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(54) Title: YARN, TEXTILE MATERIAL, AND GARMENT COMPRISING THE SAME

(57) Abstract: A yarn comprises: (a) about 45% to about 85% by weight of regenerated cellulose fibers, the regenerated cellulose fibers having a dry tenacity of about 27 cN/tex or more, the regenerated cellulose fibers comprising a flame retardant compound within the fiber; and (b) about 5% to about 25% by weight of para-aramid fibers. A textile material, such as a fabric, comprises a plurality of these yarns. A garment, such as a shirt or a pant, comprises such a textile material. A method for protecting an individual from infrared radiation that can be generated during an arc flash utilizes such a textile material.



**YARN, TEXTILE MATERIAL,
AND GARMENT COMPRISING THE SAME**

TECHNICAL FIELD

[0001] This application relates to yarns, textile materials, and garments exhibiting flame resistant properties.

BACKGROUND

[0002] Flame resistant fabrics are useful in many applications, including the production of garments worn by personnel in a variety of industries or occupations, such as the military, electrical (for arc protection), petroleum chemical manufacturing, and emergency response fields. Cellulosic or cellulosic-blend fabrics have typically been preferred for these garments, due to the relative ease with which these fabrics may be made flame resistant and the relative comfort of such fabrics to the wearer.

[0003] Notwithstanding the popularity of cellulosic or cellulosic-blend flame resistant fabrics, existing fabrics do suffer from limitations. The flammability performance of many cellulosic flame resistant fabrics is not sufficient to meet the demanding requirements of certain industries. Accordingly, a need remains to provide alternative flame resistant fabrics that are capable of meeting applicable flame resistance standards at lower cost.

BRIEF SUMMARY OF THE INVENTION

[0004] In a first embodiment, the invention provides a yarn comprising: (a) about 45% to about 85% by weight of regenerated cellulose fibers, the regenerated cellulose fibers having a dry tenacity of about 27 cN/tex or more, the regenerated cellulose fibers comprising a flame retardant compound within the fiber; and (b) about 5% to about 25% by weight of *para*-aramid fibers.

[0005] In a second embodiment, the invention provides a textile material comprising a plurality of yarns, the yarns comprising: (a) about 45% to about 85% by weight of regenerated cellulose fibers, the regenerated cellulose fibers having a dry tenacity of about 27 cN/tex or more, the regenerated cellulose fibers comprising

a flame retardant compound within the fiber; and (b) about 5% to about 25% by weight of *para*-aramid fibers.

[0006] In a third embodiment, the invention provides a garment comprising one or more fabric panels, at least one of the fabric panels comprising a plurality of yarns, the yarns comprising: (a) about 45% to about 85% by weight of regenerated cellulose fibers, the regenerated cellulose fibers having a dry tenacity of about 27 cN/tex or more, the regenerated cellulose fibers comprising a flame retardant compound within the fiber; and (b) about 5% to about 25% by weight of *para*-aramid fibers.

[0007] In a fourth embodiment, the invention provides a shirt comprising a plurality of fabric panels, at least one of the fabric panels defining a body covering portion of the shirt and at least two of the fabric panels defining sleeves attached to the body covering portion of the shirt, at least one of the fabric panels comprising a plurality of yarns, the yarns comprising: (a) about 45% to about 85% by weight of regenerated cellulose fibers, the regenerated cellulose fibers having a dry tenacity of about 27 cN/tex or more, the regenerated cellulose fibers comprising a flame retardant compound within the fiber; and (b) about 5% to about 25% by weight of *para*-aramid fibers.

[0008] In a fifth embodiment, the invention provides a pant comprising a plurality of fabric panels, at least two of the fabric panels defining leg covering portions of the pant, at least one of the fabric panels comprising a plurality of yarns, the yarns comprising: (a) about 45% to about 85% by weight of regenerated cellulose fibers, the regenerated cellulose fibers having a dry tenacity of about 27 cN/tex or more, the regenerated cellulose fibers comprising a flame retardant compound within the fiber; and (b) about 5% to about 25% by weight of *para*-aramid fibers.

[0009] In a sixth embodiment, the invention provides a method for protecting an individual from infrared radiation that can be generated during an arc flash, the method comprising the step of positioning a textile material between an individual and an apparatus capable of producing an arc flash, the textile material comprising a plurality of yarns, the yarns comprising: (a) about 45% to about 85% by weight of regenerated cellulose fibers, the regenerated cellulose fibers having a dry tenacity of

about 27 cN/tex or more, the regenerated cellulose fibers comprising a flame retardant compound within the fiber; and (b) about 5% to about 25% by weight of *para*-aramid fibers.

DETAILED DESCRIPTION OF THE INVENTION

[0010] As noted above, the invention provides flame resistant textile materials. As utilized herein, the term “flame resistant” refers to a material that burns slowly or is self-extinguishing after removal of an external source of ignition. The flame resistance of textile materials can be measured by any suitable test method, such as those described in National Fire Protection Association (NFPA) 701 entitled “Standard Methods of Fire Tests for Flame Propagation of Textiles and Films,” ASTM D6413 entitled “Standard Test Method for Flame Resistance of Textiles (vertical test)”, NFPA 2112 entitled “Standard on Flame Resistant Garments for Protection of Industrial Personnel Against Flash Fire”, ASTM F1506 entitled “The Standard Performance Specification for Flame Resistant Textile Materials for Wearing Apparel for Use by Electrical Workers Exposed to Momentary Electric Arc and Related Thermal Hazards”, and ASTM F1930 entitled “Standard Test Method for Evaluation of Flame Resistant Clothing for Protection Against Flash Fire Simulations Using an Instrumented Manikin.”

