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(54) METHOD OF MANUFACTURING A DRAWN MULTIFILAMENT YARN

VERFAHREN ZUR HERSTELLUNG EINES GEZOGENEN MULTIFILAMENTGARNS

PROCÉDÉ DE FABRICATION D'UN FIL MULTIFILAMENT ÉTIRÉ

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DescriptionTECHNICAL FIELD OF THE INVENTION

5 **[0001]** The invention relates to a method of manufacturing a multifilament yarn, such as a high performance polyethylene (HPPE) multifilament yarn. More particularly, the invention relates to a method of manufacturing and/or cleaning a multifilament yarn, where no organic spin finish is required.

BACKGROUND OF THE INVENTION

10 **[0002]** Multifilament polyolefin yarn is typically manufactured by spinning of a fluid, such as molten polyethylene or a solution (sometimes also referred to as a gel) of polyethylene in a spin solvent, through a spinneret with a multiplicity of spinholes to form filaments. Thereafter, the filaments are cooled and drawn. If a spin solvent is used, then at least some of this solvent is removed by for example evaporation or extraction. Examples of manufacturing processes are melt-spinning process (as for example disclosed in EP1445356), solid state process (as for example disclosed in EP1627719) or gelspinning (as for example disclosed in WO 2005/066401). A general description is also presented in "Advanced Fibre Spinning Technology", Ed. T. Nakajima, Woodhead Publ. Ltd (1994), ISBN 185573 182 7, all incorporated herein by reference.

20 **[0003]** One problem when manufacturing multifilament yarn of polyethylene is that polyethylene is an electrical isolator and hence tends to build up electro static charge during manufacturing and since the individual filaments of the multifilament yarn are charged similarly (plus or minus), then individual filaments will electro statically repel each other. This means that the multifilament yarn will tend to loosen up instead of forming a unity. Furthermore, in case of filament breakage, the filament ends will tend to move as far away as possible from the main body of the multifilament yarn reducing the quality of the manufactured multifilament yarn by fluff formation or even risk of a loose filament (end) being

25 **[0004]** Traditionally, this has been solved by adding an organic spin finish to the multifilament yarn during the drawing process. However, organic spin finish is a surface active product and should be avoided for environmental reasons.

[0005] One route to reduce influence of the spin finish has been suggested in WO2004/053212, wherein use of a volatile spin finish is suggested.

OBJECTS OF THE INVENTION

[0006] It is the object of the invention to provide an improved method of manufacturing a multifilament yarn.

[0007] It is another object of the invention to provide an improved multifilament yarn or yarn construction.

DISCLOSURE OF THE INVENTION

[0008] The improvement may for example be one or more of a reduction of the environmental impact, better logistics, reduced handling or another improvement provided by the present invention as discussed below.

40 **[0009]** In a first aspect of the invention, the object of the invention is achieved by a method according to claim 1.

[0010] The partially drawn multifilament yarn may be provided directly from the spinning process in the case where the spin holes of the multifilament spinneret have a contraction zone shaped to provide partially drawing or aligning of the filaments already in the spin holes for example as disclosed in WO 2005/066401. The partially drawn multifilament yarn may also be a result of drawing in an airgap after the spinneret. Preferably, the partially drawn multifilament yarn is a solid stage yarn for example after cooling in a quench bath after the spinning. If the partially drawn multifilament yarn is a gelspun multifilament yarn, it is preferred that at least a part of the solvent has been removed (as compared to the solvent content during spinning through the spinneret) prior to twisting of the partially drawn multifilament yarn.

45 **[0011]** Drawing of the multifilament yarn takes place in multiple steps. The twisting of the partially drawn multifilament yarn may be realized inline with a drawing step, or offline not connected with a drawing step. By inline is herein meant that the partially drawn yarn runs directly between a station where twisting of the partially drawn multifilament yarn is conducted and a station where the multifilament yarn is drawn. Offline typically means that a winding step takes place between drawing and twisting.

BRIEF DESCRIPTION OF THE DRAWINGS

55 **[0012]** The invention will be explained more fully below with reference to exemplary embodiments as well as the drawings, in which

Fig. 1 shows schematic flowcharts of methods according to the invention, and

Fig. 2 shows a schematic flowchart of a method of manufacturing a HPPE multifilament yarn according to the invention.

[0013] All figures show only steps which are necessary in order to elucidate the invention, other parts being omitted or merely suggested.

DETAILED DESCRIPTION

[0014] The drawing of the multifilament yarn may be conducted in one or more of the following variations (see Fig. 1): a) inline before twisting and followed by offline post-twist-drawing; b) inline before and inline after twisting of the partially drawn multifilament yarn; c) offline before twisting and inline after twisting; d) offline before and offline after twisting, so twisting of the partially drawn yarn takes place in a step separated (in time and/or space) from drawing of the partially drawn multifilament yarn before and after the twisting.

[0015] It is preferred that twisting the partially drawn multifilament yarn and post-twist-drawing are conducted inline. The method according to the invention may incorporate more than one post-twist-drawing step. If more post-twist-drawing steps are conducted in the method according to the invention, then it is preferred that twisting of the partially drawn multifilament yarn is conducted inline with at least one of the post-twist-drawing steps, and more preferably twisting of the partially drawn multifilament yarn is conducted inline with all post-twist-drawing steps. The method according to the invention may incorporate more than one twisting step. If more twisting steps are conducted in the method according to the invention, then it is preferred that at least one of the twisting steps is conducted inline with a post-twist-drawing step.

[0016] Twisting of the partially drawn multifilament yarn may be conducted on dedicated (freestanding) equipment or may be combined into one piece of equipment with one or more of a drawing oven, a quench bath, a winder, an unwinder, a spinning plate. In one embodiment, twisting the partially drawn yarn is conducted by an inline twister system for example as described in US 6,155,037. Inline twister system as described in US 6,155,037 is hereinafter referred to as an Uster twister system. As this type of equipment allows for introducing a twist to a partially drawn multifilament yarn without having access to the ends of the yarn, this type of equipment is particularly advantageous for retrofitting of existing equipment, such as an existing drawing oven, or an existing winder or unwinder. One aspect of the invention therefore concerns a combination of an Uster twister system and a drawing oven, an Uster twister system and a winder, or a Uster twister system and an unwinder.

