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(54) **Title:** HYBRID FABRICS FOR EXTREME WEAR INDUSTRIAL AND APPAREL APPLICATIONS

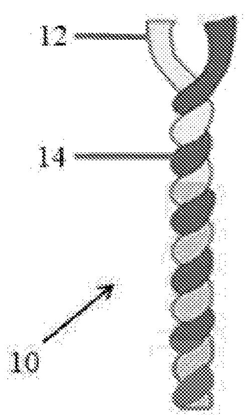

FIG. 1

(57) **Abstract:** Twisted, non-blended hybrid yarns are provided that are suitable for the fabrication of abrasion resistant garments and other textile articles. One or more polyolefin fibers are ply twisted together with one or more non-polyolefin fibers in a manner that utilizes the properties of each fiber type. A plurality of the twisted, non-blended hybrid yarns is then woven or knitted into fabrics, such as twill woven denim, or formed into ropes, such as braided ropes.

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HYBRID FABRICS FOR EXTREME WEAR INDUSTRIAL AND APPAREL APPLICATIONS

BACKGROUND

TECHNICAL FIELD

This technology relates to hybrid yarns and articles made from the hybrid yarns.

DESCRIPTION OF THE RELATED ART

High performance fibrous materials formed from high strength fibers are well known in various industries. High tenacity fibers, such as SPECTRA® polyethylene fibers or aramid fibers such as KEVLAR® fibers, are well known as useful for the formation of high performance armor articles because of their very high strength to weight performance, good wear resistance, cut resistance and slash resistance at low fiber volumes. In recent years, the use of such high performance fibers has been extended to various non-armor industries, such as textile industries that fabricate wearable textile articles such as sports apparel and footwear.

Traditionally, such wearable textile articles have been fabricated from low strength natural fibers, such as cotton or wool, or low strength synthetic fibers, such as polyester or elastomeric fibers such as polyurethane (e.g., spandex) fibers. Such low strength fibers are very comfortable and are easily colored to be given a fashionable appearance, but they are also known to have relatively poor durability and wear resistance. Therefore, fabrics formed from these low strength fiber types are not ideal for use in apparel that will be subjected to extreme wear conditions, such as protective clothing for motorcyclists, bicyclists, skateboarders, industrial workers, or the like. One alternative material useful in fabricating extreme use protective garments is leather, which is known to have better wear resistance and durability than similar articles formed the aforementioned low strength fibers and is considered fashionable by many. However, leather articles having the desired level of durability and wear resistance must be quite thick, which makes the material very heavy and potentially uncomfortable for the user, so they too are not ideal. This has led to the exploration of using high performance fibers such as polyethylene or aramid fibers in such non-traditional applications for such fiber types.

In one example, it has been known to incorporate high performance fabrics within existing clothing garments to provide added abrasion resistance to the entire article or to portions of the article. U.S. patent 9,003,563, for example, provides protective clothing wherein a layer of KEVLAR® aramid-based fabric or a polyethylene based fabric is provided as an interior liner that is sewn onto selected interior surfaces of an existing garment.

In another example, it is known to fabricate textile articles having improved durability by weaving or knitting together yarns of different materials. For example, U.S. patent 9,624,608 provides architecturally reinforced denim fabrics for manufacturing athletic gear for athletes engaging in extreme sports, having moisture regulation properties and high abrasion resistance. The reinforced denim materials incorporate both natural cotton fibers and high performance fibers such as KEVLAR® aramid fibers or polyethylene fibers as warp and/or fill (weft) threads in the woven structure. The natural fibers and the high performance synthetic fibers remain separate from each other but together form a single fabric layer.

In yet another example, it has also been known to manufacture fabrics by weaving or knitting together a plurality of hybrid yarns, wherein the individual hybrid yarns are formed by blending together more than one type of fiber. For example, related U.S. pre-grant publications 2002/0104576, 2002/0106956 and 2002/0111099 teach blending a non-performance fiber having properties such as good dyeability and softness with a high performance fiber having great strength to form an intimate blend yarn that mixes together different filament types in forming a single fiber (a bundle of filaments). Similarly, U.S. pre-grant publication 2005/0208855 teaches forming blends combining modacrylic filaments, cotton staples and aramid filaments into single fibers with are fabricated into textile articles having electrical arc and flame protection.

Each of these types of hybrid fabrics of the related art, except for U.S. pre-grant publication 2005/0208855, alleges to be abrasion resistant materials without providing supporting data. U.S. pre-grant publication 2005/0208855 does provide data in the form of an industry standard Taber Abrasion testing as per ASTM D3884 (Standard

Guide for Abrasion Resistance of Textile Fabrics (Rotary Platform, Double-Head Method)). However, their abrasion resistance properties remain insufficient for extreme protective clothing applications, such as motorcyclists. The present disclosure provides a solution to this need by manufacturing fabrics from new hybrid yarns wherein high tenacity polyolefin fibers are twisted together with non-polyolefin fibers, rather than being blended or formed into core-sheath fibers, wherein the polyolefin fibers form greater than 20% of the total yarn surface area but preferably less than 75%, and a plurality of the hybrid yarns are then formed into garments such as by weaving or knitting. The significant presence of the high tenacity polyolefin fiber at the yarn surface provides the enhanced abrasion resistance without adding too much weight or cost to the material. The different fiber types are not blended together because polyolefin filaments positioned in the interior of the blended yarn rather than at the surface do not aid in improving abrasion resistance and therefore are wasteful and even deleterious to the desired fabric properties where a balance of properties is needed, such as softness, low weight and dyeability, which are properties provided by the non-polyolefin fiber types.

As further proven by the inventive examples, the present disclosure provides improvements in abrasion resistance and durability not achieved by any other fabric of the related art, while also possessing desirable properties such as good softness, low weight and dyeability that are desirable in garment applications. Even in comparison to U.S. 2005/020885, the materials of the present disclosure have a Taber Abrasion resistance of over 15 times greater, with the present materials even being tested against an even coarser testing wheel than that of U.S. pre-grant publication 2005/0208855 with a load of the same weight. Accordingly, the presently disclosed materials are especially attractive and effective for use in protective clothing applications when a user can be seriously hurt if the clothing they are wearing wears out and exposes skin to extreme conditions. This need for abrasion resistant, highly durable, dyeable and lightweight textile materials also extends to many non-wearable textile applications, such as tents, canopies, upholstery, curtains, parachutes and tarps, etc.

SUMMARY

Hybrid yarns are formed by twisting together low denier ultra-high molecular weight polyolefin fibers, which are preferably multifilament polyolefin fibers, with non-polyolefin fibers that are high quality, soft, and colored or colorable fibers. When each fiber type comprises multifilament fibers the fibers are twisted together such that the filaments of each fiber are not mixed with each other, i.e., each of the fibers remain as discrete entities without blending or mixing of their component filaments together. When fabricated into garments, the resulting products have desirable properties that satisfy a great need is the art. The polyolefin fibers enhance the strength and durability of the product, while the non-polyolefin fibers enhance the look and feel. Together, the yarn and fabric constructions achieve products having outstanding physical properties at a low weight, with low thickness and at a low cost that are attractive for use in a wide range of industries.

Particularly provided is a twisted yarn comprising a twisted combination of one or more discrete polyolefin fibers and one or more discrete non-polyolefin fibers, wherein the twisted yarn has a yarn surface area, wherein said polyolefin fibers form greater than 20% of said yarn surface area, and wherein said polyolefin fibers and said non-polyolefin fibers are twisted together. More particularly provided is a twisted, non-blended yarn comprising a twisted combination of one or more polyolefin fibers and one or more non-polyolefin fibers, wherein the twisted yarn has a yarn surface area, wherein said polyolefin fibers form greater than 20% of said yarn surface area, and wherein said polyolefin fibers and said non-polyolefin fibers are twisted together.

Also provided is a twisted yarn comprising a twisted combination of one or more discrete polyolefin fibers and one or more discrete non-polyolefin fibers, each of said discrete non-polyolefin fibers having a tenacity of 20 g/denier or less and each of said non-polyolefin fibers having a density of greater than 1.0 grams/cm^3, and wherein said fibers are twisted together. In the preferred embodiments the discrete polyolefin fibers comprise multifilament polyolefin fibers and the discrete non-polyolefin fibers comprise multifilament fibers or multi-staple spun yarn fibers (e.g., cotton yarns), and the component filaments/staples of each of the discrete fibers are preferably entirely non-blended and non-intermingled with each other. More particularly provided is a twisted, non-blended yarn comprising a twisted combination of one or more polyolefin fibers and one or more non-polyolefin fibers, said non-polyolefin fibers having a tenacity of 20 g/denier or less and said non-polyolefin fibers having a density of greater than 1.0 grams/cm^3, and wherein said fibers are twisted together.