[0011] In a first embodiment, the invention provides a yarn comprising regenerated cellulose fibers and *para*-aramid fibers. The yarns can be any suitable type of yarn. Preferably, the regenerated cellulose fibers and *para*-aramid fibers are staple fibers, and the yarns are spun yarns. Such spun yarns can be formed by any suitable spinning process, such as ring spinning, air-jet spinning, or open-end spinning. In certain embodiments, the yarns are spun using a ring spinning process (i.e., the yarns are ring spun yarns).

[0012] The yarn of the invention comprises regenerated cellulose fibers. The term “regenerated cellulose fibers” is utilized herein to refer to fibers made by dissolving cellulose in a suitable solvent and then spinning or extruding the solution in an appropriate medium so that the cellulose precipitates or coagulates in the form of filaments or fibers. There are several different types of regenerated cellulose fibers available. Suitable regenerated cellulose fibers include, but are not limited to,

rayon fibers (e.g., viscose rayon fibers, high wet modulus rayon fibers, modal fibers, and polynosic fibers), lyocell fibers, and mixtures thereof. In a preferred embodiment, the regenerated cellulose fibers are selected from the group consisting of rayon fibers, lyocell fibers, and mixtures thereof. In a more preferred embodiment, the regenerated cellulose fibers are lyocell fibers.

[0013] Regenerated cellulose fibers typically exhibit a degree of softness and moisture regain that makes them particularly useful in producing textile materials that are comfortable when worn. However, some regenerated cellulose fibers suffer from relatively low tenacity (especially wet tenacity). The weakness of such regenerated cellulose fibers means that they cannot be used in textile materials in large amounts without sacrificing the durability of the textile material. Therefore, the regenerated cellulose fibers utilized in the embodiments of the invention preferably exhibit a relatively high tenacity, both when dry and when wet. More specifically, the regenerated cellulose fibers preferably exhibit a dry tenacity of about 27 cN/tex or more, more preferably about 30 cN/tex or more, and most preferably about 35 cN/tex or more. The regenerated cellulose fibers also preferably exhibit a wet tenacity of about 20 cN/tex or more or about 25 cN/tex or more.

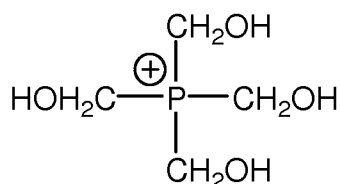
[0014] The regenerated cellulose fibers can be present in the yarn in any suitable amount. When the regenerated cellulose fibers possess the relatively high tenacities described above, the regenerated cellulose fibers can be incorporated into the yarn (and the yarns into textile materials) without sacrificing the durability of the yarn and any textile material into which the yarns are incorporated. In a preferred embodiment, the regenerated cellulose fibers are present in the yarn in an amount of about 40% or more, about 45% or more, about 50% or more, about 55% or more, about 60% or more, or about 65% or more (e.g. about 70%) by weight based on the total weight of fibers present in the yarn. While regenerated cellulose fibers possessing the relatively high tenacities described above can be used in relatively high amounts, the yarn of the invention can comprise other fibers (e.g., *para*-aramid fibers) that produce and/or enhance the other desirable properties of the yarn. Thus, the regenerated cellulose fibers preferably are present in the yarn in an amount of about 85% or less (e.g., about 80% or less or about 75% or less) by weight based on the total weight of fibers present in the yarn. Accordingly, in a series of preferred

embodiments, the regenerated cellulose fibers preferably are present in the yarn in an amount of about 45% to about 85%, about 50% to about 85%, about 55% to about 85%, about 60% to about 85%, or about 65% to about 85% (e.g., about 65% to about 80% or about 65% to about 75%) by weight based on the total weight of fibers present in the yarn.

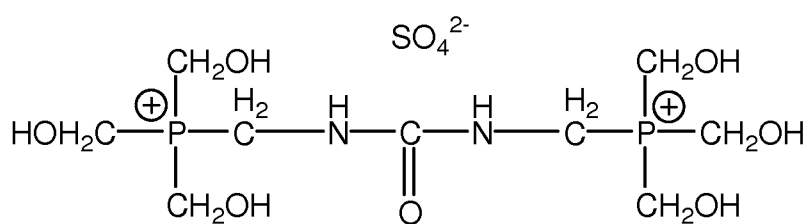
[0015] The regenerated cellulose fibers preferably comprise a flame retardant compound within the fiber. This flame retardant compound preferably is incorporated into the regenerated cellulose fiber in such a way that it does not significantly decrease the tenacity of the virgin regenerated cellulose fiber (i.e., the regenerated cellulose fiber without the flame retardant). Indeed, the regenerated cellulose fibers preferably exhibit tenacities within the ranges recited above even after the flame retardant compound is incorporated into the fibers. This distinguishes the regenerated cellulose fibers used in the invention from other flame retardant regenerated cellulose fibers, such as FR rayon, which can exhibit dramatic decreases in tenacity owing to the incorporation of the flame retardant compound. The regenerated cellulose fibers can comprise any suitable flame retardant compound. Preferably, the regenerated cellulose fibers comprise a phosphorous-containing flame retardant compound.