[0017] In a particularly preferred embodiment, twisting the partially drawn yarn is conducted by first winding an untwisted partially drawn multifilament yarn followed by twisting the partially drawn multifilament yarn by unwinding the untwisted partially drawn multifilament yarn using a twisting creel system. Preferably the twisting creel system is arranged to conduct the unwinding and twisting inline with the post-twist-drawing process wherein the unwinding speed and rotation speed of the twisting creel system is adjusted to the inline post-twist-drawing process.

[0018] The method according to the invention may further comprise the step of tensioning the multifilament yarn in a tensioning station after twisting the partially drawn multifilament yarn and before post-twist-drawing of the partially drawn yarn. This allows to keep the tension in the partially drawn multifilament yarn relatively low during twisting while the tension during drawing may be kept sufficiently high to ensure the required drawing. Examples of suitable tensioning stations include a number of rolls, a break system and a friction system.

[0019] For all aspects of the invention, drawing of the multifilament yarn typically takes place at an elevated temperature. It is preferred that at least one drawing step takes place at a temperature of above 100°C, and preferably at least one drawing step takes place at a temperature above 120°C. It is preferred that at least one drawing step takes place below the melting point of the multifilament yarn. More preferably, all drawing steps after the spinning take place below the melting point of the multifilament yarn. Yet more preferably, all drawing steps after spinning take place at a temperature of at least 5°C below the melting point of the multifilament yarn, and more preferably at a temperature of at least 10°C below the melting point of the multifilament yarn. Particularly, it is preferred that post-twist-drawing takes place in a range between the melting point of the multifilament yarn and 30°C below the melting point of the multifilament yarn, more preferably the post-twist drawing takes place at a temperature at least 5°C below the melting point of the multifilament yarn, such as 10°C below the melting point of the multifilament yarn. For gelspun UHMWPE multifilament yarn, it is preferred that drawing - and particularly post-twist-drawing - takes place at a temperature below 138°C, preferably at a temperature below 135°C and more preferably at a temperature below 132°C. For gelspun UHMWPE multifilament yarn, it is preferred that drawing - and particularly post-twist-drawing - takes place at a temperature above 100°C, preferably at a temperature above 110°C, more preferably at a temperature above 120°C, and more preferably at a temperature above 130°C.

[0020] Within the context of the present invention, monofilaments are understood to mean elongated bodies of indefinite length and with length dimension much greater than their transversal dimensions, e.g. width, thickness or radius, and can have regular or irregular cross-section. The monofilaments may have continuous lengths, known in the art as

filaments, or discontinuous lengths, known in the art as staple fibers. A multifilament yarn according to the present invention is an elongated body comprising a plurality of monofilaments.

[0021] By a gel-spun multifilament yarn is herein understood a multifilament yarn manufactured by spinning a solution (sometimes also referred to as a gel) comprising a polymer and a solvent for said polymer. The spinning of the solution may be conducted by converting a suspension of polymer and solvent into a solution in an extruder and extruding said solution through a spinneret containing more than one spinning aperture. Particularly preferred are gel-spun polyolefin multifilament yarns, which are spun from a solution containing the polyolefin and a solvent for polyolefin, which solvent can be removed from the multifilament yarn after spinning of the yarn by evaporation, like for example naphthenes such as decaline, tetralin or methylcyclohexane.

[0022] Preferably, the gel-spun multifilament yarns obtained according to the invention are high performance gel-spun multifilament yarns with a tenacity of at least 1.5 N/tex, preferably at least 2.0 N/tex, more preferably at least 2.5 N/tex or even at least 3.0 N/tex. There is no reason for an upper limit of the tenacity of the multifilament yarns, but gel-spun multifilament yarns typically having a tenacity of at most about 5 to 6 N/tex may be manufactured. Generally such high performance gel-spun multifilament yarns also have a high tensile modulus (also referred to as Young's modulus), of e.g. at least 50 N/tex, preferably at least 75 N/tex, more preferably 100 N/tex, most preferably at least 125 N/tex. There is no reason for an upper limit of the tensile modulus, but gelspun multifilament yarns typically having a tenacity of at most about 180 N/tex.

[0023] Tensile strength (also simply referred to as strength) tenacity and modulus of multifilament yarns are determined by known methods, as based on ASTM D2256-97.

[0024] The multifilament yarns obtained according to the invention have a titer of preferably at least 2 dtex, preferably at least 7 dtex and more preferably at least 8 dtex. For practical reasons, the titer of the multifilament yarns of the invention are at most several thousand dtex, preferably at most 2500 dtex, more preferably at most 500 dtex. The multifilament yarns comprising a plurality of filaments preferably have a titer per filament in the 0.2 - 5 dtex range, preferably 0.5-2 dtex. Partially drawn multifilament yarns comprising a plurality of filaments preferably have a titer per filament in the 0.5 - 25 dtex range.

[0025] The multifilament yarn is preferably selected from the group consisting of polyolefin (such as polyethylene and polypropylene), polyester (such as PET, Vectran® and PLA), polyamide (such as nylons and aramids) and more preferably the multifilament yarn is polyolefin. It is preferred that polyolefin used in accordance with the present invention is polypropylene or polyethylene, more preferably ultrahigh molecular weight polyethylene (UHMWPE).

