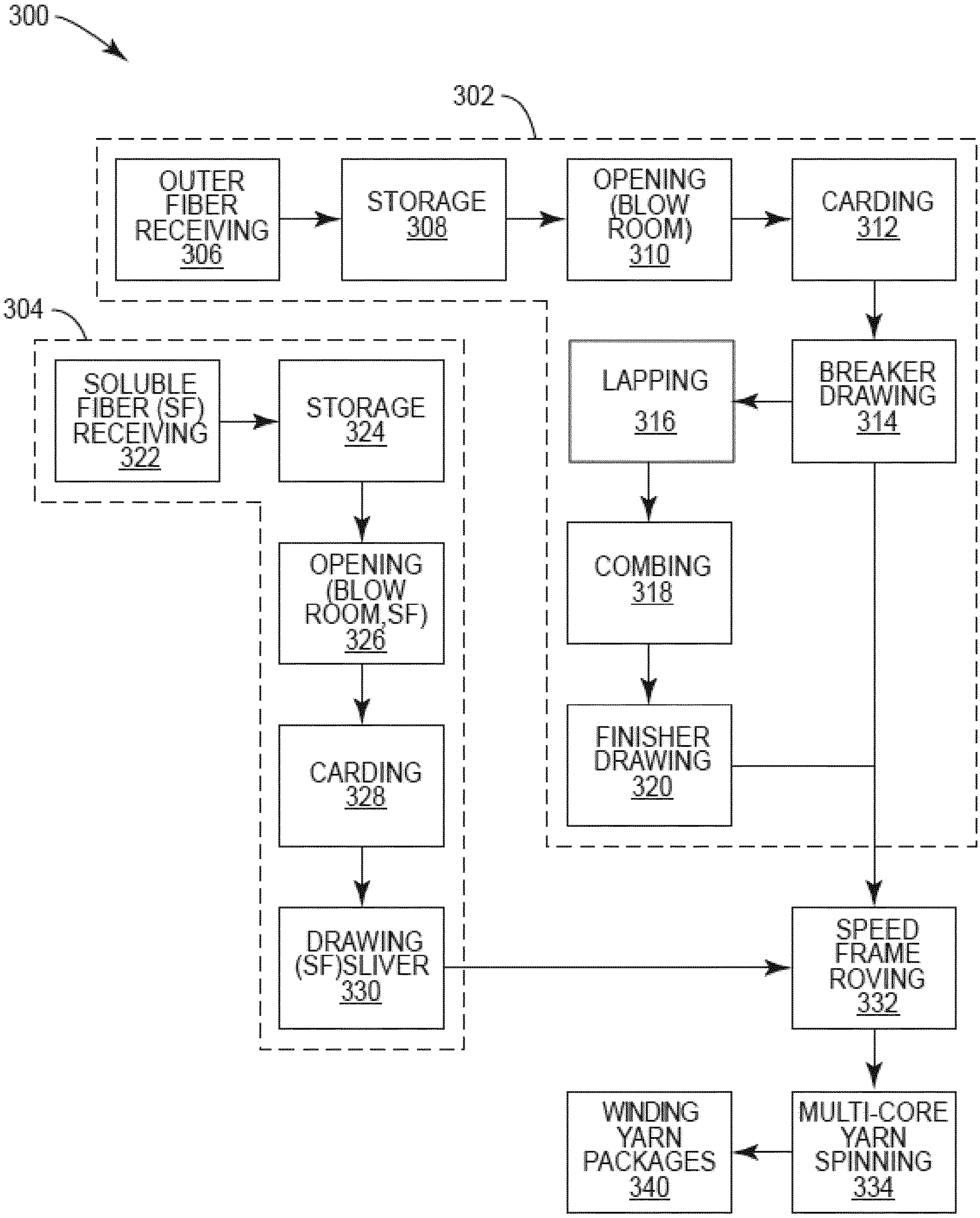


FIG. 8B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LAPPING 316
BREAKER DRAWING 314
OPENING (BLOW ROOM,SF) 326
COMBING 318
CARDING 328
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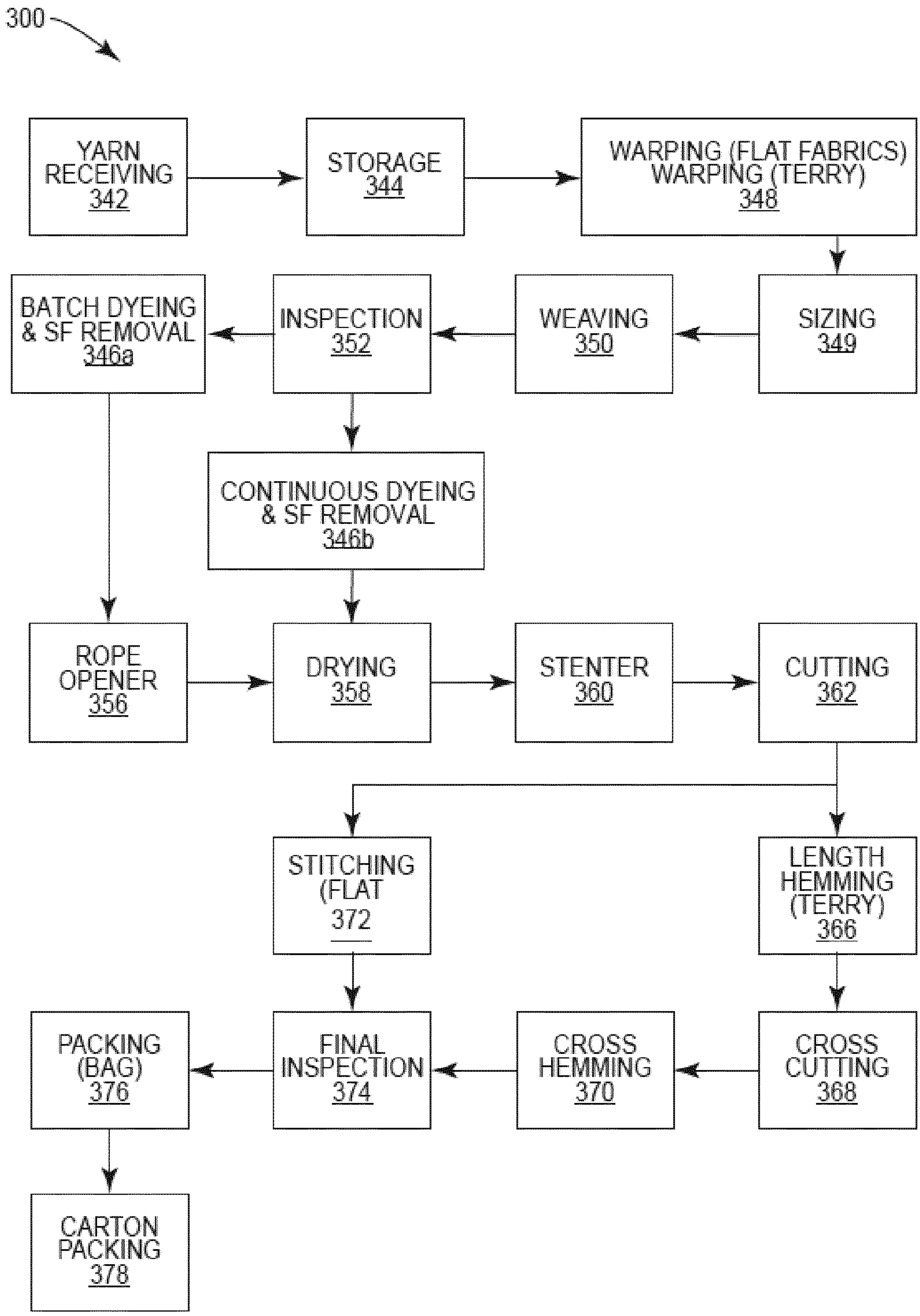
DRAWING (SF)SLIVER 330
SPEED FRAME ROVING 332
WINDING YARN PACKAGES 340
MULTI-CORE YARN SPINNING 334

FIG. 9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INSPECTION 352
WEAVING 350
SIZING 349
CONTINUOUS DYEING & SF REMOVAL 346b
ROPE OPENER 356
DRYING 358
STENTER 360
CUTTING 362
STITCHING (FLAT 372
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CROSS HEMMING 370
CROSS CUTTING 368
CARTON PACKING 378