[0016] The phosphorous-containing flame retardant compound can be any suitable phosphorous-containing flame retardant compound. Preferably, the phosphorous-containing flame retardant compound is a compound produced by first reacting (i) a tetrahydroxymethyl phosphonium salt, a condensate of a tetrahydroxymethyl phosphonium salt, or a mixture thereof and (ii) a cross-linking agent. The resulting condensation product is then oxidized, which is believed to convert at least a portion of the phosphorous atoms in the condensation product from a trivalent form to a more stable pentavalent form. The condensation product can be oxidized using any suitable oxidant, such as hydrogen peroxide, sodium perborate, or sodium hypochlorite.

[0017] The term "tetrahydroxymethyl phosphonium salt" refers to salts containing the tetrahydroxymethyl phosphonium (THP) cation, which has the structure



including, but not limited to, the chloride, sulfate, acetate, carbonate, borate, and phosphate salts. As utilized herein, the term “condensate of a tetrahydroxymethyl phosphonium salt” (THP condensate) refers to the product obtained by reacting a tetrahydroxymethyl phosphonium salt, such as those described above, with a limited amount of a cross-linking agent, such as urea, guanazole, or biguanide, to produce a compound in which at least some of the individual tetrahydroxymethyl phosphonium cations have been linked through their hydroxymethyl groups. The structure for such a condensate produced using urea is set forth below



The synthesis of such condensates is described, for example, in Frank et al. (*Textile Research Journal*, November 1982, pages 678-693) and Frank et al. (*Textile Research Journal*, December 1982, pages 738-750). These THPS condensates are also commercially available, for example, as PYROSAN® CFR from Emerald Performance Materials.

[0018] The cross-linking agent is any suitable compound that enables the cross-linking and/or curing of THP. Suitable cross-linking agents include, for example, urea, a guanidine (i.e., guanidine, a salt thereof, or a guanidine derivative), guanyl urea, glycoluril, ammonia, an ammonia-formaldehyde adduct, an ammonia-acetaldehyde adduct, an ammonia-butyraldehyde adduct, an ammonia-chloral adduct, glucosamine, a polyamine (e.g., polyethyleneimine, polyvinylamine, polyetherimine, polyethyleneamine, polyacrylamide, chitosan, aminopolysaccharides), glycidyl ethers, isocyanates, blocked isocyanates and

combinations thereof. Preferably, the cross-linking agent is urea or ammonia, with urea being the more preferred cross-linking agent.

[0019] The flame retardant compound can be incorporated into the regenerated cellulose fibers in any suitable way. For example, the flame retardant compound can be incorporated into the solvent in which the cellulose is dissolved or into the cellulose stock. When this is done, the flame retardant compound is incorporated into the fiber as it is extruded. Alternatively, the fiber or yarn (or a textile materials made from the yarn) can be post-treated with the flame retardant compound using techniques that are known in the art.

[0020] When the flame retardant is applied to the fiber or yarn (or a textile material made from the yarn), the THP or THP condensate can be applied in any suitable amount. Typically, the THP salt or THP condensate is applied in an amount that provides at least 0.5% (e.g., at least 1%, at least 1.5%, at least 2%, at least 2.5%, at least 3%, at least 3.5%, at least 4%, or at least 4.5%) of elemental phosphorus based on the weight of the untreated fiber or yarn (or a textile material made from the yarn). The THP salt or THP condensate is also typically applied in an amount that provides less than 5% (e.g., less than 4.5%, less than 4%, less than 3.5%, less than 3%, less than 2.5%, less than 2%, less than 1.5%, or less than 1%) of elemental phosphorus based on the weight of the untreated fiber or yarn (or a textile material made from the yarn). Preferably, the THP salt or THP condensate is applied in an amount that provides about 1% to about 4% (e.g., about 1% to about 3% or about 2% to about 3%) of elemental phosphorous based on the weight of the untreated fiber or yarn (or a textile material made from the yarn). The cross-linking agent can be applied to the fiber or yarn (or a textile material made from the yarn) in any suitable amount. Typically, the cross-linking agent is applied in an amount of at least 0.1% (e.g., at least 1%, at least 2%, at least 3%, at least 5%, at least 7%, at least 10%, at least 15%, at least 18%, or at least 20%) based on the weight of the untreated fiber or yarn (or a textile material made from the yarn). The cross-linking agent is also typically applied in an amount of less than 25% (e.g., less than 20%, less than 18%, less than 15%, less than 10%, less than 7%, less than 5%, less than 3%, or less than 1%) based on the weight of the untreated fiber or yarn (or a textile material made from the yarn). In a potentially preferred embodiment, the cross-

linking agent is applied in an amount of about 2% to about 7% based on the weight of the untreated fiber or yarn (or a textile material made from the yarn).