[0026] By HPPE multifilament yarn is herein understood high performance polyethylene, which is yarn comprising drawn polyethylene with a Young's modulus of at least 30 GPa. A particularly preferred type of HPPE is gelspun ultra high molecular weight polyethylene (UHMWPE), where the UHMWPE has an intrinsic viscosity (IV) as measured on a solution of UHMWPE in decalin at 135°C, of at least 5 dl/g, preferably at least 10 dl/g, more preferably at least 15 dl/g, most preferably at least 21 dl/g. Preferably, the IV is at most 40 dl/g, more preferably at most 30 dl/g, even more preferably at most 25 dl/g. Gelspun UHMWPE typically has a Young's modulus of at least 50 GPa. Preferably the HPPE multifilament yarn has a tenacity of at least 1 GPa. Preferably the HPPE multifilament yarn comprises at least 90 wt-% UHMWPE filaments and most preferably the HPPE multifilament yarn consists of UHMWPE filaments.

[0027] By yarn construction is herein meant a collection of at least two multifilament yarns connected for example by braiding, weaving, knitting, twisting, heat treatment involving partial melting, air entanglement and glueing.

[0028] By post-twist-drawing is herein meant the process of drawing a yarn by a factor of at least 1.1 after twisting of the yarn by at least 4 turns per meter and before optionally converting the yarn into a yarn construction. It should be observed that drawing of a yarn construction (such as drawing of a rope construction as described in EP 0 398 434) is a fundamentally different process than post-twist-drawing since drawing of a yarn construction realizes the fundamentally different effect of realigning filaments of the construction by creep and does not improve the coherence between the individual filaments in one multifilament yarn of the yarn construction. Furthermore, in addition to a more coherent filament bundle twisting of the partially drawn multifilament yarn before post-twist-drawing appeared to provide a better heat and stress distribution in the multifilament yarn during post-twist-drawing, which again allowed for a more uniform drawing on filament level. A more uniform drawing leads to improved processability of the obtained multifilament yarn as well as improved yield of the manufacturing process, since more uniform drawing appeared to lead to reduced filament breakage. Post-twist-drawing also results in a higher reduction of the titer as compared to drawing a yarn construction.

[0029] In a preferred embodiment, the partially drawn multifilament yarn is twisted to a partially-drawn-twist-level of 10 to 500, and more preferably the partially drawn yarn is twisted to a partially-drawn-twist-level of 12 to 200 turns per meter. The optimum partially-drawn-twist-level depends on the titer of the multifilament yarn, the post-twist-drawing ratio, the desired twist level of the multifilament yarn and the optional twist level to be applied to the multifilament yarn after post-twist-drawing.

[0030] In another preferred embodiment, the twisted partially drawn multifilament yarn is post-twist-drawn by DR_{pt} of at least 1.5, and more preferably post-twist-drawn by DR_{pt} of at least 2, and most preferably post-twist-drawn by DR_{pt} of at least 3. The upper limit of the post-twist-drawing ratio DR_{pt} , depends on the condition of the yarn prior to the twisting

of the partially drawn yarn, such as for example, the type of polymer, and the draw ratio prior to twisting of the partially drawn yarn, the temperature of the post-twist-drawing. Typically, the post-twist-drawing ratio is less than 1000; preferably DR_{pt} is at most 100; more preferably DR_{pt} is less than 50; more preferably DR_{pt} is at most 25; more preferably DR_{pt} is at most 10 or less than 10.

[0031] The partially-drawn-twist-level is the number of turns per meter that the partially drawn multifilament yarn has directly after the twisting of the partially drawn multifilament yarn. In a preferred embodiment of the invention, the partially drawn multifilament yarn is twisted to a level where the factor between the partially-drawn-twist-level and the draw ratio, DR_{pt} , of the post-twist-drawing is between 2 - 250 turns per meter, preferably the partially-drawn-twist-level / DR_{pt} is between 2 - 120 turns per meter, more preferably the partially-drawn-twist-level / DR_{pt} is between 2 - 20 turns per meter, such as 5 to 20 turns per meter. In one embodiment, the twist level of the partially drawn multifilament yarn is sufficiently high such that no further twisting of the multifilament yarn is required after post-twist-drawing.

[0032] The partially drawn multifilament yarn may be a homo-yarn or a hetero-yarn. By homo-yarn is meant that the multifilament yarn consists of filaments having the same composition. By hetero-yarn is meant that at least one of the filaments of the multifilament yarn has a different composition than other filaments of the multifilament yarn. In one embodiment, at least one of the filaments of the partially drawn multifilament yarn is selected from the group consisting of (coloured or uncoloured) polyester filaments, HD polyethylene filaments, UHMWPE filaments, polypropylene filaments. Preferably, the partially drawn multifilament yarn comprises at least 75 number-% UHMWPE filaments and more preferably the partially drawn multifilament yarn comprises at least 90 number-% UHMWPE filaments. Most preferably, the filaments of the partially drawn multifilament yarn consist of UHMWPE filaments, as this provides the strongest and most homogeneous performance of the multifilament yarn.

[0033] Another aspect of the invention concerns a method of removing a spin solvent from a gelspun multifilament polyolefin yarn. The method comprises the steps of providing a multifilament yarn comprising polyolefin filaments and a spin solvent, twisting the yarn to a twist level of 10 to 600 turns per meter, and removing at least a part of the spin solvent from the multifilament yarn after twisting the yarn. The multifilament yarn provided in the first step may be an undrawn, a partially drawn or post-twist-drawn gelspun multifilament yarn, however, it is preferred that the multifilament yarn is partially drawn or post-twist-drawn. The removing of spin solvent is preferably by evaporation or extraction. Evaporation is particularly relevant when the spin solvent is a naphthene such as decaline, tetralin and/or methylcyclohexane. Extraction is particularly relevant when the spin solvent comprises paraffin. Twisting of the multifilament yarn before removing at least a part of the solvent from the multifilament yarn allows conducting the conversion into a yarn construction without addition of spin finish to the multifilament yarn. In other words, this aspect of the invention allows removal of the spin solvent from a multifilament yarn in a more environmentally friendly way without jeopardizing the handlability of the yarn, since a spin finish is not required or a smaller amount of spin finish is required. In this embodiment of the invention, it is also preferred to post-twist-draw the multifilament yarn, however, this is not a requirement. Preferred twisting levels and optional post-twist-drawing levels correspond to the levels as described herein for other aspects of the invention.