FIG. 10

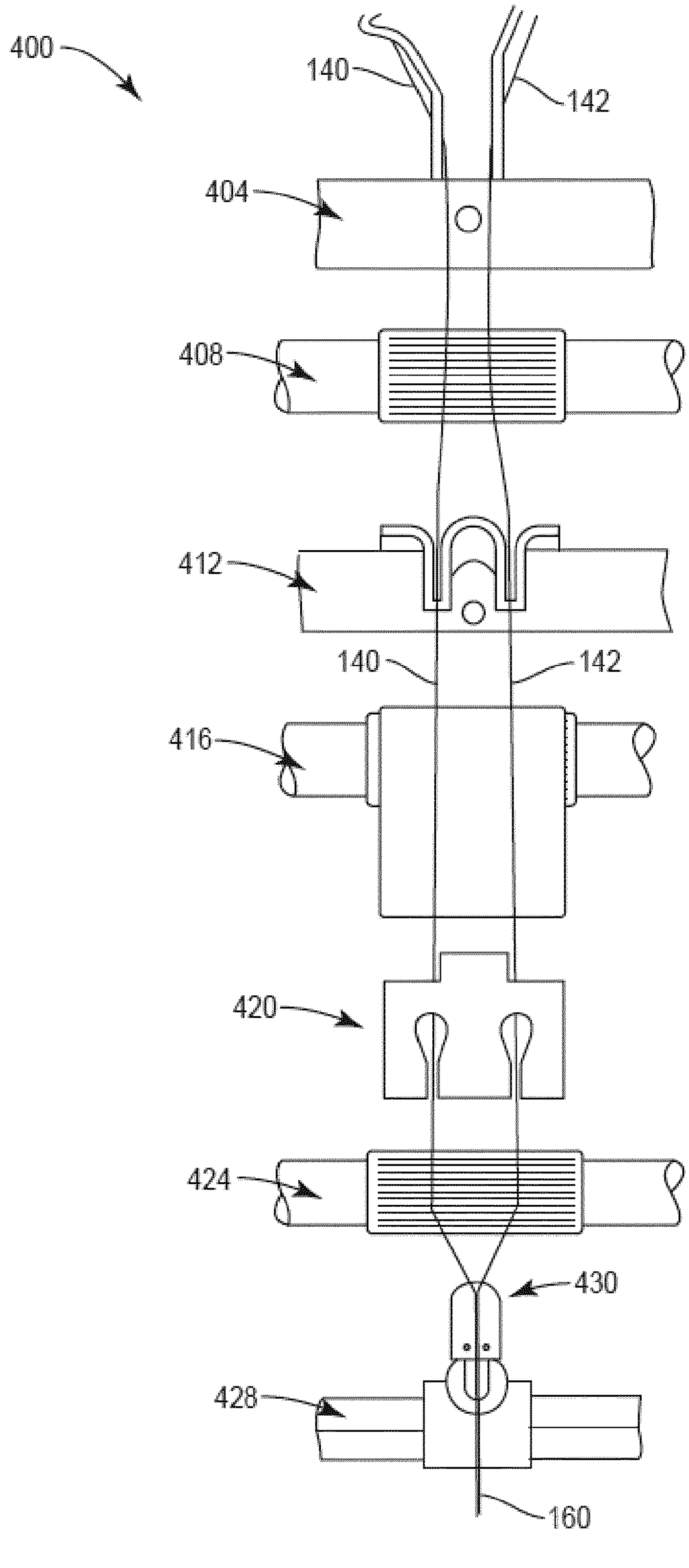

FIG. 11

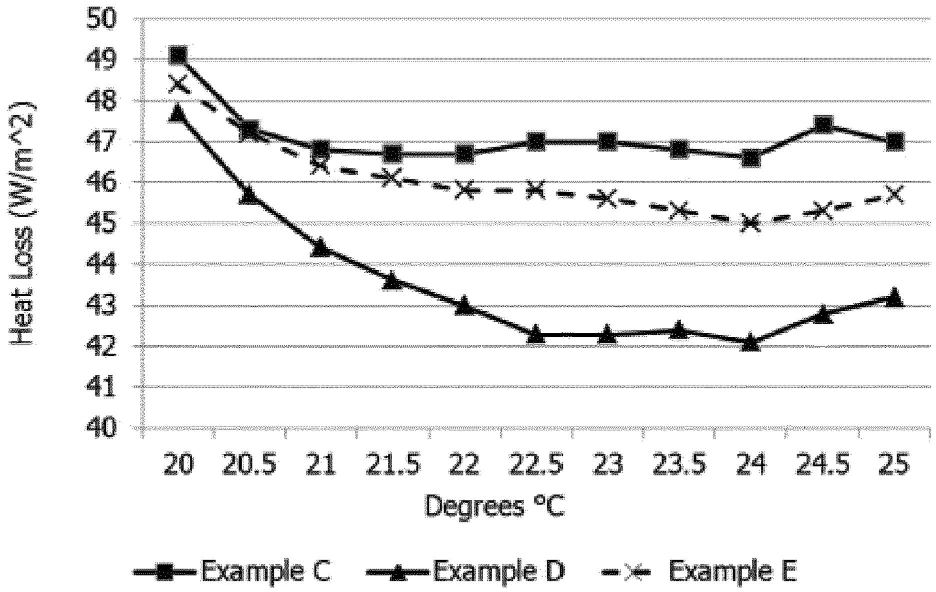

FIG. 12A

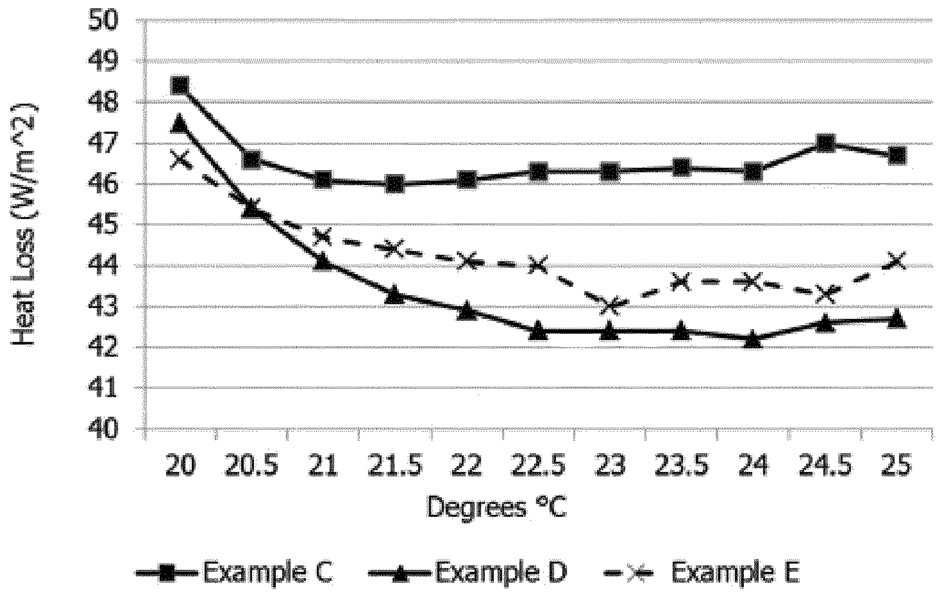

FIG. 12B

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EUROPEAN SEARCH REPORT

Application Number
EP 18 17 6376

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	CN 106 435 952 A (YU YANPING; LIU WEIGUO; YU ERQI) 22 February 2017 (2017-02-22) * abstract * * claims 2-4 * * pages 3-5,8-10 * * example 4 * -----	1-15	INV. D02G3/40 D02G3/36
X Y	US 2 387 320 A (FOSTER BOUTWELL H) 23 October 1945 (1945-10-23) * figures 4-6 * * columns 1-3,5-7 * * example Fig. 7 * -----	1-3,5-11 12-15	
Y	EP 2 562 299 A1 (KURARAY TRADING CO LTD [JP]; ASANO NENSHI CO LTD [JP]) 27 February 2013 (2013-02-27) * abstract * * paragraphs [0001], [0012], [0013], [0019], [0020], [0060], [0086] * -----	12-15	
			TECHNICAL FIELDS SEARCHED (IPC)
			D02G

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	12 October 2018	Heinzelmann, Eric

CATEGORY OF CITED DOCUMENTS

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12-10-2018

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
CN 106435952 A	22-02-2017	CN 106435952 A	22-02-2017
		US 2018105960 A1	19-04-2018
US 2387320 A	23-10-1945	NONE	
EP 2562299 A1	27-02-2013	CN 103097595 A	08-05-2013
		EP 2562299 A1	27-02-2013
		JP 5734280 B2	17-06-2015
		JP WO2011132708 A1	18-07-2013
		US 2013037163 A1	14-02-2013
		WO 2011132708 A1	27-10-2011

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

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Patent documents cited in the description

- US 8733075 B **[0010]**