[0021] The yarn of the invention also comprises *para*-aramid fibers. These fibers are included in the yarn for various reasons, such as increasing the strength and durability of the yarn and any textile material made from the yarn. The *para*-aramid fibers can be present in the yarn in any suitable amount. Preferably, the *para*-aramid fibers are present in the yarn in an amount of about 5% or more, about 10% or more, or about 15% or more by weight based on the total weight of fibers present in the yarn. While the *para*-aramid fibers are useful in increasing the strength and durability of the yarn, yarns with too high an amount of *para*-aramid fibers can produce textile materials that are not comfortable when worn. Accordingly, the *para*-aramid fibers preferably are present in the yarn in an amount of about 30% or less, about 25% or less, or about 20% or less by weight based on the total weight of fibers present in the yarn. Thus, in a series of preferred embodiment, the *para*-aramid fibers are present in the yarn in an amount of about 5% to about 25%, about 10% to about 25%, or about 15% to about 25% by weight of the total weight of fibers present in the yarn.

[0022] The yarn of the invention can further comprise other fibers, such as other synthetic fibers. These additional synthetic fibers can be any suitable synthetic fiber and can be included for various reasons. For example, the additional synthetic fibers can be thermoplastic synthetic fibers. These thermoplastic synthetic fibers typically can be included in the yarn in order to increase its durability to, for example, industrial washing conditions. In particular, thermoplastic synthetic fibers tend to be rather durable to abrasion and harsh washing conditions employed in industrial laundry facilities and their inclusion in, for example, a cellulosic fiber-containing spun yarn can increase that yarn's durability to such conditions. This increased durability of the yarn, in turn, leads to an increased durability for textile materials made from the yarn. Suitable thermoplastic synthetic fibers include, but are not necessarily limited to, polyester fibers (e.g., poly(ethylene terephthalate) fibers, poly(propylene terephthalate) fibers, poly(trimethylene terephthalate) fibers), poly(butylene terephthalate) fibers, and blends thereof), polyamide fibers (e.g., nylon 6 fibers, nylon 6,6 fibers, nylon 4,6 fibers, and nylon 12 fibers), polyvinyl alcohol fibers, and

combinations, mixtures, or blends thereof. In a preferred embodiment, the yarn further comprises polyamide fibers (e.g., nylon 6 fibers, nylon 6,6 fibers, nylon 4,6 fibers, and nylon 12 fibers), with nylon 6,6 fibers being preferred.

[0023] The additional synthetic fibers can also be inherent flame resistant fibers. As utilized herein, the term “inherent flame resistant fibers” refers to synthetic fibers which, due to the chemical composition of the material from which they are made, exhibit flame resistance without the need for an additional flame retardant treatment. In such embodiments, the inherent flame resistant fibers can be any suitable inherent flame resistant fibers, such as polyoxadiazole fibers, polysulfonamide fibers, poly(benzimidazole) fibers, poly(phenylenesulfide) fibers, *meta*-aramid fibers, polypyridobisimidazole fibers, polybenzylthiazole fibers, polybenzylloxazole fibers, melamine-formaldehyde polymer fibers, phenol-formaldehyde polymer fibers, oxidized polyacrylonitrile fibers, polyamide-imide fibers and combinations, mixtures, or blends thereof. In a preferred embodiment, the yarn further comprises polyoxadiazole fibers.

[0024] In a preferred embodiment, the synthetic fibers are selected from the group consisting of polyamide fibers, polyester fibers, *meta*-aramid fibers, modacrylic fibers, polyoxadiazole fibers, acrylic fibers, polyvinyl alcohol fibers, and mixtures thereof.

[0025] These additional synthetic fibers can be present in the yarn in any suitable amount. When they are present in the yarn, these additional synthetic fibers preferably are present in an amount of about 0.1% or more, about 0.5% or more, about 1% or more, about 2% or more, about 3% or more, about 4% or more, about 5% or more, about 6% or more, about 7% or more, about 8% or more, about 9% or more, or about 10% or more by weight based on the total weight of the fibers in the yarn. When they are present in the yarn, these additional synthetic fibers preferably are present in an amount of about 40% or less, about 35% or less, about 30% or less, about 25% or less, or about 20% or less by weight based on the total weight of the fibers present in the yarn. Thus, in a series of preferred embodiments, these additional synthetic fibers are present in the yarn in an amount of about 0.1% to about 30% (e.g., about 0.5% to about 30%, about 1% to about 30%, or about 5% to about 30%) or about 5% to about 25% (e.g., about 5% to about 20%) by weight

based on the total weight of fibers present in the yarn. Of course, the optimal weight of the additional synthetic fibers will depend, at least in part, on the particular type(s) of additional synthetic fibers included in the yarn. Thus, for example, when the additional synthetic fibers are polyamide fibers, the polyamide fibers preferably are present in the yarn in an amount of about 5% to about 20% or about 5% to about 15% (e.g., about 10%) by weight based on the total weight of the fibers in the yarn. In another example, such as when the additional synthetic fibers are polyoxadiazole fibers, the polyoxadiazole fibers preferably are present in the yarn in an amount of about 5% to about 25% or about 10% to about 20% (e.g., about 15%) by weight based on the total weight of fibers in the yarn.