Further provided is a process for producing a twisted yarn, comprising: a) providing one or more discrete polyolefin fibers; b) providing one or more discrete non-polyolefin fibers, wherein said non-polyolefin fibers comprise one or more elastic fibers, one or more natural fibers, or both one or more elastic fibers and one or more natural fibers; c) laying said polyolefin fibers and said non-polyolefin fibers side-by-side in parallel to thereby form an untwisted fiber bundle of discrete fibers, wherein the untwisted fiber bundle has a surface area, and wherein said polyolefin fibers form greater than 20% of said fiber bundle surface area; and d) twisting said fiber bundle of discrete fibers to form a twisted yarn, wherein said polyolefin fibers and said non-polyolefin fibers are twisted together at a 1:1 ratio relative to each other, wherein the twisted yarn has a yarn surface area and wherein said polyolefin fibers form greater than 20% of said twisted yarn surface area. More particularly provided is a process for producing a twisted, non-blended yarn, comprising: a) providing one or more polyolefin fibers; b) providing one or more non-polyolefin fibers, wherein said non-polyolefin fibers comprise one or more synthetic fibers, one or more natural fibers, or both one or more synthetic fibers and one or more natural fibers; c) laying said polyolefin fibers and said non-polyolefin fibers side-by-side in parallel to thereby form a non-blended, untwisted fiber bundle wherein the untwisted fiber bundle has a surface area, and wherein said polyolefin fibers form greater than 20% of said fiber bundle surface area; and d) twisting said non-blended fiber bundle to form a twisted yarn, wherein said polyolefin fibers and said non-polyolefin fibers are twisted together at a 1:1 ratio relative to each other, wherein the twisted yarn has a yarn surface area and wherein said polyolefin fibers form greater than 20% of said twisted yarn surface area.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic representation of a 2-ply, ply twisted hybrid yarn.

FIG. 2 is a schematic representation of a 3-ply, ply twisted hybrid yarn.

DETAILED DESCRIPTION

As used herein, a “hybrid” has the ordinary and customary meaning of a thing made by combining two or more different elements, which in the context of the present disclosure are two or more different fiber types. As used herein, the term “yarn” is defined as a single continuous strand consisting of multiple fibers, and a “hybrid yarn” combines together at least two different discrete fibers (with a spun cotton yarn also being referred to as a fiber in this context). Also as used herein, “non-blended” means that the filaments of each fiber are not mixed with each other and are not an “intimate blend” (a term that is understood by those skilled in the art), wherein the component filaments of each component discrete fiber are preferably entirely not intermingled with each other, i.e., preferably none of the individual filaments of one discrete multifilament fiber/spun yarn are surrounded by filaments/staples of another discrete multifilament fiber or even positioned between two filaments/staples of another discrete multifilament fiber (fully or partially). Rather, in the preferred embodiment, each fiber of the hybrid yarn remains entirely as a discrete fiber before and after the fibers are twisted together, such as illustrated in FIGS. 1 and 2, with each filament/staple of each respective component discrete fiber remaining joined together with the other filaments of said respective discrete fibers. The hybrid yarns of this disclosure include at least two chemically different fiber types, at least one of which is a high tenacity, high tensile modulus polyolefin fiber and at least one other being a non-polyolefin fiber. As used herein, a “high tenacity, high tensile modulus” fiber is one which has a tenacity of at least 7 g/denier or more and a tensile modulus of at least 150 g/denier or more, and preferably an energy-to-break of at least about 8 J/g or more, each as measured by ASTM D2256 and all tensile strength properties (tenacity, tensile modulus and energy-to-break) are measurements for dry fibers.

Provided that at least one polyolefin fiber and at least one non-polyolefin fiber are incorporated, the hybrid yarns may also include multiple different types of polyolefin fibers, for example different types of polyethylene fiber having at least one dissimilar physical property, and/or multiple different types of non-polyolefin fibers of the same chemical fiber type, for example, two different types of polyester fiber having at least one dissimilar physical property.

Examples of physical properties of fibers include fiber tensile properties, such as tenacity, initial tensile modulus, ultimate tensile strength and ultimate elongation/elongation-at-break. Other physical properties include fiber density, fiber denier, denier per filament, creep tendency (as determined by ASTM D6992), fiber diameter, electric properties (including dielectric properties, such as dielectric constant, and loss tangent properties), and thermal properties, including the coefficient of thermal expansion in fiber axial and transverse directions.

For the purposes of the present disclosure, a “fiber” is an elongate body the length dimension of which is much greater than the transverse dimensions of width and thickness. The cross-sections of fibers for use in this disclosure may vary widely, and they may be circular, oblong or even flat in cross-section. Thus the term “fiber” includes filaments, ribbons, strips and the like having regular or irregular cross-section. It is preferred that the fibers have a rounded or circular cross-section. A fiber is preferably a long, continuous strand rather than a short segment of a strand referred to in the art as a “staple” or “staple fiber.” A fiber may be a continuous filament fiber, i.e. a continuous “strand,” or alternatively may be a short segment of a strand referred to in the art as a “staple” or “staple fiber.” In this regard, a “strand” by its ordinary definition is a single, thin length of something, such as a thread, fiber or wire. As is conventionally known in the art, a plurality of staple fibers may also be combined to form a continuous (long, non-filament) strand, such as by conventional spinning techniques. Cotton yarns are spun yarns that are conventionally made in this manner wherein each staple may have a length ranging from less than one inch to about two inches or more, and for the purposes of this disclosure such spun cotton yarns are also referred to as “non-polyolefin fibers” herein.

A single fiber may be formed from just one filament or from multiple filaments. A fiber formed from just one filament is referred to herein as either a “single-filament” fiber or a “monofilament” fiber, and a fiber formed from a plurality of filaments is referred to herein as a “multifilament” fiber. The definition of multifilament fibers herein also encompasses pseudo-monofilament fibers, which is a term of art describing multifilament fibers that are at least partially fused together with heat and look like monofilament fibers. Multifilament fibers of this disclosure preferably include from 2 to about 1000 filaments, more preferably from 30 to 500 filaments, still more preferably from 100 to 500 filaments, still more preferably from 100 to 375 filaments still more preferably from about 100 filaments to about 250 filaments and most preferably from about 120 to about 240 filaments. A multifilament fiber is also often referred to in the art as a “filament bundle.” A combination of a plurality of fibers (whether monofilament fibers, multifilament fibers or a combination thereof) is referred to herein as a “fiber bundle.” For example, when laying together polyolefin fibers and non-polyolefin fibers in side-by-side in parallel (though non-blended/unmixed and untwisted), the combination of the polyolefin and non-polyolefin fibers collectively is referred to as a “fiber bundle” wherein each of the polyolefin and non-polyolefin fibers individually is a “filament bundle” if they are multifilament fibers.

The term “fabric” describes structures that may include one or more fiber plies, with or without attachment of or consolidation of the plies. For example, a woven fabric or felt may comprise a single fiber ply or a plurality of plies of woven or felt fabrics may be sewn or stitched together. A non-woven fabric formed from unidirectionally oriented fibers or non-parallel, randomly oriented fibers (e.g., a felt or mat) may comprise a single fiber ply or plurality of fiber plies stacked on each other and laminated together (i.e., consolidated), typically with a binder being used to adhere the plies to each other, or the plies may be sewn/stitched together. As described herein, “non-woven” fabrics include all fabric structures that are not formed by weaving. This includes knit fabrics formed from a single fiber ply or a plurality of fiber plies, forming loops or knit elements that are interconnected with each other as is conventionally known in the art.

As used herein, the term “denier” refers to the unit of linear density, equal to the mass in grams per 9000 meters of fiber. As used herein, the term “tenacity” refers to the tensile stress expressed as force (grams) per unit linear density (denier) of an unstressed specimen. The “tensile modulus” of a fiber is the property of a material representative of its resistance to deformation, referring to the ratio of the change in tenacity, expressed in grams-force per denier (g/d) to the change in strain, expressed as a fraction of the original fiber length (in/in).

Particularly suitable high tenacity, high tensile modulus polyolefin fibers include high density and low density polyethylene. Particularly preferred are extended chain polyolefin fibers, such as highly oriented, high molecular weight polyethylene fibers, particularly ultra-high molecular weight polyethylene fibers, and polypropylene fibers, including ultra-high molecular weight polyethylene fibers, and particularly including high toughness modulus (as determined by ASTM D2256-02) polypropylene fibers such as Innegra™ S fibers commercially available from Innegra Technologies LLC, of Greenville, South Carolina. In the case of polyethylene, preferred fibers are extended chain polyethylenes having molecular weights of at least 300,000, preferably at least one million and more preferably between two million and five million. Such extended chain polyethylene (ECPE) fibers may be grown in solution spinning processes such as described in U.S. patents 4,137,394 or 4,356,138, which are incorporated herein by reference, or may be spun from a solution to form a gel structure, such as described in U.S. patents 4,413,110; 4,536,536; 4,551,296; 4,663,101; 5,006,390; 5,032,338; 5,578,374; 5,736,244; 5,741,451; 5,958,582; 5,972,498; 6,448,359; 6,746,975; 6,969,553; 7,078,099; 7,344,668; 7,846,363; 8,361,366; 8,444,898; 8,747,715 and 9,365,953, all of which are incorporated herein by reference. Particularly preferred fiber types are any of the polyethylene fibers sold under the trademark SPECTRA® from Honeywell International Inc. of Morris Plains, NJ. SPECTRA® fibers are well known in the art.