[0034] In one embodiment of the invention, the spin solvent content of the multifilament yarn is already very low before twisting of the partially drawn multifilament yarn. In this embodiment, it is preferred that the spin solvent of the multifilament yarn during twisting is 10 ppm to 1000 ppm based on the weight of polyethylene and spin solvent. Preferably, the spin solvent of the partially drawn multifilament yarn during twisting is 20 ppm to 500 ppm.

[0035] In another embodiment of the invention, the spin solvent content of the multifilament yarn during twisting of the multifilament yarn is at least 0.1 wt-% based on the weight of polyethylene and spin solvent, preferably the spin solvent content of the multifilament yarn is at least 0.5 wt-%, more preferably the spin solvent content of the multifilament yarn is at least 2 wt-%, more preferably the spin solvent content of the multifilament yarn is at least 5 wt-%, such as for example at least 10 wt-%. Typically, the spin solvent content of the multifilament yarn during twisting of the multifilament yarn is below 90 wt-%.

[0036] The amount of solvent removed after twisting of the multifilament yarn depends to a large extent on the content before twisting. Furthermore, the lower the solvent content of the post-twist-drawn multifilament yarn, the higher the effect on coherency of the twisting before removing the solvent from the yarn. In one embodiment, at least 10 wt-% of the spin solvent present during the twisting is removed after twisting the multifilament yarn and preferably at least 90 wt-% of the spin solvent present during the twisting is removed after twisting the multifilament yarn. Most preferably at least 99 wt-% of the spin solvent present during the twisting is removed after twisting the multifilament yarn. It should be observed that if more twisting steps are utilized, then the solvent content during twisting is the solvent content during the first twisting step. The fraction of solvent removed from the multifilament yarn after twisting depends to some extent on the amount present before twisting. It is preferred that 100% of the solvent is removed, but since traces of solvent may stay in the multifilament yarn, in one embodiment at most 99.999% of the solvent is removed. The removed spin solvent is preferably collected and recycled by known means.

[0037] In the cleaning process according to this aspect of the invention, it is highly preferred that the process further comprises a post-twist-drawing step. Particularly, it was found to be advantageous to post-twist-draw the multifilament

yarn by a draw ratio DR_{pt} of at least 1.1 to form a HPPE multifilament yarn. More preferably the post-twist drawing draw ratio is at least 1.5, and even more preferably DR_{pt} is at least 2, and most preferably DR_{pt} is at least 3. The upper limit of the post-twist-drawing ratio DR_{PT} , depends on the condition of the yarn prior to the twisting of the partially drawn yarn, such as for example, the type of polymer, and the draw ratio prior to twisting of the partially drawn yarn, the temperature of the post-twist-drawing. Typically, the post-twist-drawing ratio, DR_{PT} , is less than 1000; preferably DR_{pt} is at most 100; more preferably DR_{PT} is less than 50; more preferably DR_{pt} is at most 25; more preferably DR_{PT} is at most 10 or less than 10.

[0038] Manufacturing of gelspun multifilament HPPE traditionally requires addition of spin finish during removal of the spin solvent as the filaments would otherwise repulse each other due to electrostatic charging effects of the electrically isolating polymer. Unfortunately, being a surface active agent, spin finish is not a desired additive from environmental perspective and particularly for medical applications spin finish should be avoided. One aspect of the invention therefore concerns a method of manufacturing a gelspun HPPE multifilament yarn without adding a spin finish. The flowchart in Fig. 2 indicates this method. The method comprises the steps of providing (2) a solution of 3-25 wt-% UHMWPE in a spin solvent (based on UHMWPE and spin solvent in the solution). The solution may for example be provided by converting a suspension of UHMWPE and spin solvent in an extruder, spinning (4) the solution through a spinneret having at least two spin holes, quenching (6) the solution in a quench bath, and drawing (7) to form a solid multifilament yarn comprising partially drawn UHMWPE filaments. Thereafter, twisting (12), the partially drawn multifilament yarn to a twist level of 2 to 600 turns per meter to form a twisted partially drawn multifilament yarn, and post-twist-drawing (13) the twisted partially drawn multifilament yarn by a draw ratio DR_{pt} of at least 1.1 to form a HPPE multifilament yarn, wherein twisting, removal of spin solvent and post-twist-drawing are conducted without adding a spin finish to the multifilament yarn. At least a part of the spin solvent is removed during the process by evaporation or extraction. Twisting of the partially drawn multifilament yarn may be conducted inline, offline or a combination of inline and offline with drawing conducted prior to twisting. Twisting of the partially drawn multifilament yarn may be conducted inline, offline or a combination of inline and offline with post-twist-drawing. It was found to be highly advantageous to conduct drawing prior to twisting offline with the twisting and to conduct twisting inline with at least a part of the post-twist-drawing as this allows for good traceability and compact process equipment.

[0039] The methods according to the present invention are particularly advantageous in relation to preparation of polyethylene yarn to be used in medical applications, medical repair products, implants and medical devices, as the methods allow for preparation of polyethylene yarn without the use of a spin finish and particularly an organic spin finish, which organic spin finish typically is not desired inside the body or in contact with the body. Examples of medical applications are medical components, like for example vascular prostheses, joint arthroplasty, orthopedic and spine implants, for example meniscus implants, surgical sutures, meshes for example hernia meshes, fabrics, woven or non-woven, textiles, sheets, tapes, ribbons, bands, artificial joints, cables such as trauma fixation cables, sternum closure cables, prophylactic or per prosthetic cables, long bone fracture fixation cables, small bone fracture fixation cables, tube-like products for example ligament replacement, endless loop products, bag-like products, balloon-like products, grafts, stent grafts, artificial veins, Y-shaped hollow structures, skirts for valve structures, such as heart valves and periphery valves and other medical components.