[0026] In another embodiment, the invention provides textile materials comprising a plurality of the above-described yarns. The textile materials of the invention can be of any suitable construction. In other words, the yarns forming the textile material can be provided in any suitable patternwise arrangement producing a fabric. Preferably, the textile materials are provided in a woven construction, such as a plain weave, basket weave, twill weave, satin weave, or sateen weave. Suitable plain weaves include, but are not limited to, ripstop weaves produced by incorporating, at regular intervals, extra yarns or reinforcement yarns in the warp, fill, or both the warp and fill of the textile material during formation. Suitable twill weaves include both warp-faced and fill-faced twill weaves, such as 2/1, 3/1, 3/2, 4/1, 1/2, 1/3, or 1/4 twill weaves.

[0027] The textile material of the invention can be provided in any suitable weight (i.e., weight per unit of area). The suitable weight for the textile material will depend upon several factors, such as the desired degree of protection that the textile material will afford a wearer. The weight ranges provided below preferably indicate the weight of the textile material after any treatments (e.g., chemical treatments and/or mechanical treatments) have been performed on the textile material.

Preferably, the textile material exhibits a weight of about 135 g/m² or more, about 140 g/m² or more, about 145 g/m² or more, about 150 g/m² or more, about 155 g/m² or more, about 160 g/m² or more, about 165 g/m² or more, about 170 g/m² or more, about 175 g/m² or more, about 180 g/m² or more, or about 185 g/m² or more.

Preferably, the textile material exhibits a weight of about 305 g/m² or less, about 300

g/m² or less, about 295 g/m² or less, about 290 g/m² or less, about 285 g/m² or less, about 280 g/m² or less, about 275 g/m² or less, about 270 g/m² or less, about 265 g/m² or less, about 260 g/m² or less, or about 255 g/m² or less. Thus, in a series of preferred embodiments, the textile material exhibits a weight of about 135 g/m² to about 305 g/m² or about 170 g/m² to about 255 g/m².

[0028] To further enhance the textile material's hand, the textile material can optionally be treated using one or more mechanical surface treatments. A mechanical surface treatment typically relaxes stress imparted to the fabric during curing and fabric handling, breaks up yarn bundles stiffened during curing, and increases the tear strength of the treated fabric. Examples of suitable mechanical surface treatments include treatment with high-pressure streams of air or water (such as those described in U.S. Patent 4,918,795, U.S. Patent 5,033,143, and U.S. Patent 6,546,605), treatment with steam jets, needling, particle bombardment, ice-blasting, tumbling, stone-washing, constricting through a jet orifice, and treatment with mechanical vibration, sharp bending, shear, or compression. A sanforizing process may be used instead of, or in addition to, one or more of the above processes to improve the fabric's hand and to control the fabric's shrinkage. Additional mechanical treatments that may be used to impart softness to the treated fabric, and which may also be followed by a sanforizing process, include napping, napping with diamond-coated napping wire, gritless sanding, patterned sanding against an embossed surface, shot-peening, sand-blasting, brushing, impregnated brush rolls, ultrasonic agitation, sueding, engraved or patterned roll abrasion, and impacting against or with another material, such as the same or a different fabric, abrasive substrates, steel wool, diamond grit rolls, tungsten carbide rolls, etched or scarred rolls, or sandpaper rolls.

[0029] The textile materials of the invention are believed to exhibit good protection against flash fire and arc flash hazards. Accordingly, the textile materials are believed to be particularly well-suited for use in the production of protective garments, such as those worn by industrial workers at risk for exposure to flash fires and arc flashes. When tested in accordance with ASTM D6413 entitled "Standard Test Method for Flame Resistance of Textiles (vertical test)", the textile materials of the invention typically exhibit very short char length with zero afterflame. Typical char

lengths exhibited by the textile materials are about 1 inch (2.5 cm) to about 2.5 inches (6.4 cm), which indicates that the textile materials exhibit relatively high mechanical strength even after exposure to the flame. Furthermore, due to the relatively high strength of the fibers in both the dry and wet states, the textile materials can withstand many repeated home and/or industrial launderings. This stands in contrast to textile materials made with conventional rayon or FR rayon, which fibers have lower tenacities and produce textile materials exhibiting relatively low durability to repeated launderings. In addition to mechanical durability, the flame resistant properties of the textile materials are also durable to repeated launderings. For example, the textile materials of the invention typically (and preferably) exhibit the flame resistant properties described above after many (e.g., 50 or more, or 100) home and/or industrial launderings.

[0030] In another series of embodiments, the invention provides a garment comprising one or more fabric panels. The one or more fabric panels can be joined (e.g., sewn) together in such a way as to enclose an interior volume, which interior volume is intended to be occupied by a wearer or at least a portion of the anatomy of a wearer. Suitable examples of such garments include, but are not limited to, shirts, jackets, vests, pants, overalls, coveralls, hoods, and gloves. Alternatively, the garment need not be constructed so that it encloses an interior volume. Rather, the garment can be constructed so that a wearer can securely fasten it to his or her body so that it covers and protects at least a portion of his or her anatomy. Suitable examples of such garments include, but are not limited to aprons, bibs, chaps, and spats.