Suitable non-polyolefin fiber types may be polymeric or non-polymeric and may comprise synthetic fibers or natural fibers. Suitable non-polymeric fibers include natural fibers such as cotton, cellulose, flax, ramie, hemp, sisal, silk and wool and may be in the form of a continuous filament fiber, a staple fiber or a continuous strand made from a plurality of staple fibers. Suitable polymeric fibers may be elastomeric fibers or non-elastomeric fibers, and may be in the form of a continuous filament fiber, a staple fiber or a continuous strand made from a plurality of staple fibers. Suitable non-polyolefin fibers include synthetic fibers formed from polyamides (nylons), aramid (meta-aramid and para-aramid), polyesters, polyvinyl alcohol, polyacrylonitrile, polyurethane, acrylics and acetate, and copolymers and blends thereof. Also useful are liquid crystal polymer fibers such as VECTRAN™ fibers manufactured and commercially available from Kuraray America, Inc. of Houston, Texas, and non-synthetic renewable resource polymers, as well as combinations and copolymers of any of the above fiber types. Suitable polyamide fibers non-exclusively include nylon 6 fibers, nylon 66 fibers and nylon 4,6 fibers. Suitable polyester fibers non-exclusively include polyethylene terephthalate (PET) fibers, polyethylene naphthalate (PEN) fibers, polybutylene terephthalate (PBT) fibers and polytrimethylene terephthalate (PTT) fibers. Suitable polyurethane fibers are those known in the art as elastane fibers, which are also known as spandex fibers, which are commercially available, for example, from DuPont under the brand name LYCRA®. Also suitable are lastol fibers commercially available from Dow Chemical of Midland, MI. Preferred aramid (aromatic polyamide) fibers are well known and commercially available, and are described, for example, in U.S. patent 3,671,542. For example, useful aramid filaments are produced commercially by DuPont under the trademark of KEVLAR®. Also useful herein are poly(m-phenylene isophthalamide) fibers produced commercially by DuPont of Wilmington, DE under the trademark NOMEX® and fibers produced commercially by Teijin Aramid Gmbh of Germany under the trademark TWARON®; aramid fibers produced commercially by Kolon Industries, Inc. of Korea under the trademark HERACRON®; *p*-aramid fibers SVM™ and RUSAR™ which are produced commercially by Kamensk Volokno JSC of Russia and ARMOS™ *p*-aramid fibers produced commercially by JSC Chim Volokno of Russia. Preferred are para-aramid (*p*-aramid) fibers having a tenacity of from about 22 g/denier to about 28 g/denier). Suitable non-polyolefin fibers formed from renewable resource polymers non-exclusively include poly-∈-caprolactone biodegradable fibers, poly-ß-propiolactone biodegradable fibers and polylactic acid-based biodegradable fibers. Also suitable are regenerated fibers such as viscose or rayon. Of all these fiber types, the most preferred non-polyolefin fiber types are formed from cotton, silk, wool, polyester and/or polyurethane fibers, particularly elastane fibers or other types of elastic fibers.

Each of the polyolefin and non-polyolefin fibers may be of any suitable denier. For example, fibers may have a denier of from about 20 to about 3000 denier, more preferably from about 50 to 3000 denier, still more preferably from about 200 to 3000 denier, still more preferably from about 650 to about 2000 denier, and most preferably from about 800 to about 1500 denier. In the most preferred embodiments, all of the individual fibers forming the hybrid yarns of this disclosure have a denier of greater than 100, preferably greater than 400, and still more preferably from about 425 to about 800, although in some embodiments each of the fiber types may have a denier of from about 50 to about 500, or about 50 to 400, or about 50 to 200, or about 50 to 150, or about 50 to 100, or at least 50 to less than 100, or greater than 50 to less than 100. As stated previously, continuous multifilament fibers of this disclosure preferably include from 2 to about 1000 filaments, more preferably from 30 to 500 filaments, still more preferably from 100 to 500 filaments, still more preferably from 100 to 375 filaments still more preferably from about 100 filaments to about 250 filaments and most preferably from about 120 to about 240 filaments. Each of the individual component filaments forming these “filament bundles” have a denier per filament (dpf) of at least 0.1, preferably from 0.1 up to about 7.0, more preferably from about 0.1 dpf up to about 6.0 dpf, more preferably from about 1.0 dpf to about 6.0 dpf, more preferably from about 2.0 dpf to about 6.0 dpf, still more preferably from about 2.5 dpf to about 5.0 dpf, and most preferably from about 3.0 dpf to about 5.0 dpf. It is not necessary for the polyolefin and non-polyolefin fibers to have the same denier or same dpf.

As stated above, the minimum tensile properties of the at least one polyolefin fiber component of the hybrid yarn are a tenacity of at least 7 g/denier, a tensile modulus of at least 150 g/denier, and preferably an energy-to-break of at least about 8 J/g or more, each as measured by ASTM D2256. Preferred fibers have a tenacity of about 10 g/denier or more, more preferably about 15 g/denier or more, more preferably about 20 g/denier or more, still more preferably about 25 g/denier or more, still more preferably about 30 g/denier or more, still more preferably about 35 g/denier or more, still more preferably about 40 g/denier or more, still more preferably about 45 g/denier or more, and most preferably about 50 g/denier or more. Preferred fibers also have a preferred tensile modulus of about 300 g/denier or more, more preferably about 400 g/denier or more, more preferably about 500 g/denier or more, more preferably about 1,000 g/denier or more and most preferably about 1,500 g/denier or more. Preferred fibers also have a preferred energy-to-break of about 15 J/g or more, more preferably about 25 J/g or more, more preferably about 30 J/g or more and most preferably have an energy-to-break of about 40 J/g or more. Methods of forming each of the preferred fiber types having these combined high strength properties are conventionally known in the art.

The tensile strength properties of the non-polyolefin fiber component are not particularly important as it is not relied upon for its strength properties, but rather its light weight, dyeability and softness. Typically, the non-polyolefin fiber component will have a tenacity of less than 10 g/denier, more typically less than 7 g/denier, still more typically having a tenacity of 6 g/denier or less, or 5 g/denier or less, or 4 g/denier or less, and most typically having a tenacity of 3.0 g/denier or less, or 2.5 g/denier or less, or 2.0 g/denier or less. Non-polyolefin fibers preferred herein also preferably have a tensile modulus of less than 150 g/denier and an energy-to-break of less than 15 J/g.

The non-polyolefin fiber type itself may alternatively comprise a hybrid or a multi-component fiber, such as a core-sheath fiber, wherein each component is a non-polyolefin staple or continuous filament (mono or multifilament) fiber. The non-polyolefin fiber type may also be a wrapped fiber, as discussed in further detail below. Such fiber types are known in the art. Additionally, more than one type of such non-polyolefin, multi-component fibers may be incorporated within the fabric constructions of this disclosure, as discussed in greater detail below.

The polyolefin and non-polyolefin fibers are joined together by well-known plying or ply twisting techniques using conventional ply twisting equipment, such as a twister, wherein two or more single fibers are brought together and twisted together in the same twisting direction. The single fibers may initially be laid together in parallel next to each other or may be otherwise inserted together into a twisting apparatus set to impart the desired amount of twist. Suitable twisting apparatuses are commercially available from manufacturers such as Saurer Technologies GmbH & Co. KG Twisting Solutions of Krefeld, Germany and Muratec Murata Machinery, Ltd. of Kyoto Prefecture, Japan. After twisting, each of the individual fiber components of the ply-twisted yarn product is distinguishable from the others, i.e., one fiber is not entirely wrapped around another fiber of the multi-ply yarn no entirely covers another fiber of the multi-ply yarn. The multi-ply yarns are not core/sheath yarns.

The number of fibers that are twisted together determines the ply count of the yarn. As illustrated in FIG. 1, a 2-ply yarn 10 refers to a yarn formed by twisting together two discrete fibers (no blending/mixing of the filaments of one fiber with the filaments of another fiber of said 2-ply hybrid yarn), identified as fibers 12 and 14 (wherein fibers 12 and 14 may be selected from monofilament fibers, multifilament fibers, or fibers/yarns formed from a plurality of spun staple fibers, such as cotton yarns). As illustrated in FIG. 2, a 3-ply yarn 20 refers to a yarn formed by twisting together three discrete fibers (with no blending/mixing of the filaments of one fiber with the filaments of another fiber of said 3-ply hybrid yarn), identified as fibers 12, 14 and 16 (wherein fibers 12, 14 and 16 may be monofilament fibers or multifilament fibers, or fibers/yarns formed from a plurality of spun staple fibers, such as cotton yarns). In the preferred embodiments, the hybrid yarns of this disclosure preferably comprise, consist of or consist essentially of from 2 fibers to 12 fibers, preferably from 2 to 10 fibers, more preferably from 2 to 8 fibers, and most preferably from about 2 to 6 fibers, wherein such yarns include at least two chemically different fiber types, with each fiber comprising one filament (i.e., a monofilament fiber) or a plurality of component filaments (i.e., a multifilament fiber; a filament bundle). However, hybrid yarns may be fabricated from more than 12 discrete fibers, such as 3-20 or more, 3-30 or more, 3-40 or more, 3-50 or more, or greater than 50 discrete fibers, such as 50-100 discrete fibers, depending on the end application.

In order to attain the preferred high abrasion resistance in a suitable balance with other preferred properties such as soft feel, dyeability and low weight, it is necessary for the one or more polyolefin fibers to account for at least 20% of the surface area of the hybrid yarn up to about 75% of the hybrid yarn, with the amount generally depending on the needs of the end use application. In applications where abrasion resistance is more important than softness or dyeability, the yarns should include sufficient polyolefin fiber(s) so that they occupy a greater amount of the surface area of the hybrid yarn than the non-polyolefin fiber(s). In this regard, in applications where softness or dyeability is more important than abrasion resistance, the yarns should include sufficient non-polyolefin fiber(s) so that they occupy a greater amount of the surface area of the hybrid yarn than the polyolefin fiber(s).