[0040] Since use of spin finish is also not desired from an environmental point of view, the methods according to the present invention are also advantageous in relation to preparation of polyethylene yarn to be used in other end-use products and applications like ropes, cables and cords, mooring lines, fishing lines and fishing nets, sports equipment, impact and abrasion resistant products and ballistic-resistant products.

EXAMPLES

Example 1: Preparation of HPPE yarn with drawing inline before twisting.

[0041] Fig. 1 a) shows a flow diagram of a method of preparation of a polyolefin multifilament yarn where drawing inline with twisting is conducted before twisting. After twisting, the partially drawn multifilament yarn is wound on a bobbin before (at a later time) conducting offline post-twist-drawing. The twisting may be conducted in conjunction with winding of the partially drawn multifilament yarn in a combined twisting and winding unit, such as for example available from the companies Alma-Sauer, Dietze & Schell, Galan, and Barmag. The twisting and winding may also be conducted in two separate steps in which case the twisting for example may be conducted in a process and equipment as disclosed in US 6,155,037 and the winding for example may be conducted on a precision cross winder, for example from SSM, Dietze & Schell, Comoli, Leesona, Georg Sahm GmbH, Oerlikon, and Barmag. The wound and twisted partially drawn yarn is later (i.e. offline) post-twist-drawing. This corresponds to the process indicated in Fig. 1a, where in addition to the drawing (8) conducted inline before twisting (12), further offline drawing (10) may be conducted prior to the inline drawing (8).

Example 2: Preparation of HPPE yarn with drawing inline before and after twisting.

[0042] Fig. 1 b) shows a flow diagram of a method of preparation of a polyolefin multifilament yarn where drawing inline with twisting is conducted before as well as after twisting. The twisting may be conducted with a twisting unit of the type for example disclosed in US 6,155,037 where a running yarn is twisted inline during transfer through the twisting unit. In one embodiment of drawing variation b), one large twisting step is utilized to achieve the desired twist level. In another embodiment of drawing variation c), multiple smaller steps of twisting (such as 2, 3, 4, 5, 6, 7, 8, 9 or 10 twisting steps) are utilized to achieve the desired twist level. The multiple smaller drawing steps may be arranged in between multiple smaller drawing steps or in groups of drawing steps between drawing steps. As indicated in Fig. 1 b), in addition to the inline drawing before (8) and after (14) the twisting (12), one or more offline drawing steps may optionally be utilized before (10) or after (16) the inline drawing and twisting steps (8, 12, 14).

Example 3: Preparation of HPPE yarn with drawing inline after twisting.

[0043] Fig. 1 c) shows a flow diagram of a method of preparation of a polyolefin multifilament yarn where drawing inline with twisting is conducted after twisting. In this case, a partially drawn multifilament yarn is prepared by drawing (10) for example in a first drawing oven the as-spun multifilament yarn and thereafter winding the partially drawn multifilament yarn on bobbin for example on a Twinstar precision cross winder from Georg Sahm GmbH. At a later time, the partially drawn multifilament yarn is twisted and post-twist-drawn. The twisting preferably takes place on a combined twist and unwinder apparatus such as for example a twisting creel available from for example Alma-Sauer, Dietze & Schell, Galan, and Barmag. Alternatively, a separate unwinder may be combined with a twisting unit of the type for example disclosed in US 6,155,037. After the inline post-twist-drawing (14), the yarn may optionally be further drawn offline (16). The advantage of this embodiment is, that the unwinding and twisting can be finely tuned with the drawing process and allows for rapid start and stop in relation to yarn breakage. Furthermore, traceability is easier to handle as compared to the drawing variation of Example 4 since less offline processes are involved.

Example 4: Preparation of HPPE yarn with drawing offline before and after twisting.

[0044] Fig. 1 d) shows a flow diagram of a method of preparation of a polyolefin multifilament yarn where drawing is conducted offline before and after twisting. The partially drawn multifilament yarn is prepared as described in Example 3 by drawing (10) for example in a first drawing oven the as-spun multifilament yarn and thereafter winding the partially drawn multifilament yarn on bobbin for example on a Twinstar precision cross winder from Georg Sahm GmbH. The partially drawn multifilament yarn is thereafter at a later time twisted on twist and rewind equipment for example available from SSM, Dietze & Schell, Comoli, Leesona, Georg Sahm GmbH, Oerlikon, and Barmag. Finally, post-twist-drawing is conducted at a later time for example in a further drawing oven. The advantage of this embodiment is that it allows for realizing the improved coherence of the multifilament yarn in a simple constellation and does not require alignment of twisting equipment with one or more drawing stations. However, due to the process steps being conducted offline, traceability needs to be handled carefully.

Example 5: Preparation of partially drawn HPPE yarn

[0045] Bobbins of partially drawn UHMWPE yarn were prepared by preparing a solution of UHMWPE in decalin in an extruder, spinning the solution through a spinneret having 200 spin holes, quenching in a quench bath, partially drawing the as-spun yarn and removing more than 99% of the spin solvent from the yarn as compared to spin solvent content of the solution. No spin finish was provided during the process. Finally, the yarn was wound on bobbins each holding about 9000 m.

Example 6: Preparation of HPPE yarn utilizing drawing inline after twisting

[0046] Bobbins of partially drawn UHMWPE yarn prepared in Example 5 were subjected to the inline drawing process as described in Fig. 1 c) using inline post-twist-drawing ratio of 4 by feeding the drawing oven via a twisting creel unwinder. Twist levels of 9 and 12 turns per meter were used. No offline post-twist-drawing was used and no spin finish was provided during the processes.