[0031] In such embodiments of the invention, at least one of the fabric panels of the garment comprises the textile material described above (i.e., a textile material comprising a plurality of the yarns described above). Preferably, if the garment comprises multiple fabric panels, all of the fabric panels comprise the textile material described above. In a specific embodiment of a garment, the garment is a shirt comprising a plurality of fabric panels. At least one of the fabric panels defines a body covering portion of the shirt, and at least two of the fabric panels define sleeves attached to the body covering portion of the shirt. As noted above, at least one of the fabric panels of the shirt comprises the textile material described above. In

another specific embodiment of such a garment, the garment is a pant comprising a plurality of fabric panels. At least two of the fabric panels define leg covering portions of the pant. As noted above, at least one of the fabric panels comprises the textile material described above.

[0032] In another embodiment, the invention provides a method for protecting an individual from infrared radiation that can be generated during an electrical arc flash. In this embodiment, the method comprises the step of positioning a textile material between an individual and an apparatus capable of producing an electrical arc flash. The textile material preferably is a textile material according to the invention (i.e., a textile material comprising a plurality of the yarns described above).

[0033] In this method embodiment of the invention, the textile material can be positioned at any suitable point between the individual and the apparatus. However, in order to ensure that the textile material is positioned to afford the greatest degree of protection to the individual, the textile material preferably forms part of a garment worn by the individual. Suitable garments include, but are not limited to, shirts, pants, coats, hoods, aprons, and gloves. In a preferred embodiment, the outward-facing textile portions of a garment worn by the individual (i.e., those portions of the garment facing towards the apparatus when the garment is being worn by the individual) consist essentially of (or even more preferably consist of) a textile material according to the invention.

[0034] The method described above can be used to protect an individual from an arc flash produced by any apparatus. Typically, the apparatus is a piece of electrical equipment. Preferably, the apparatus is capable of producing an arc flash having an incident energy of about 1.2 calories/cm² or more (about 5 J/cm² or more) at a position at which the individual is located. More preferably, the apparatus is capable of producing an arc flash having an incident energy of about 4 calories/cm² or more (about 17 J/cm² or more) at a position at which the individual is located. The apparatus preferably is capable of producing an arc flash having an incident energy of about 8 calories/cm² or more (about 33 J/cm² or more) at a position at which the individual is located. An arc flash having an incident energy such as those described above (especially an arc flash having an incident energy of about 4 calories/cm² or more or about 8 calories/cm² or more) is capable of inflicting significant injury (e.g.,

second degree burns) to the unprotected or under-protected skin of an individual exposed to the arc flash.

[0035] In order to protect an individual from high energy arc flash exposure, such as 25 cal/cm² (105 J/cm²) to 60 cal/cm² (250 J/cm²), multiple layers of the textile material described above can be used, or the textile material can be used in combination with other textile materials or insulation layers. For example, in one such embodiment, the textile material described above can be used as an outer layer with other arc flash resistant fabrics and/or insulation materials underlying the textile material (i.e., between the textile material and the wearer). In such an embodiment, it is believed that the high break-open resistance of the textile materials of the invention will provide a multilayer structure that affords desirable levels of arc flash protection and maintains its mechanical integrity following exposure to an arc flash or flame.

[0036] The following examples further illustrate the subject matter described above but, of course, should not be construed as in any way limiting the scope thereof.

EXAMPLE 1

[0037] This method demonstrates the production of a yarn and textile material according to the invention. An intimate fiber blend containing approximately 70% by weight lyocell fibers, approximately 20% by weight *para*-aramid fibers, and approximately 10% by weight nylon 6,6 fibers was spun using a ring-spinning process to produce a yarn. The resulting yarn was then used to produce a sateen weave fabric (the yarn was used as both the warp and fill yarns of the woven fabric). The fabric was dyed and finished to incorporate a phosphorous-containing flame retardant compound inside the lyocell fibers. The resulting fabric had a weight of approximately 5.6 oz/yd² (190 g/m²).

[0038] The resulting fabric was then tested to determine its flame resistant properties. The fabric exhibited a char length of approximately 1.4 inches (3.6 cm) in both the warp and fill directions. The fabric was tested in accordance with ASTM F 1959 – “Standard Test Method for Determining the Arc Thermal Performance Value of Materials for Clothing”. The fabric exhibited a breakopen threshold energy (Ebt) of

approximately 14.3 cal/cm^2 (59.8 J/cm^2). By comparison, a 5.5 oz/yd^2 (190 g/m^2) 88% cotton/ 12% Nylon fabric treated with a commercial ammonia process flame retardant is reported to have a breakopen threshold energy of about 10 cal/cm^2 (40 J/cm^2), and a 6 oz/yd^2 (200 g/m^2) Nomex fabric is reported to have a breakopen threshold energy of about 13 cal/cm^2 (54 J/cm^2).

EXAMPLE 2

[0039] This method demonstrates the production of a yarn and textile material according to the invention. An intimate fiber blend containing approximately 75% by weight lyocell fibers, approximately 15% by weight *para*-aramid fibers, and approximately 10% by weight polyoxadiazole fibers was spun using a ring-spinning process to produce a yarn. The resulting yarn was then used to produce a twill weave fabric (the yarn was used as both the warp and fill yarns of the woven fabric). The fabric was dyed and finished to incorporate a phosphorous-containing flame retardant compound inside the lyocell fibers. The resulting fabric had a weight of approximately 7.2 oz/yd^2 (240 g/m^2).