Accordingly, in one embodiment of the twisted, non-blended hybrid yarns of this disclosure, the polyolefin fibers form less than or equal to 50% of the total surface area of the twisted, non-blended hybrid yarn. In another embodiment the polyolefin fibers form greater than or equal to 50% of the total surface area of the twisted, non-blended hybrid yarn. In a particularly preferred embodiment, the polyolefin fibers form from greater than 66% of the total surface area of the twisted, non-blended hybrid yarn up to 75% of the total surface area of the twisted, non-blended hybrid yarn. In another particularly preferred embodiment, the polyolefin fibers form from greater than 15% of the total surface area of the twisted, non-blended hybrid yarn up to 75% of the total surface area of the twisted, non-blended hybrid yarn, which is intended herein to be inclusive of all ranges between these minimum and maximum values, including, for example, from 20% of the total surface area of the twisted, non-blended hybrid yarn up to 75% of the total surface area of the twisted, non-blended hybrid yarn, more preferably from 20% of the total surface area of the twisted, non-blended hybrid yarn up to 70% of the total surface area of the twisted, non-blended hybrid yarn. In yet another embodiment, the polyolefin fibers form from about 25% of the total surface area of the twisted, non-blended hybrid yarn up to about 75% of the total surface area of the twisted, non-blended hybrid yarn. In yet another embodiment, the polyolefin fibers form from about 25% of the total surface area of the twisted, non-blended hybrid yarn up to about 65% of the total surface area of the twisted, non-blended hybrid yarn. In still another embodiment, the polyolefin fibers form from about 25% of the total surface area of the twisted, non-blended hybrid yarn up to about 50% of the total surface area of the twisted, non-blended hybrid yarn. In still another embodiment, the polyolefin fibers form from about 30% of the total surface area of the twisted, non-blended hybrid yarn up to about 50% of the total surface area of the twisted, non-blended hybrid yarn.

As schematically represented in FIGS. 1 and 2, each of the illustrated fibers as shown has approximately equal size (denier), and thus each fiber accounts for approximately one half (FIG. 1) or one third (FIG. 2) of the total surface area of the hybrid yarn. However, this will not be the case for all embodiments because the denier of each component fiber may vary, and thus, their contribution to the surface area of the hybrid yarn will correspondingly vary.

The extent of the total surface area occupied by a particular fiber type in the hybrid yarn (total surface area exposure) is determined by: (1) for each component fiber/yarn, first calculating the length of fiber/yarn in cm for 1 gram of material using the known fiber/yarn denier; then, (2) from this, calculate the volume occupied by each respective yarn component using the known yarn/fiber density (e.g., cotton density = 1.54 cm^3; SPECTRA® fiber density = 0.97 cm^3); then (3), since the volume of a cylinder (the fiber) = π x r^2 x h (= pi times radius squared times height), the mass, density and length of the fiber are known, r^2 can be calculated, and then r (cm), followed by using r to calculate the surface area, which = (2 x π x r^2 + 2 x π x r x h) cm^2 ((2 times pi times radius squared) plus (2 times pi times radius times height), units= cm^2). The surface area occupied by each yarn can be manipulated by increasing the denier of the fiber types (greater denier will accordingly correspond to greater surface area exposure, and lower denier will accordingly correspond to a lower surface area exposure).

In this regard, preferred polyolefin fibers are those having a preferred density of about 1.0 grams/cm^3 or less, more preferably from 0.9 grams/cm^3 to about 1.0 g/cm^3, and most preferably from about 0.93 g/cm^3 to about 0.97 g/cm^3. Ultra-high molecular weight polyethylene, which is the polymer of the most preferred polyolefin fiber types, has a density of 0.97 cm^3, though at very high molecular weights that may increase to from about 0.98 $cm^3$to about 0.995 cm^3, as would be known by one skilled in the art. The preferred non-polyolefin fibers have a density of greater than 1.0 g/cm^3, preferably from greater than 1.0 g/cm^3 to about 2.0 g/cm^3, more preferably about 1.25 g/cm^3 or greater, preferably from 1.25 g/cm^3 to about 2.0 g/cm^3, still more preferably from 1.25 g/cm^3 to 1.60 g/cm^3, still more preferably from 1.30 g/cm^3 to 1.60 g/cm^3 and most preferably from 1.30 g/cm^3 to 1.55 g/cm^3. In other embodiments, the non-polyolefin fibers have a density of greater than 1.5 g/cm^3, or from 1.5 g/cm^3 to about 2.0 g/cm^3.

In a preferred embodiment, the hybrid yarn preferably, but not necessarily, comprises a greater percentage by volume of said polyolefin fibers relative to said non-polyolefin fibers. In a preferred embodiment, the hybrid yarn has a polyolefin fiber content of from about 20.0% by volume to about 70.0% by volume of the hybrid yarn with a corresponding non-polyolefin fiber content of from 30.0% by volume to about

80.0% by volume, and inclusive of all ranges therebetween. In another preferred embodiment, the hybrid yarn has a polyolefin fiber content of from about 33.3% by volume to about 66.7% by volume of the yarn with a corresponding non-polyolefin fiber content of from 66.7% by volume to about 33.3% by volume. In another embodiment, the hybrid yarn has a polyolefin fiber content of from about 40% by volume to about 60% by volume of the yarn with a corresponding non-polyolefin fiber content of from 60% by volume to about 40% by volume. In another embodiment, the hybrid yarn has a polyolefin fiber content of from about 40% by volume to about 70% by volume of the yarn with a corresponding non-polyolefin fiber content of from 60% by volume to about 30% by volume. In one particularly preferred embodiment, the hybrid yarns of the disclosure incorporate one type of polyolefin fiber (e.g., a single UHMW PE fiber) and two different non-polyolefin fiber components (e.g., one cotton fiber and one polyester fiber, or one cotton fiber and one elastane fiber). In this embodiment, the volume ratio of the first non-polyolefin fiber type relative to the second non-polyolefin fiber type may vary but is preferably from about 1:3 to about 3:1. Additionally, the hybrid yarn preferably comprises a greater percentage by weight of said polyolefin fibers relative to the non-polyolefin fibers. In a preferred embodiment, the hybrid yarn has a polyolefin fiber content of from about 33.3% by weight to about 66.7% by weight of the yarn with a corresponding non-polyolefin fiber content of from 66.7% by weight to about 33.3% by weight. In another embodiment, the hybrid yarn has a polyolefin fiber content of from about 40% by weight to about 60% by weight of the yarn with a corresponding non-polyolefin fiber content of from 60% by weight to about 40% by weight. In another embodiment, the hybrid yarn has a polyolefin fiber content of from about 40% by weight to about 70% by weight of the yarn with a corresponding non-polyolefin fiber content of from 60% by weight to about 30% by weight.

Each of these fiber types may be individually twisted or untwisted before they are ply twisted together. Additionally, when multiple polyolefin or non-polyolefin fibers are incorporated in the hybrid yarn, two or more of them may be twisted together (e.g., ply twisted) or entangled (if they are multifilament fibers; e.g., air entangled) prior to being ply twisted with the one or more polyolefin fibers. Various methods of twisting fibers are known in the art and any method may be utilized. Useful twisting methods are described, for example, in U.S. patents 2,961,010; 3,434,275; 4,123,893;

4,819,458 and 7,127,879, the disclosures of which are incorporated herein by reference to the extent consistent herewith. Similarly, various methods of air entangling multifilament fibers are conventionally known and described, for example, in U.S. patents 3,983,609; 4,125,922; and 4,188,692, the disclosures of which are incorporated by reference herein to the extent consistent herewith. In a preferred embodiment, the individual component fibers of the hybrid yarn are neither twisted nor air entangled prior to ply twisting of the multiple fibers together to form a multi-ply hybrid yarn.

The twister apparatus may be configured to impart any desired number of twists to the combined yarn wherein the twist ratio of each fiber type relative to each other fiber type is most preferably 1:1, i.e., the same amount of twist is imparted to each fiber regardless of the number of polyolefin or non-polyolefin fiber types forming the twisted, non-blended hybrid yarn. However, the twist ratio of the one or more polyolefin fibers to the one or more non-polyolefin fibers may vary, for example, from about 10:1 to 1:10 inclusive of all ratios in between such as from about 5:1 to about 1:5, or from about 4:1 to about 1:4, or from about 3:1 to about 1:3 or from about 2:1 to about 1:2. These twist ratio are irrespective of the number of polyolefin or non-polyolefin yarns forming the twisted, non-blended yarn, and the preferred twist ratio may vary depending on the intended end use application as would be determined by one skilled in the art .

Preferably, the fibers are twisted together a twist amount of from about 0.5 twists per inch to about 20.0 twists per inch of the twisted yarn, more preferably from about 1.0 twists per inch to about 15.0 twists per inch, still more preferably from about 1.0 twists per inch to about 12.0 twists per inch of the yarn, still more preferably from about 1.0 twists per inch to about 10.0 twists per inch of the yarn, and most preferably from about 1.0 twists per inch to about 8.0 twists per inch of the yarn, most preferably wherein the twist ratio of each fiber type relative to each other fiber type is 1:1, i.e., the component yarns are brought together, without mixing or blending the filaments of the fibers together (i.e., they remain discrete and collectively the filaments forming the hybrid yarn are “non-blended”), and they are twisted together with the same twist amount for the combined bundle of yarns/fibers. The standard method for determining twist in twisted yarns is ASTM D1423-02. Each of the individual fiber/yarn components of the hybrid yarn may similarly be twisted at or within the same twist amount ranges.