Twist level	9 turns per meter	12 turns per meter
Total number of bobbins	75	17

(continued)

Twist level	9 turns per meter	12 turns per meter
Minimum number of defects per bobbin	0	0
Maximum number of defects per bobbin	16	10
Average number of defects per bobbin	3	1.5

[0047] It was therefore observed that the maximum number of defects per bobbin as well as the average number of defects per bobbin decreased when the twist level was increased.

Comparative Example 1: Preparation of HPPE yarn utilizing no twisting

[0048] Experiment 6 was repeated using 0 turns per meter inline twist. The resulting yarn showed very low coherency and no stable bobbins could be prepared after final drawing.

Example 7: Preparation of HPPE yarn utilizing drawing offline before and after twisting

[0049] Bobbins of partially drawn UHMWPE yarn prepared in Example 5 were subjected to the offline drawing process as described in Fig. 1 d). A twist level of 16 turns per meter was provided by unwinding using a ring-twister, parallel winding and a separate step of rewinding using cross winding. The bobbins of partially drawn and twisted UHMWPE yarn were hereafter drawn using an offline post-twist-drawing ratio of 4. No spin finish was provided during the twisting or post-twist-drawing processes.

[0050] Two batches of bobbins (each about 400 g) were prepared.

- Batch 1: 50 bobbins of which 16 bobbins had one or more defects
- Batch 2: 75 bobbins of which 24 bobbins had one or more defects

It was therefore observed that a very high quality level and high consistency was realized utilizing a process involving twisting of the yarn and post-twist-drawing despite no spin finish was added during the process.

Comparative Example 2: Preparation of HPPE yarn utilizing no twisting

[0051] Experiment 7 was repeated using rewinding without twisting. The resulting yarn showed very low coherency and no stable bobbins could be prepared after final drawing.

[0052] An individual feature or combination of features from an embodiment of the invention described herein, as well as obvious variations thereof, are combinable with or exchangeable for features of the other embodiments described herein, unless the person skilled in the art would immediately realize that the resulting embodiment is not physically feasible.

Reference numbers in figures

[0053]

- 2: Mixing
- 4: Spinning
- 6: Quenching and removing part of solvent
- 7: Drawing
- 8: Inline drawing
- 10: Offline drawing
- 12: Twisting
- 13: Post-twist-drawing
- 14: Inline post-twist-drawing
- 16: Offline post-twist-drawing
- 18: Un-drawn yarn
- 20: Multifilament yarn

Claims

1. A method of manufacturing a multifilament yarn comprising the steps of

- providing a partially drawn multifilament yarn comprising partially drawn filaments,
- twisting the partially drawn multifilament yarn to a partially-drawn-twist-level of 4 turns per meter to 600 turns per meter to form a twisted partially drawn multifilament yarn, preferably twisting the partially drawn yarn to a partially-drawn-twist-level of 10 turns per meter to 500 turns per meter, more preferably twisting the partially drawn yarn to a partially-drawn-twist-level of 12 to 200 turns per meter, and
- post-twist-drawing the twisted partially drawn multifilament yarn by a draw ratio DR_{pt} of at least 1.1, preferably post-twist-drawing by DR_{pt} of at least 1.5, more preferably post-twist-drawing by DR_{pt} of at least 2, and most preferably post-twist-drawing by DR_{pt} of at least 3.

2. Method according to claim 1, wherein the partially-drawn-twist-level / DR_{pt} is between 2 - 250 turns per meter, preferably the partially-drawn-twist-level / DR_{pt} is between 2 - 120 turns per meter.

3. Method according to claim 1 or 2, wherein at least one of the filaments of the partially drawn multifilament yarn is selected from the group consisting of polyester filaments, HD polyethylene filaments, UHMWPE filaments, and polypropylene filaments.

4. Method according to claim 3, wherein the partially drawn multifilament yarn comprises at least 75 number-% UHMWPE filaments; preferably the partially drawn multifilament yarn comprises at least 90 number-% UHMWPE filaments; and more preferably the filaments of the partially drawn multifilament yarn consist of UHMWPE filaments.

5. Method according to any one of the claims 1 to 4, wherein twisting of the partially drawn multifilament yarn is realized inline with a drawing step.

6. Method according to any one of the claims 1 to 4, wherein the steps of twisting the partially drawn multifilament yarn and post-twist-drawing are conducted inline.

7. Method according to any one of the claims 1 to 6, wherein twisting the partially drawn yarn is conducted by an Uster twister system.

8. Method according to any one of the claims 1 to 7, wherein twisting the partially drawn yarn is conducted by first winding an untwisted partially drawn multifilament yarn followed by twisting of the partially drawn multifilament yarn by unwinding the partially drawn multifilament yarn using a twisting creel system.

9. Method according to claim 8, wherein the twisting creel system is arranged to conduct the unwinding and twisting inline with the post-twist-drawing process, and wherein unwinding speed and rotation speed of the twisting creel system is adjusted to the inline post-twist-drawing process.

10. Method according to any one of the claims 6 to 9, further comprising the step of tensioning the multifilament yarn in a tensioning station after twisting the partially drawn yarn and before post-twist-drawing of the partially drawn yarn.

11. Method according to any one of the claims 1 to 10, wherein the partially drawn multifilament yarn is post-twist-drawn by a draw ratio DR_{pt} of at most 100, preferably by a DR_{pt} of at most 25, and more preferably by a DR_{pt} of at most 10.

12. Method according to any one of the claims 1 to 11, wherein the partially drawn multifilament yarn comprises at least 75 number-% UHMWPE filaments, and preferably at least 90 number-% UHMWPE filaments, to form a HPPE multifilament yarn.