[0040] The resulting fabric was then tested to determine its flame resistant properties. The fabric exhibited a char length of about 1.2 inches (3 cm) in both the warp and fill directions. After exposure to a $2 \text{ cal/cm}^2\cdot\text{sec}$ ($8.4 \text{ J/cm}^2\cdot\text{sec}$) flame for approximately 10 seconds, the fabric maintained good flexibility and mechanical integrity. The fabric is believed to be suitable for use in arc flash and flash fire protective apparel where resistance to breakopen after exposure to high thermal energy from flame and electric arc is required.

EXAMPLE 3

[0041] This method demonstrates the production of a yarn and textile material according to the invention. A high strength lyocell fiber containing a phosphorous-containing flame retardant compound is used in the following intimate fiber blend: approximately 70% by weight lyocell fibers; approximately 20% by weight *para*-aramid fibers; and approximately 10% by weight polyoxadiazole fibers. The intimately blended fibers are made into a ring-spun yarn, and the yarn is woven into a twill weave fabric (the yarn is used as both the warp and fill yarns of the woven

fabric). The fabric is then scoured, dyed and finished. The fabric can be made into a weight of approximately 5.6 oz/yd² (190 g/m²) and approximately 7.5 oz/yd² (250 g/m²). These fabrics are expected to exhibit good flexibility and mechanical integrity after exposure to a high energy electric arc and/or flame.

[0042] All references, including publications, patent applications, and patents, cited herein are hereby incorporated by reference to the same extent as if each reference were individually and specifically indicated to be incorporated by reference and were set forth in its entirety herein.

[0043] The use of the terms “a” and “an” and “the” and similar referents in the context of describing the subject matter of this application (especially in the context of the following claims) are to be construed to cover both the singular and the plural, unless otherwise indicated herein or clearly contradicted by context. The terms “comprising,” “having,” “including,” and “containing” are to be construed as open-ended terms (i.e., meaning “including, but not limited to,”) unless otherwise noted. Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, unless otherwise indicated herein, and each separate value is incorporated into the specification as if it were individually recited herein. All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context. The use of any and all examples, or exemplary language (e.g., “such as”) provided herein, is intended merely to better illuminate the subject matter of the application and does not pose a limitation on the scope of the subject matter unless otherwise claimed. No language in the specification should be construed as indicating any non-claimed element as essential to the practice of the subject matter described herein.

[0044] Preferred embodiments of the subject matter of this application are described herein, including the best mode known to the inventors for carrying out the claimed subject matter. Variations of those preferred embodiments may become apparent to those of ordinary skill in the art upon reading the foregoing description. The inventors expect skilled artisans to employ such variations as appropriate, and the inventors intend for the subject matter described herein to be practiced otherwise

than as specifically described herein. Accordingly, this disclosure includes all modifications and equivalents of the subject matter recited in the claims appended hereto as permitted by applicable law. Moreover, any combination of the above-described elements in all possible variations thereof is encompassed by the present disclosure unless otherwise indicated herein or otherwise clearly contradicted by context.

WHAT IS CLAIMED IS:

1. A yarn comprising:
 - (a) about 45% to about 85% by weight of regenerated cellulose fibers, the regenerated cellulose fibers having a dry tenacity of about 27 cN/tex or more, the regenerated cellulose fibers comprising a flame retardant compound within the fiber; and
 - (b) about 5% to about 25% by weight of *para*-aramid fibers.
2. The yarn of claim 1, wherein the regenerated cellulose fibers and the *para*-aramid fibers are staple fibers and are intimately blended in the yarn.
3. The yarn of claim 1, wherein the regenerated cellulose fibers have a wet tenacity of about 20 cN/tex or more.
4. The yarn of claim 1, wherein the regenerated cellulose fibers are selected from the group consisting of rayon fibers, lyocell fibers, and mixtures thereof.
5. The yarn of claim 1, wherein the regenerated cellulose fibers are lyocell fibers.
6. The yarn of claim 1, wherein the regenerated cellulose fibers comprise about 65% to about 85% by weight of the yarns.
7. The yarn of claim 1, wherein the flame retardant compound is a phosphorous-containing flame retardant compound.
8. The yarn of claim 1, wherein the *para*-aramid fibers comprise about 15% to about 25% by weight of the yarn.

9. The yarn of claim 1, wherein the yarns comprise additional synthetic fibers.

10. The yarn of claim 9, wherein the synthetic fibers are selected from the group consisting of polyamide fibers, polyester fibers, *meta*-aramid fibers, modacrylic fibers, polyoxadiazole fibers, acrylic fibers, polyvinyl alcohol fibers, and mixtures thereof.

11. The yarn of claim 9, wherein the additional synthetic fibers comprise about 0.1% to about 30% by weight of the yarns.

12. A textile material comprising a plurality of yarns, the yarns comprising:
(a) about 45% to about 85% by weight of regenerated cellulose fibers, the regenerated cellulose fibers having a dry tenacity of about 27 cN/tex or more, the regenerated cellulose fibers comprising a flame retardant compound within the fiber; and

(b) about 5% to about 25% by weight of *para*-aramid fibers.

13. The textile material of claim 12, wherein the regenerated cellulose fibers and the *para*-aramid fibers are staple fibers and are intimately blended in the yarns.