Prior to twisting the polyolefin and non-polyolefin fibers together to form the hybrid yarn, each of the fiber components may individually be coated with a thermoplastic resin or polymeric binder material as would be determined by one skilled in the art, such as a polymeric binder material having adhesive properties. Alternatively, the hybrid yarn product comprising the twisted together fibers may be coated with a thermoplastic resin or polymeric binder material for the same purposes. Suitable thermoplastic resins non-exclusively include polyolefin resins such as polyolefin wax, low density polyethylene, linear low density polyethylene, polyolefin copolymers, ethylene copolymers such as ethylene-acrylic acid copolymer, ethylene-ethyl acrylate copolymer, ethylene-vinyl acetate copolymer, polyisoprene-polystyrene-block copolymers (such as KRATON® D1107 commercially available from Kraton Polymers of Houston, TX), polyurethanes, polyvinylidene fluoride, polychlorotetrafluoroethylene (PCTFE), and copolymers and blends of one or more of the foregoing. Suitable polyolefin waxes non-exclusively include ACumist® micronized polyolefin waxes commercially available from Honeywell International Inc. of Morris Plains, NJ. The most preferred thermoplastic resin will have a lower melting point than the individual fiber components of the hybrid yarn.

The fibers of the hybrid yarn may also be thermally bonded together or fused together with or without an adhesive coating. Thermal bonding and fusion are typically accomplished with the application of heat and tension, with the temperature conditions depending on the fiber types and their melting or softening points. The fibers may also be at least partially pre-coated with an oil, solvent or plasticizing material prior to fusing or bonding, such as mineral oil, paraffin oil or vegetable oil as is conventionally known in the art, such as is described in U.S. patents 5,540,990; 5,749,214; and 6,148,597. As stated in said patents, mineral oil acts as a plasticizer that enhances the efficiency of the fusion/bonding process permitting the process to be performed at lower temperatures. However, in the most preferred embodiments, the fibers forming the hybrid yarn are not fused together, i.e., they are unfused. It should also be understood that as used herein, the term “coated” is not intended to limit the method by which the resin, polymeric binder, oil or other coating is applied onto the individual fiber or hybrid yarn surfaces, and any conventional method may be used to coat the fibers, such as dipping, spraying or otherwise passing the fibers or hybrid yarn through bath of the coating material.

When the fibers of the hybrid yarn are coated with a thermoplastic resin or other polymeric binder material (either by coating the fibers individually before ply twisting or as one after ply twisting), only a small amount of the resin/binder is needed. In this regard, the quantity of resin/binder applied is typically no more than 5% by weight based on the total weight of the fibers (individually or collectively) plus the weight of the coating, such that the fibers comprise at least 95% by weight based on the total weight of the fibers plus the weight of the coating, and therefore the hybrid yarn will comprise at least 95% by weight of the component fibers. In more preferred embodiments, the hybrid yarn comprises at least about 96% fiber by weight, still more preferably at least 97% fiber by weight, still more preferably at least 98% fiber by weight, and still more preferably at least 99% fiber by weight. Most preferably, the hybrid yarns are completely resin and binder free, i.e., they most preferably are not coated with any resin or polymeric binder and consist essentially of or consist of only fibers/filaments.

After ply twisting, the hybrid yarn body itself may optionally be drawn to improve its properties, provided that the component fibers are capable of being drawn. Drawing of the hybrid yarn is a separate process from drawing of the component fibers forming the hybrid yarn. In this regard, polyolefin fibers are almost always drawn during their fabrication prior to being ply twisted with other fibers in order to enhance their tenacity, as described in commonly owned U.S. patents 7,846,363; 8,361,366; 8,444,898; 8,747,715 and 9,365,953. When it is desired to draw the hybrid yarn with heat, but without fusing the component fibers together, fusing is avoided by heating the hybrid yarn to a temperature below the melting point of the fibers. For example, when the hybrid yarn incorporates one or more ultra-high molecular weight, gel spun polyethylene multifilament fibers, the hybrid yarn stretching temperature is preferably within the range of from about 145°C to about 153°C, more preferably from about 148°C to about 151°C. In this regard, it is noted that highly oriented, ultra-high molecular weight polyethylene fibers generally have a higher melting point than bulk UHMW PE or lower molecular weight polyethylenes. During a drawing without fusion process, the hybrid yarn is preferably held under tension that is preferably applied continuously, and the stretching is preferably conducted at an overall stretching ratio in one or more stages of stretching of from about 1.01 to about 3.0, and more preferably from about 1.1 to about 1.8, with the application of heat.

The hybrid yarns of this disclosure may be produced into woven fabrics, knitted fabrics or non-woven fabrics. Non-woven fabrics include both unidirectional non-woven fabrics, felts and non-woven mats. Alternatively the hybrid yarns may be formed into other non-fabric fibrous structures, such as ropes, including braided ropes as described in U.S. patent 9,834,872 and U.S. pre-grant publications 2007/0202328 and 2007/0202331, each of which is incorporated herein by reference to the extent consistent herewith, or may be used as reinforcement threads materials in articles such as fiber reinforced paper (e.g., kraft paper) and fiber reinforced tape (e.g., packaging or strapping tape) and the like.

Methods of forming non-woven fabrics are well known in the art, such as by the methods described in U.S. patent 6,642,159, the disclosure of which is incorporated herein by reference. For example, the yarns may be formed into one or more non-woven plies by arranging a plurality of the hybrid yarns in a unidirectional, substantially parallel array, with the ply optionally being coated with a polymeric binder material to adhere the fibers together in the ply form. Suitable polymeric binder materials are well known in the art and include both thermoplastic and thermosetting materials. A plurality of such plies may then be stacked and adjoined, such as by stitching or consolidation with heat and pressure by conventional lamination or molding techniques, or fabric layers may just be glued together as is the case in a wet lamination process.

Woven fabrics may be formed using techniques that are well known in the art using any fabric weave, such as plain weave, crowfoot weave, basket weave, satin weave, twill weave and the like. Plain weave is most common, where fibers are woven together in an orthogonal 0°/90° orientation. Also useful are 3D weaving methods wherein multi-ply woven structures are fabricated by weaving warp and weft threads both horizontally and vertically. Prior to weaving, the hybrid yarns or fibers forming the yarns may or may not be coated with a thermoplastic or thermosetting polymeric binder material.

Whether the fabrics are woven or non-woven, the polymeric binder material may be a low modulus, thermoplastic material, a high modulus, rigid material or a combination thereof. Suitable low modulus polymeric binders include elastomeric materials having an initial tensile modulus less than about 6,000 psi (41.3 MPa), a preferred glass transition temperature (Tg) of less than about 0°C, more preferably the less than about -40°C, and most preferably less than about -50°C; and a preferred elongation to break of at least about 50%, more preferably at least about 100% and most preferably has an elongation to break of at least about 300%. Suitable high modulus, rigid materials have an initial tensile modulus at least about 1×10^6 psi (6895 MPa), each as measured at 37°C by ASTM D638. Examples of such materials are disclosed, for example, in U.S. Patent 6,642,159, the disclosure of which is expressly incorporated herein by reference. As used herein throughout, the term tensile modulus means the modulus of elasticity as measured by ASTM 2256 for a fiber and by ASTM D638 for a polymeric binder material.

The polymeric binder may be applied to a yarn of the disclosure in a variety of ways and as stated previously the term “coated” is not intended to limit the method by which the polymeric binder is applied onto the fiber/yarn surfaces. When a binder is used, the binder quantity in the woven or non-woven fabrics will be from about 1% to about 50% of the total weight of the fabric, more preferably from about 1% to about 25% of the total weight of the fabric and most preferably from about 1% to about 10% of the total weight of the fabric.

While the yarns of this disclosure are useful for generally any textile application, including wearable textile applications as well as non-wearable textile applications, such as tents, canopies, upholstery, curtains, parachutes and tarps, they are particularly attractive in the fabrication of protective garments, including seamless garments, and most particularly for the fabrication of high strength, abrasion resistant denim that is both functional and aesthetically attractive when used in garment applications.

Denim is a fabric that is traditionally made 100% from cotton yarns that are woven in a twill weave, forming a pattern of diagonal, parallel ribs or ridges. As is conventionally known, the fibers in a twill weave may be oriented in either in a left hand (LH or LHT (left hand twill) direction, being oriented diagonally upward to the left and downward to the right, or in a right hand (RH or RHT (right hand twill)) direction, being oriented diagonally upward to the right and downward to the left). Denims are also typically characterized in the number of warp threads (yarns/fibers) relative to the number of weft threads (yarns/fibers) in the weave. A 2x1 weave means that there are 2 warp threads in the weave for every one weft thread. A 3x1 weave means that there are 3 warp threads in the weave for every one weft thread, etc. The front face tends to have greater abrasion resistance than the rear because of the presence of more warp fibers in the construction (2x1, 3x1, 4x1, etc.).

In accordance with the present disclosure, rather than a denim fabric being formed entirely from cotton fibers, an abrasion resistant denim fabric is formed where the twill woven fibers comprise, consist of or consist essentially of the hybrid (twisted, non-blended) yarns of this disclosure wherein at least one polyolefin fiber is twisted together with at least one cotton yarn. In the most preferred denim application, a twill woven, abrasion resistant denim fabric is fabricated wherein each of the yarns forming the denim fabric are hybrid yarns in accordance with this disclosure wherein all of the hybrid yarns comprise, consist of or consist essentially of three discrete fibers such as illustrated in FIG. 2, one of which is a polyolefin fiber, most preferably a continuous multifilament UHMWPE fiber, and the other two fibers being discrete cotton fibers, with each cotton yarn being substantially similar to or identical to each other. In this example, the twill weave may be either LHT or RHT and may be any conventional denim weave style (2:1, 3:1, 4:1, etc.).