Patentansprüche

1. Verfahren zur Herstellung eines Multifilamentgarns, umfassend die Schritte:

- Bereitstellung eines teilverstreckten Multifilamentgarns, umfassend teilverstreckte Filamente,
- Verdrehung des teilverstreckten Multifilamentgarns auf eine Drehung-teilverstreckt von 4 Touren pro Meter

bis 600 Touren pro Meter zur Bildung eines gedrehten teilverstreckten Multifilamentgarns, bevorzugt Verdrehung des teilverstreckten Garns auf eine Drehung, teilverstreckt von 10 Touren pro Meter bis 500 Touren pro Meter, besonders bevorzugt Verdrehung des teilverstreckten Garns auf eine Drehung, teilverstreckt von 12 bis 200 Touren pro Meter, und

- Nachverstreckung des gedrehten teilverstreckten Multifilamentgarns um ein Streckverhältnis DR_{pt} von mindestens 1,1, bevorzugt Nachverstreckung um DR_{pt} gleich mindestens 1,5, besonders bevorzugt Nachverstreckung um DR_{pt} gleich mindestens 2 und ganz besonders bevorzugt Nachverstreckung um DR_{pt} gleich mindestens 3.

2. Verfahren nach Anspruch 1, bei dem Drehungsteilverstreckt/ DR_{pt} zwischen 2-250 Touren pro Meter, bevorzugt zwischen 2-120 Touren pro Meter liegt.

3. Verfahren nach Anspruch 1 oder 2, bei dem unter den Filamenten des teilverstreckten Multifilamentgarns mindestens eins ausgewählt wird aus der Gruppe bestehend aus Polyesterfilamenten, HD-Polyethylen-Filamenten, UHMWPE-Filamenten und Polypropylenfilamenten.

4. Verfahren nach Anspruch 3, bei dem das teilverstreckte Multifilamentgarn zahlenmäßig mindestens 75% UHMWPE-Filamente umfasst, das teilverstreckte Multifilamentgarn zahlenmäßig bevorzugt mindestens 90% UHMWPE-Filamente umfasst und die Filamente des teilverstreckten Multifilamentgarns besonders bevorzugt aus UHMWPE-Filamenten besteht.

5. Verfahren nach einem der Ansprüche 1 bis 4, bei dem die Verdrehung des teilverstreckten Multifilamentgarns im Zuge einer Verstreckung erfolgt.

6. Verfahren nach einem der Ansprüche 1 bis 4, bei dem die Verdrehung des teilverstreckten Multifilamentgarns und die Nachverstreckung in einem Arbeitsgang erfolgen.

7. Verfahren nach einem der Ansprüche 1 bis 6, bei dem die Verdrehung des teilverstreckten Garns nach dem System Uster erfolgt.

8. Verfahren nach einem der Ansprüche 1 bis 7, bei dem die Verdrehung des teilverstreckten Garns durch anfängliches Aufwickeln eines ungedrehten teilverstreckten Multifilamentgarns mit anschließender Verdrehung des teilverstreckten Multifilamentgarns durch Abwickeln des teilverstreckten Multifilamentgarns mittels Drehgatter erfolgt.

9. Verfahren nach Anspruch 8, bei dem die Anordnung des Drehgatters ein in einem Arbeitsgang mit der Nachverstreckung erfolgreiches Abwickeln und Verdrehen ermöglicht, wobei Abwickel- und Drehgeschwindigkeit des Drehgatters auf die in einem Zug erfolgende Nachverstreckung eingestellt wird.

10. Verfahren nach einem der Ansprüche 6 bis 9, ferner umfassend den Schritt: Spannen des Multifilamentgarns in einer Spannstelle nach Verdrehung des teilverstreckten Garns und vor Nachverstreckung des teilverstreckten Garns.

11. Verfahren nach einem der Ansprüche 1 bis 10, bei dem das teilverstreckte Multifilamentgarn um ein Streckverhältnis DR_{pt} von höchstens 100, bevorzugt um ein DR_{pt} von höchstens 25 und besonders bevorzugt um ein DR_{pt} von höchstens 10 nachverstreckt wird.

12. Verfahren nach einem der Ansprüche 1 bis 11, bei dem das teilverstreckte Multifilamentgarn zahlenmäßig mindestens 75% UHMWPE-Filamente umfasst, und zahlenmäßig bevorzugt mindestens 90% UHMWPE-Filamente umfasst zur Bildung eines HPPE-Multifilamentgarns.

Revendications

1. Procédé de fabrication d'un fil multifilament, comprenant les étapes qui consistent à :

- fournir un fil multifilament partiellement étiré comprenant des filaments partiellement étirés,
- appliquer une torsion au fil multifilament partiellement étiré jusqu'à un niveau de torsion partiellement étiré de 4 tours par mètre à 600 tours par mètre pour former un fil multifilament partiellement étiré retordu, préférentiellement appliquer une torsion au fil partiellement étiré jusqu'à un niveau de torsion partiellement étiré de 10 tours par

mètre à 500 tours par mètre, plus préférablement appliquer une torsion au fil partiellement étiré jusqu'à un niveau de torsion partiellement étiré de 12 tours par mètre à 200 tours par mètre, et

- appliquer un étirage post-torsion au fil multifilament partiellement étiré retordu selon un rapport d'étirage DR_{pt} d'au moins 1,1, préférablement appliquer un étirage post-torsion selon un DR_{pt} d'au moins 1,5, plus préférablement appliquer un étirage post-torsion selon un DR_{pt} d'au moins 2, et idéalement appliquer un étirage post-torsion selon un DR_{pt} d'au moins 3.

2. Procédé selon la revendication 1, dans lequel le niveau de torsion partiellement étiré / DR_{pt} est de 2 à 250 tours par mètre, préférablement le niveau de torsion partiellement étiré / DR_{pt} est de 2 à 120 tours par mètre.

3. Procédé selon la revendication 1 ou 2, dans lequel au moins un des filaments du fil multifilament partiellement étiré est sélectionné dans le groupe constitué de filaments de polyester, de filaments de polyéthylène HD, de filaments d'UHMWPE, et de filaments de polypropylène.

4. Procédé selon la revendication 3, dans lequel le fil multifilament partiellement étiré comprend au moins 75 % en nombre de filaments d'UHMWPE ; préférablement le fil multifilament partiellement étiré comprend au moins 90 % en nombre de filaments d'UHMWPE ; et plus préférablement les filaments du fil multifilament partiellement étiré se composent de filaments d'UHMWPE.