14. The textile material of claim 12, wherein the regenerated cellulose fibers have a wet tenacity of about 20 cN/tex or more.

15. The textile material of claim 12, wherein the regenerated cellulose fibers are selected from the group consisting of rayon fibers, lyocell fibers, and mixtures thereof.

16. The textile material of claim 12, wherein the regenerated cellulose fibers are lyocell fibers.

17. The textile material of claim 12, wherein the regenerated cellulose fibers comprise about 65% to about 85% by weight of the yarns.

18. The textile material of claim 12, wherein the flame retardant compound is a phosphorous-containing flame retardant compound.

19. The textile material of claim 12, wherein the *para*-aramid fibers comprise about 15% to about 25% by weight of the yarns.

20. The textile material of claim 12, wherein the yarns comprise additional synthetic fibers.

21. The textile material of claim 20, wherein the synthetic fibers are selected from the group consisting of polyamide fibers, polyester fibers, *meta*-aramid fibers, modacrylic fibers, polyoxadiazole fibers, acrylic fibers, polyvinyl alcohol fibers, and mixtures thereof.

22. The textile material of claim 20, wherein the additional synthetic fibers comprise about 0.1% to about 30% by weight of the yarns.

23. The textile material of claim 12, wherein the textile material is a woven textile material.

24. The textile material of claim 23, wherein the plurality of yarns are woven in a twill pattern.

25. The textile material of claim 12, wherein the textile material has a weight of about 135 g/m² to about 305 g/m².

26. The textile material of claim 25, wherein the textile material has a weight of about 170 g/m² to about 255 g/m².

27. A garment comprising one or more fabric panels, at least one of the fabric panels comprising a plurality of yarns, the yarns comprising:

(a) about 45% to about 85% by weight of regenerated cellulose fibers, the regenerated cellulose fibers having a dry tenacity of about 27 cN/tex or more, the regenerated cellulose fibers comprising a flame retardant compound within the fiber; and

(b) about 5% to about 25% by weight of *para*-aramid fibers.

28. The garment of claim 27, wherein the regenerated cellulose fibers and the *para*-aramid fibers are staple fibers and are intimately blended in the yarns.

29. The garment of claim 27, wherein the regenerated cellulose fibers have a wet tenacity of about 20 cN/tex or more.

30. The garment of claim 27, wherein the regenerated cellulose fibers are selected from the group consisting of rayon fibers, lyocell fibers, and mixtures thereof.

31. The garment of claim 30, wherein the regenerated cellulose fibers are lyocell fibers.

31. The garment of claim 27, wherein the regenerated cellulose fibers comprise about 65% to about 85% by weight of the yarns.

33. The garment of claim 27, wherein the flame retardant compound is a phosphorous-containing flame retardant compound.

34. The garment of claim 27, wherein the *para*-aramid fibers comprise about 15% to about 25% by weight of the yarns.

35. The garment of claim 27, wherein the yarns comprise additional synthetic fibers.

36. The garment of claim 35, wherein the synthetic fibers are selected from the group consisting of polyamide fibers, polyester fibers, *meta*-aramid fibers, modacrylic fibers, polyoxadiazole fibers, acrylic fibers, polyvinyl alcohol fibers, and mixtures thereof.

37. The garment of claim 36, wherein the additional synthetic fibers comprise about 0.1% to about 30% by weight of the yarns.

38. The garment of claim 27, wherein the textile material is a woven textile material.

39. The garment of claim 38, wherein the plurality of yarns are woven in a twill pattern.

40. The garment of claim 27, wherein the textile material has a weight of about 135 g/m² to about 305 g/m².

41. The garment of claim 40, wherein the textile material has a weight of about 170 g/m² to about 255 g/m².

42. A shirt comprising a plurality of fabric panels, at least one of the fabric panels defining a body covering portion of the shirt and at least two of the fabric panels defining sleeves attached to the body covering portion of the shirt, at least one of the fabric panels comprising a plurality of yarns, the yarns comprising:

(a) about 45% to about 85% by weight of regenerated cellulose fibers, the regenerated cellulose fibers having a dry tenacity of about 27 cN/tex or more, the regenerated cellulose fibers comprising a flame retardant compound within the fiber; and

(b) about 5% to about 25% by weight of *para*-aramid fibers.

43. A pant comprising a plurality of fabric panels, at least two of the fabric panels defining leg covering portions of the pant, at least one of the fabric panels comprising a plurality of yarns, the yarns comprising:

(a) about 45% to about 85% by weight of regenerated cellulose fibers, the regenerated cellulose fibers having a dry tenacity of about 27 cN/tex or more, the regenerated cellulose fibers comprising a flame retardant compound within the fiber; and

(b) about 5% to about 25% by weight of *para*-aramid fibers.

44. A method for protecting an individual from infrared radiation that can be generated during an arc flash, the method comprising the step of positioning a textile material between an individual and an apparatus capable of producing an arc flash, the textile material comprising a plurality of yarns, the yarns comprising:

(a) about 45% to about 85% by weight of regenerated cellulose fibers, the regenerated cellulose fibers having a dry tenacity of about 27 cN/tex or more, the regenerated cellulose fibers comprising a flame retardant compound within the fiber; and

(b) about 5% to about 25% by weight of *para*-aramid fibers.