Additionally, it is conventional in a denim fabric that some of the cotton fibers will be dyed blue (e.g., with an indigo dye or blue reactive dye) while other cotton fibers are white (naturally white, dyed white or bleached). That is also preferred in the denim applications of the present disclosure, with any decorative pattern being acceptable as desired by the manufacturer. Similarly, the polyolefin fiber component of the twisted, non-blended hybrid yarns may be colored or non-colored. In one embodiment, the polyolefin is a black colored SPECTRA® fiber. In another embodiment, the polyolefin is a white SPECTRA® fiber. In another embodiment, the polyolefin fibers in some of the hybrid yarns are black while others are white in the same fabric article, as would be readily determined by one skilled in the art. Each of the yarn types (with blue dyed cotton yarns; with white cotton yarns; with black polyethylene fibers; or with white polyethylene fibers, in any combination) may be used as either the warp threads or the weft threads as the manufacturer desires.

In another desirable denim application, a twill woven fabric is formed wherein all the yarns forming the woven fabric are 3-ply hybrid yarns (again as illustrated in FIG. 2) as formed in accordance with the present disclosure, wherein the first discrete fiber of the yarn is a polyolefin fiber, most preferably a UHMWPE fiber; the second discrete fiber of the yarn is a cotton fiber (any color, such as blue and/or white); and the third discrete fiber of the yarn is a polyurethane fiber such as spandex (e.g., LYCRA™; also any color, e.g., black, white, blue, etc.) or another type of elastic/elastomeric fiber/yarn. In a particularly preferred embodiment, each of the twisted, non-blended hybrid yarns of this disclosure is a 3-ply (3-fiber/yarn) hybrid including two cotton yarns and one UHMWPE fiber (e.g., SPECTRA®), wherein each cotton yarn has a preferred denier of from about 80 to about 250, or from about 90 to about 225, preferably each having a denier of about 100, and wherein each UHMWPE fiber has a denier of from about 175 to about 425, more preferably from about 200 to about 400, with a most preferred hybrid yarn incorporating two cotton yarns each having a denier of 100 or about 100 and one UHMWPE fiber having a denier of 400 or about 400, or incorporating two cotton yarns each having a denier of 100 or about 100 and one UHMWPE fiber having a denier of 200 or about 200, incorporating two cotton yarns each having a denier of 221 or about 221 and one UHMWPE fiber having a denier of 400, or incorporating two cotton yarns each having a denier of 221 or about 221 and one UHMWPE fiber having a denier of 400 or about 400. Each fiber in each of these exemplary embodiments may be dyed or colored using conventional techniques in the art, including embodiments where the UHMWPE fiber is either a white SPECTRA® fiber or a black SPECTRA® fiber, and wherein the cotton fibers may be white or dyed blue.

In yet another embodiment, denim type fabrics may be fabricated from the twisted, non-blended hybrid yarns of this disclosure wherein the non-polyolefin fiber component of the hybrid yarn is a bi-component or wrapped fiber/yarn (e.g., helically wrapped core fiber/yarn), such as an elastomeric yarn (e.g., spandex fiber, such as LYCRA™) wrapped with a cover of another fiber/yarn type such as one or more cotton yarns, one or more nylon fibers, one or more polyester fibers, one or more polyolefin (e.g., polyethylene, such as UHMWPE, or polypropylene), having any denier as would be determined by one skilled in the art, including fibers/yarns having deniers within the denier ranges as described in this disclosure. For example, a denim fabric may be twill woven in a 3x1 or 2x1 LHT or RHT construction with warp threads that comprise hybrid yarns of this disclosure comprising two blue cotton yarn components, each cotton yarn having an English Cotton Count (ECC) of from about 12 to about 36, and one black or white SPECTRA® multi-filament fiber component having a denier of from about 200 to 600, preferably about 400, and with weft threads also comprising hybrid yarns of this disclosure which comprise covered elastomeric yarn (e.g., spandex fiber, such as LYCRA™) wrapped with cotton yarns or wrapped with nylon, polyester, UHMWPE or another polyolefin fiber of any selected denier. The wrapped yarn weft threads in this embodiment may also comprise more than one hybrid yarn type. For example, a first weft yarn type may comprise an elastomeric yarn wrapped with cotton yarn(s) and a second weft yarn type may be an elastomeric yarn wrapped with nylon fiber(s). Any combination and/or variation of weft yarns can be used to tailor the desired properties of the end fabric as determined by one skilled in the art.

In this regard, the abrasion resistance, and thus wear performance, of any fabric formed from the twisted, non-blended, hybrid yarns of this disclosure, including denim fabrics, may be tailored for either the front face of the fabric or the rear (back) of the fabric by increasing the surface area exposure of the polyolefin component (e.g., SPECTRA® fiber) of the hybrid yarn. This may be done by modifying the components used in the manufacturing of the hybrid yarn. For example, a hybrid yarn may be formed from two or more polyolefin (e.g., SPECTRA®) fibers rather than one, in combination with one natural fiber yarn or one non-polyolefin synthetic fiber/yarn. Or, the denier of the SPECTRA® fiber may be increased relative to the combined deniers or cotton counts (in ECC). In this regard, 24 ECC cotton yarn (approximately 221.5 denier) is half the denier of a 12 ECC cotton yarn (approximately 443 denier), and a 36 ECC cotton yarn (approximately 147.6 denier) is one third the denier of a 12 ECC cotton yarn. Thus a single 400 denier SPECTRA® UHMWPE continuous filament fiber will have a greater surface area exposure than two 36 ECC cotton yarns, and thus the abrasion resistance will be greater for fabrics made entirely of this type of yarn relative to a fabric formed exclusively from hybrid yarns formed by ply twisting together two 24 ECC cotton yarns with one 400 denier SPECTRA® UHMWPE continuous filament fiber. The surface area exposure of each fiber type may also be manipulated by altering the twist amount of each individual fiber/yarn component of the hybrid yarn. In this regard, each individual polyolefin or non-polyolefin fiber/yarn may be twisted before the multiple yarns are ply twisted together. Twisting the polyolefin fiber more will expose more of the polyolefin fiber at the surface of the hybrid yarn product per unit area, and twisting less will reduce the amount of polyolefin fiber exposed at the surface of the hybrid yarn product per unit area, and the same is true for the non-polyolefin yarn/fiber component.

While twill woven, denim applications including one or more cotton fibers is of particular interest herein, the hybrid yarns of this disclosure may be made into fabrics using any weaving, non-woven or knitting style, and twill woven fabrics may be fabricated without the hybrid yarns incorporating cotton fibers. For example, in another preferred embodiment, the twisted, non-blended hybrid yarn may comprise a single UHMWPE fiber (e.g., SPECTRA®), one polyester fiber and one nylon fiber, with a particularly preferred example being a combination of a 50 denier SPECTRA® fiber being combined with a 100 denier polyester fiber and a 200 denier nylon fiber (~12% SPECTRA® loading), but these deniers may vary as detailed above (e.g., 50-450 denier SPECTRA® fiber combined with a 50-250 denier polyester fiber and a 50-250 denier nylon fiber).

In addition, it is not necessary for fabric articles of this disclosure to be fabricated from only the hybrid yarns of this disclosure. Other discrete fibers (monofilament or multifilament), hybrid yarns (e.g., bi-component yarns or different hybrid yarns than taught herein) or non-hybrid yarns (e.g., formed from multiple interconnected fibers such as by twisting or entangling) may be incorporated.

In one alternative embodiment, a plurality of hybrid yarns of this disclosure may be woven together with a plurality of polyethylene fibers, such as SPECTRA® 900

UHMW PE fibers, SPECTRA® 1000 UHMW PE fibers or SPECTRA® 3000 UHMW PE fibers, all of which are commercially available from Honeywell International Inc. of Morristown, NJ. In another alternative embodiment, a plurality of hybrid yarns of this disclosure may be woven together with a plurality of one or more non-polyolefin fiber types as described above.

In addition, fabrics formed solely or partially from the hybrid yarns of this disclosure may be combined with or attached to other fabrics that are not formed either solely or partially from the hybrid yarns. In one embodiment, a woven fabric formed by weaving the hybrid yarns of this disclosure together with said hybrid yarns forming both the warp yarns and the weft/fill yarns may be combined (e.g., adhered, stitched to or sewn together) with a different woven fabric that incorporates no polyolefin fibers, e.g., a fabric formed from cotton yarns, wool yarns, elastane yarns, or a combination thereof, as may be desirable for certain end us applications. Fabrics formed from the hybrid yarns of this disclosure may also be used as protective patches or sections of garments, protective clothing or athletic wear, or non-wearable textile articles, to enhance abrasion resistance in targeted sections of the articles as would be determined by one skilled in the art.