5. Procédé selon l'une quelconque des revendications 1 à 4, dans lequel la torsion du fil multifilament partiellement étiré est réalisée en ligne avec une étape d'étirage.

6. Procédé selon l'une quelconque des revendications 1 à 4, dans lequel les étapes de torsion du fil multifilament partiellement étiré et d'étirage post-torsion sont conduites en ligne.

7. Procédé selon l'une quelconque des revendications 1 à 6, dans lequel la torsion du fil partiellement étiré est conduite par un système à retordre Uster.

8. Procédé selon l'une quelconque des revendications 1 à 7, dans lequel la torsion du fil partiellement étiré est conduite en enroulant d'abord un fil multifilament partiellement étiré non retordu, puis en appliquant une torsion au fil multifilament partiellement étiré en déroulant le fil multifilament partiellement étiré en utilisant un système à râtelier de torsion.

9. Procédé selon la revendication 8, dans lequel le système à râtelier de torsion est agencé pour conduire le déroulement et la torsion en ligne avec le processus d'étirage post-torsion, et dans lequel la vitesse de déroulement et la vitesse de rotation du système à râtelier de torsion sont réglées en fonction du processus d'étirage post-torsion en ligne.

10. Procédé selon l'une quelconque des revendications 6 à 9, comprenant en outre l'étape qui consiste à tendre le fil multifilament dans une station de tension après la torsion du fil partiellement étiré et avant l'étirage post-torsion du fil partiellement étiré.

11. Procédé selon l'une quelconque des revendications 1 à 10, dans lequel le fil multifilament partiellement étiré est soumis à un étirage post-torsion selon un rapport d'étirage DR_{pt} d'au maximum 100, préférablement selon un rapport d'étirage DR_{pt} d'au maximum 25, et plus préférablement selon un rapport d'étirage DR_{pt} d'au maximum 10.

12. Procédé selon l'une quelconque des revendications 1 à 11, dans lequel le fil multifilament partiellement étiré comprend au moins 75 % en nombre de filaments d'UHMWPE, et préférablement au moins 90 % en nombre de filaments UHMWPE, pour former un fil multifilament de HPPE.

FIG. 1/2

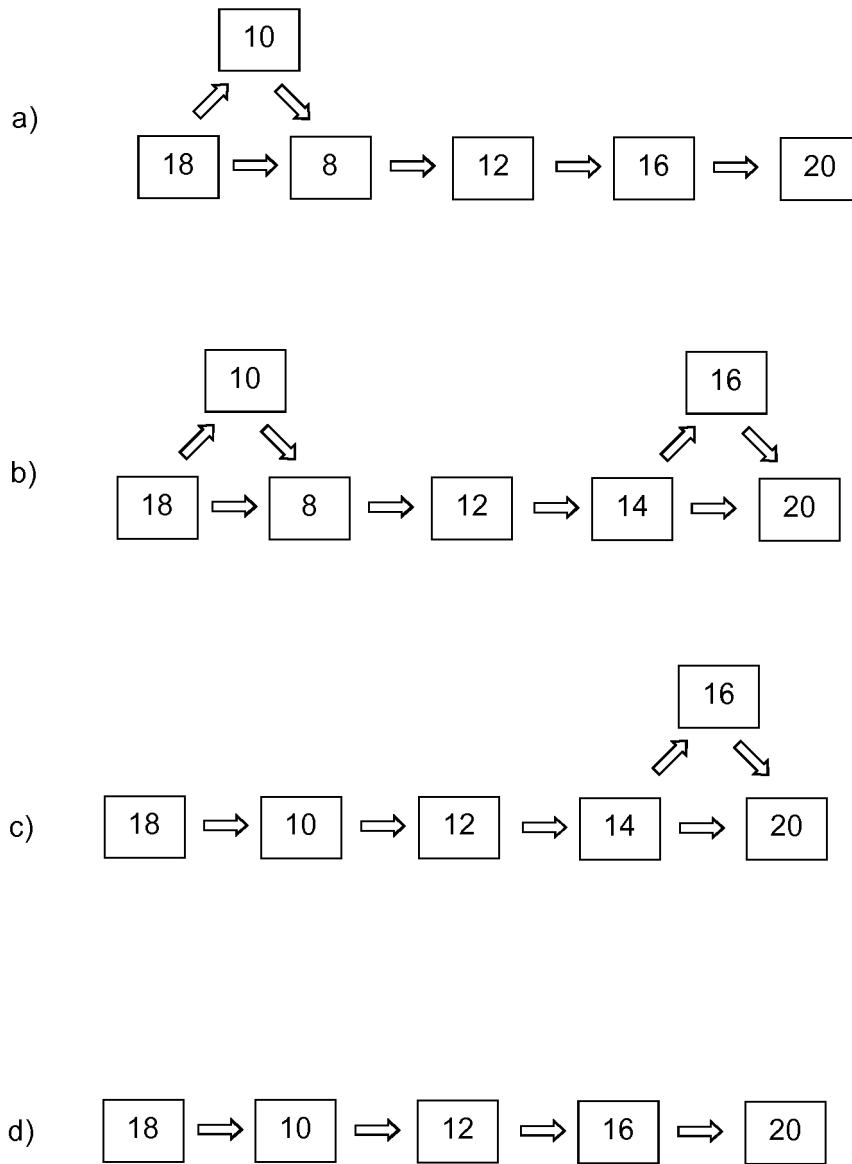
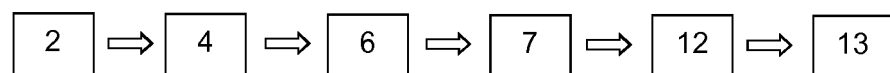


FIG. 2/2



REFERENCES CITED IN THE DESCRIPTION

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