Finally, due to the enhanced fabric strength imparted by the polyolefin fibers, highly abrasion resistant fabrics of this disclosure may be made thinner than comparative fabrics made from other materials such as 100% cotton fibers without sacrificing abrasion resistance performance. In this regard, the thickness of a single fabric layer produced from the hybrid yarns of this disclosure will generally depend on the denier of the hybrid yarns forming the fabric, so the thicknesses may vary. In this regard, a single layer of fabric may generally have a thickness of from about 25 µm to about 600 µm per layer (i.e., per ply), or from about 50 µm to about 385 µm per layer/ply, or from about 75 µm to about 255 µm per layer/ply, with the greater thicknesses generally being achieved by increasing the denier of the yarns by increasing the number of component fibers twisted together to form the hybrid yarns. Additionally, in order to further improve abrasion resistance, coatings may be applied to the face of the fabric, such as a coating of polyurethane or any other well-known abrasion resistant coating as is conventionally known in the art.

The following examples serve to illustrate the preferred embodiments.

EXAMPLE 1

A denim fabric of this disclosure was made by weaving together a plurality of twisted, non-blended composite yarns of the disclosure in a twill weave. Each twisted, non-blended composite yarn was made from three fiber/yarn types. The three fibers/yarns used to form each composite yarn of the twill woven fabric were two cotton yarns and one ultra-high molecular weight polyethylene (UHMWPE) fiber. Cotton yarns are spun yarns which are made by spinning together (or otherwise joining) a plurality of cotton staple fibers into the form of a single yarn, as is conventionally known in the art. Such cotton yarns are commercially available in several varieties. The UHMWPE fiber used for all of these examples were 400 denier, continuous filament, multi-filament SPECTRA® S-1000 fibers having a tenacity of 36 g/denier, commercially available from Honeywell International Inc. However, any fibers available the SPECTRA® trademark are useful herein as well as other polyolefin fiber brands, including other types of UHMWPE fibers.

To form the hybrid composite yarn, all three fibers/yarns forming the hybrid were first laid together in parallel with each other and then they were twisted together (at a 1:1 twist ratio relative to each other). This resulted in the UHMWPE fiber being visible on the surface of the composite yarn, in a proportionate ratio among itself and the cotton yarns. In this example, the composite yarns used as warp direction yarns incorporated two cotton yarns that were dyed deep blue (from indigo dyes) and have an English Cotton Count (ECC) of 24. The SPECTRA® fiber was a 400 denier black (colored) fiber. The composite yarns used as weft direction yarns incorporated two white 24 ECC cotton yarns (either dyed white and/or bleached white and/or naturally white (non-dyed)). The SPECTRA® fiber was a 400 denier white fiber.

In this example, a 3x1 LH (3-by-1 Left Hand) twill weave was used. The 3-to-1 denotes that there are three warp yarns for each one weft yarn. Left Hand twill weave means that the warp threads are in a diagonal pattern that starts at the bottom right and moves up to the left of the fabric relative to the weft yarns that are used as interlacing. This weaving style was continued across the fabric giving a characteristic denim feature of twill lines and exposing the highly abrasion resistant SPECTRA® fiber for the unique wear resistance feature of the denim fabric.

EXAMPLE 2

Similar to Example 1, another denim fabric was woven in a 3x1 LH twill weave construction with composite yarns having two cotton yarn components and one SPECTRA® fiber component. The composite yarn used in the warp direction had two 24 ECC cotton yarns that were dyed deep blue with a reactive blue dye and the SPECTRA® fiber was a black 400 denier fiber. The composite yarns used in the weft direction included two 24 ECC white cotton yarns (dyed white and/or bleached and/or naturally white (undyed)) and the SPECTRA® fiber was a white 400 denier fiber. In each of Examples 1 and 2, the hybrid yarns had the following properties:

TABLE 1

		Weight Ratio		
	Type	**ECC**	**Denier (g/9000 m)**	**Weight Proportion**
Yarn 1	Cotton	24	221	26%
Yarn 2	Cotton	24	221	26%
Yarn 3	UHMWPE	N/A	400	47%

TABLE 2

	Volume Ratio				
	Density (g/cm^3)	Grams/Meter	Grams/cm	Volume (cm^3)	Volume Proportion
Yarn 1	1.54	0.02460	0.00025	0.00016	21%
Yarn 2	1.54	0.02460	0.00025	0.00016	21%
Yarn 3	0.97	0.04444	0.00044	0.00046	59%

TABLE 3

Surface Area								
Weight (g)	Meters	1 Gram (m)	1 Meter (grams)	Volume (cm^3)	r^2	r (radius)	Surface Area (3.14r^2)	Surface Area %
221	9000	40.7	0.02456	0.01595	0.0051	0.07126	0.01595	21%
221	9000	40.7	0.02456	0.01595	0.0051	0.07126	0.01595	21%
400	9000	22.5	0.04444	0.04582	0.0146	0.12080	0.04582	59%

EXAMPLE 3

The front faces and rear surfaces of the twill woven fabrics of Examples 1 and 2 were tested for abrasion resistance according to ASTM D4060 using an H-18 testing wheel and a 1000-gram load weight. Compared to a standard cotton denim fabric fabricated with 100% cotton (all warp and weft threads being 24 ECC cotton yarns in a 3x1 LHT construction), the abrasion resistance of the denim fabrics formed from the hybrid (composite) yarns of this disclosure was substantially improved, increasing from 467 cycles to failure (standard cotton denim fabric) to 6968 cycles to failure (denim fabric with all warp and weft threads being the twisted, non-blended hybrid yarns as outlined in Tables 1-3) when comparing abrasion resistance at the front faces of each fabric type, and from 407 cycles to failure (standard cotton denim fabric) to 4879 cycles to failure (the same denim fabric with all warp and weft threads being the twisted, non-blended hybrid yarns as outlined in Tables 1-3) at the rear faces of each fabric type. That is an improvement in abrasion resistance performance of greater than 10x on both the front face and rear surface of the fabric. The front face has a greater abrasion resistance than the rear because of the presence of more warp fibers in the 3x1 construction than weft fibers at the rear face.

EXAMPLE 4 (COMPARATIVE)

The abrasion resistance of a comparable DYNEEMA® denim fabric (fibers manufactured by DSM Dyneema B.V. of The Netherlands) was tested according to the same conditions as in Example 3 (ASTM D4060; H-18 testing wheel; 1000-gram load weight). The face of the fabric had a failure per unit weight of 467 cycles compared to 550 cycles (each fabric being normalized to per unit weight of the fabric) with an increase of 17% increase in abrasion performance on a per unit basis.

EXAMPLE 5 (COMPARATIVE)

Example 4 was repeated but the tested competitor's fabric was coated with a polyurethane coating to improve abrasion resistance. The uncoated, twisted, non-blended hybrid yarn based fabric of this disclosure was still superior, with the competitor's fabric failing at 537 cycles on a per unit basis compared to 550 cycles (again with each fabric being normalized to per unit weight of the fabric) for the fabrics of Examples 1 and 2. The fabrics of this disclosure without a supplemental abrasion resistant coating was superior to the competitor's product that included the additional coating that enhanced abrasion resistance.

EXAMPLE 6

Fabrics as per Examples 1 and 2 made with a 3x1 LH twill construction from all hybrid composite yarn of SPECTRA® fiber twisted together with two cotton yarns were evaluated for weight loss after reaching their failure points during abrasion testing under the conditions of ASTM D4060 as per Example 3. The hybrid yarn-based fabrics had a lower weight loss than standard denim fabrics formed with 100% cotton yarns. The fabrics of Examples 1 and 2 had a 34% lower loss of weight on the face of the fabric and a 40% lower loss of weight on the back of the abrasion testing machine.

EXAMPLE 7

Fabrics as per Examples 1 and 2 made with a 3x1 LH twill construction from all hybrid composite yarn of SPECTRA® fiber twisted together with two cotton yarns were evaluated for tensile strength loss after reaching their failure points during abrasion testing under the conditions of ASTM D4060 as per Example 3. The fabric tensile strength per unit weight for the fabrics of Examples 1 and 2 in both the warp and weft directions of the fabric was compared to the standard 100% cotton fabric and to both coated and uncoated DYNEEMA fabrics as described in Examples 4 and 5. The fabric tensile strength of the hybrid yarn-based fabrics per unit weight was 1016% higher than standard 100% cotton denim, 31% higher than uncoated DYNEEMA® fabric and 22% higher than coated DYNEEMA® fabric.

EXAMPLE 8

Similar to Example 1, another denim fabric was fabricated but with a 2x1 LH twill weave with the warp hybrid composite yarns comprising two 24 ECC indigo dyed blue cotton yarns twisted together with one 400 denier black SPECTRA® fiber and the weft hybrid composite yarns comprising two 24 ECC white cotton yarns twisted together with one 400 denier white SPECTRA® fiber.

EXAMPLE 9

Similar to Example 2, another denim fabric was fabricated but with a 2x1 LH twill weave with the warp hybrid composite yarns comprising two 24 ECC reactive blue dye dyed cotton yarns twisted together with one 400 denier black SPECTRA® fiber and the weft hybrid composite yarns comprising two 24 ECC white cotton yarns twisted together with one 400 denier white SPECTRA® fiber.

EXAMPLE 10

Similar to Example 1, another denim fabric was fabricated but with a 4x1 LH twill weave with the warp hybrid composite yarns comprising two 24 ECC indigo dyed blue cotton yarns twisted together with one 400 denier black SPECTRA® fiber and the weft hybrid composite yarns comprising two 24 ECC white cotton yarns twisted together with one 400 denier white SPECTRA® fiber.

EXAMPLE 11

Similar to Example 2, another denim fabric was fabricated but with a 4x1 LH twill weave with the warp hybrid composite yarns comprising two 24 ECC reactive blue dye dyed cotton yarns twisted together with one 400 denier black SPECTRA® fiber and the weft hybrid composite yarns comprising two 24 ECC white cotton yarns twisted together with one 400 denier white SPECTRA® fiber.

EXAMPLE 12

Similar to Example 1, another denim fabric was fabricated but with a 3x1 RH twill weave with the warp hybrid composite yarns comprising two 24 ECC indigo dyed blue cotton yarns twisted together with one 400 denier black SPECTRA® fiber and the weft hybrid composite yarns comprising two 24 ECC white cotton yarns twisted together with one 400 denier white SPECTRA® fiber.

EXAMPLE 13

Similar to Example 2, another denim fabric was fabricated but with a 3x1 RH twill weave with the warp hybrid composite yarns comprising two 24 ECC reactive blue dye dyed cotton yarns twisted together with one 400 denier black SPECTRA® fiber and the weft hybrid composite yarns comprising two 24 ECC white cotton yarns twisted together with one 400 denier white SPECTRA® fiber.

EXAMPLE 14

Similar to Example 1, another denim fabric was fabricated but with a 2x1 RH twill weave with the warp hybrid composite yarns comprising two 24 ECC indigo dyed blue cotton yarns twisted together with one 400 denier black SPECTRA® fiber and the weft hybrid composite yarns comprising two 24 ECC white cotton yarns twisted together with one 400 denier white SPECTRA® fiber.

EXAMPLE 15

Similar to Example 2, another denim fabric was fabricated but with a 3x1 RH twill weave with the warp hybrid composite yarns comprising two 24 ECC reactive blue dye dyed cotton yarns twisted together with one 400 denier black SPECTRA® fiber and the weft hybrid composite yarns comprising two 24 ECC white cotton yarns twisted together with one 400 denier white SPECTRA® fiber.

EXAMPLE 16

Similar to Example 1, another denim fabric was fabricated but with a 4x1 RH twill weave with the warp hybrid composite yarns comprising two 24 ECC indigo dyed blue cotton yarns twisted together with one 400 denier black SPECTRA® fiber and the weft hybrid composite yarns comprising two 24 ECC white cotton yarns twisted together with one 400 denier white SPECTRA® fiber.

EXAMPLE 17

Similar to Example 2, another denim fabric was fabricated but with a 4x1 RH twill weave with the warp hybrid composite yarns comprising two 24 ECC reactive blue dye dyed cotton yarns twisted together with one 400 denier black SPECTRA® fiber and the weft hybrid composite yarns comprising two 24 ECC white cotton yarns twisted together with one 400 denier white SPECTRA® fiber.

While the present disclosure has been particularly shown and described with reference to preferred embodiments, it will be readily appreciated by those of ordinary skill in the art that various changes and modifications may be made without departing from the spirit and scope of the disclosure. It is intended that the claims be interpreted to cover the disclosed embodiments, those alternatives which have been discussed above and all equivalents thereto.

What is claimed is:

1. A twisted, non-blended yarn comprising a twisted combination of one or more polyolefin fibers and one or more non-polyolefin fibers, wherein the twisted yarn has a yarn surface area, wherein said polyolefin fibers form greater than 20% of said yarn surface area, and wherein said polyolefin fibers and said non-polyolefin fibers are twisted together.

2. The twisted, non-blended yarn of claim 1 wherein said polyolefin fibers are continuous ultra-high molecular weight polyethylene fibers and wherein said non-polyolefin fibers comprise one or more synthetic fibers, one or more natural fibers or both one or more synthetic fibers and one or more natural fibers.

3. The twisted, non-blended yarn of claim 1 wherein said non-polyolefin fibers comprise both cotton fibers and elastic fibers and wherein said polyolefin fibers form from about 25% of the surface area of the yarn up to about 65% of the surface area of the yarn.

4. The twisted, non-blended yarn of claim 1 wherein said polyolefin fibers form from greater than 66% of the surface area of the yarn up to 75% of the surface area of the yarn and wherein said twisted yarn comprises a greater percentage by weight of said polyolefin fibers relative to said non-polyolefin fibers.

5. The twisted, non-blended yarn of claim 1 wherein said yarn comprises a first non-polyolefin fiber and a second non-polyolefin fiber, wherein said first non-polyolefin fiber and said second non-polyolefin fiber are chemically different, and wherein the volume ratio of the first non-polyolefin fiber type relative to the second non-polyolefin fiber type is from about 1:3 to about 3:1.

6. The twisted, non-blended yarn of claim 5 wherein said first non-polyolefin fiber comprises one or more nylon fibers and said second non-polyolefin fiber comprises one or more polyester fibers.

7. The twisted, non-blended yarn of claim 1 wherein the yarn has a polyolefin fiber content of from about 40% by volume to about 70% by volume of the yarn.

8. A twisted, non-blended yarn comprising a twisted combination of one or more polyolefin fibers and one or more non-polyolefin fibers, said non-polyolefin fibers having a tenacity of 20 g/denier or less and said non-polyolefin fibers having a density of greater than 1.0 grams/cm^3, and wherein said fibers are twisted together.

9. The twisted, non-blended yarn of claim 8 wherein said twisted yarn has from about 0.5 to about 15 twists per inch of length of the twisted yarn, wherein said polyolefin fibers are continuous ultra-high molecular weight polyethylene fibers having a tenacity of greater than 20 g/denier, wherein said non-polyolefin fibers have a tenacity of at least about 10 g/denier and wherein said non-polyolefin fibers have a density of greater than 1.5 grams/cm^3.

10. A process for producing a twisted, non-blended yarn, comprising:
a) providing one or more polyolefin fibers;
b) providing one or more non-polyolefin fibers, wherein said non-polyolefin fibers comprise one or more synthetic fibers, one or more natural fibers, or both one or more synthetic fibers and one or more natural fibers;
c) laying said polyolefin fibers and said non-polyolefin fibers side-by-side in parallel to thereby form a non-blended, untwisted fiber bundle wherein the untwisted fiber bundle has a surface area, and wherein said polyolefin fibers form greater than 20% of said fiber bundle surface area; and
d) twisting said non-blended fiber bundle to form a twisted yarn, wherein said polyolefin fibers and said non-polyolefin fibers are twisted together at a 1:1 ratio relative to each other, wherein the twisted yarn has a yarn surface area and wherein said polyolefin fibers form greater than 20% of said twisted yarn surface area.

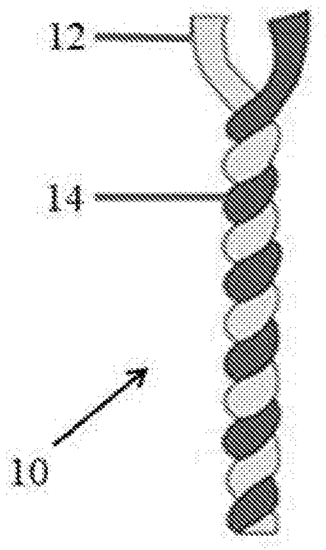

FIG. 1

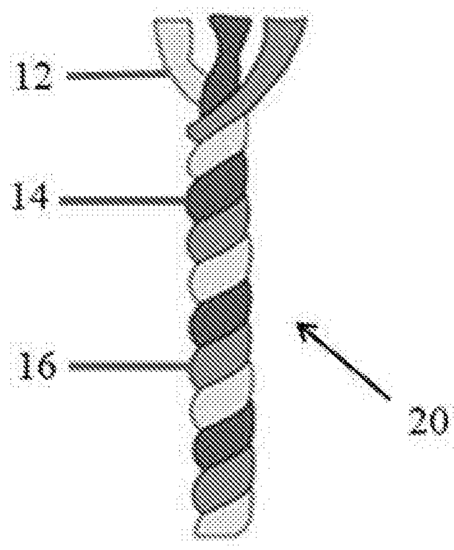

FIG. 2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2019/059046

A. CLASSIFICATION OF SUBJECT MATTER

D02G 3/04(2006.01)i, D02G 3/28(2006.01)i, D02G 3/44(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
D02G 3/04; B32B 38/00; B32B 5/02; B32B 5/26; B66C 1/12; D01F 6/46; D02G 3/00; D02G 3/44; D03D 11/00; D04B 1/12; D04B 1/18; D02G 3/28

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords:twisted yarn, polyolefin fiber, non-polyolefin fiber, yarn surface area, ultra-high molecular weight polyethylene fiber

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 2009-026215 A1 (HONEYWELL INTERNATIONAL INC. et al.) 26 February 2009 See page 2, line 24 - page 9, line 20; page 15, lines 4-5.	1-10
Y	WO 2009-130001 A1 (DSM IP ASSETS B.V.) 29 October 2009 See page 5, line 29 - page 6, line 1; page 12, line 1 - page 13, line 9.	1-10
A	US 2013-0095716 A1 (HANKS, JEFFREY ALAN et al.) 18 April 2013 See paragraphs [0045]-[0062].	1-10
A	US 2016-0185078 A1 (HONEYWELL INTERNATIONAL INC.) 30 June 2016 See paragraphs [0045]-[0062].	1-10
A	WO 2018-081057 A1 (INVISTA NORTH AMERICA S.A R.L.) 03 May 2018 See paragraphs [0010]-[0062].	1-10

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 February 2020 (26.02.2020)	**26 February 2020 (26.02.2020)**

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