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(57) Abstract: The invention relates to a method for producing a composite fabric comprising the steps of: a) providing HPPE fibres; b) assembling the HPPE fibres to form a fabric; c) optionally, applying an aqueous suspension or solvent solution of a polymeric material to the HPPE fibres before, during or after assembling; d) optionally, at least partially drying the aqueous suspension or the solvent suspension of the polymeric material applied in step c); to obtain a fabric upon completion of steps a), b), c) and d); e) optionally, applying a temperature in the range from the melting temperature of the polymeric material to 153°C to the fabric of step c) or after step d) to at least partially melt the polymeric material; f) optionally, applying a pressure to the fabric before, during and/or after step e) to at least partially compact the fabric; and g) applying a polymeric material as used in step c) or a chemically distinct polymeric material than the polymeric material used in step c) on at least one side of the fabric at a temperature above the melting temperature of the polymeric material applied in step g); to obtain a composite fabric upon completion of steps a) - g); and h) compressing the composite fabric by applying a compression pressure of at least 1 bar at a temperature of between the melting temperature of the polymeric material applied in step g) and c) and the melting temperature of the HPPE fibers; wherein the polymeric material is selected from the group consisting of homopolymers of ethylene, homopolymers of propylene, copolymers of ethylene and copolymers of propylene, and/or mixtures thereof, the polymeric material having a density as measured according to ISO1183-2004 in the range from 875 to 970 kg/m3, a melting temperature in the range from 40 to 140°C and a heat of fusion of at least 5 J/g.

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METHOD TO PRODUCE A HIGH PERFORMANCE POLYETHYLENE FIBERS COMPOSITE FABRIC

The present invention concerns a method for manufacturing a composite fabric comprising high performance polyethylene fibers and a polymeric material. Furthermore, the present invention directs to a composite fabric and to the use of the composite fabric in different applications.

Such methods to make composite materials and composite materials comprising high performance polyethylene fibers and a polymeric material used as a matrix material are for instance known from US4623574, US5766725, US7211291 and US8999866. US4623574 discloses the manufacture of fabrics by cross-plying and stacking a plurality of monolayers comprising unidirectionally aligned extended chain polyethylene fibers and a matrix material, followed by pressing the cross-plied and stacked monolayers into a sheet. EP2488363 discloses a flexible woven sheet having a total shrinkage of at most 1.9% and comprising: a) a woven fabric having a warp direction and a weft direction and comprising yarns containing polyethylene fibers containing; and b) a plastomer layer adhered to the surface of the woven fabric, the plastomer being a semi-crystalline copolymer of ethylene or propylene and one or more C2 to C12 alpha-olefin co-monomers and having a density as measured according to ISO1183 of between 870 and 930 kg/m^3.

Radomes are known highly electromagnetically transparent structures used for covering or enclosing and protecting antennas and satellite communications (SATCOM) antennas. Antennas used in e.g. radar installations, wireless telecom infrastructure and radio telescopes often need a radome or a covering structure of some kind to protect them from weather conditions, sunlight, wind, and moisture or water resulting from rain, snow, fog, ice etc. The presence of the radome is particularly mandatory for antennas placed in regions where high winds or storms often occur, in order to protect the antennas from hale and impacts from projectiles such as debris carried by the wind. Radomes are generally made of either rigid self-supporting materials or air-inflated flexible fabrics. Different types of radomes including dielectric, space frame, composite, and air inflatable radomes are already known in the art.

Composite fabrics comprising high-performance polyethylene (HPPE) fibers and polymeric materials used in radome constructions are also known in the prior art, for instance from WO2016041954. This document discloses a space frame radome with good hydrophobicity, i.e. forms high contact angle on the surface of the fabric, over a long life time of the radome, the radome comprising a sheet, preferably a woven sheet, comprising high strength polymeric fibers and a plastomer, wherein said plastomer is a copolymer of ethylene or propylene and one or more C2 to C12 alpha-olefin co-monomers and has a density as measured according to ISO1183 of between 860 and 940 kg/m^3 and wherein the sheet has an areal density that is with at most 500% higher than the areal density of the high strength polymeric fibers.

WO2012126885 discloses an inflatable radome containing a flexible radome wall, said radome wall comprising high strength polymeric fibers, said wall further containing a plastomer wherein said plastomer is a semi-crystalline copolymer of ethylene or propylene and one or more C2 to C12 α-olefin co-monomers and the plastomer having a density as measured according to ISO1183 of between 860 and 930 kg/m^3.

US9555442B2 discloses a composite material that includes a carrier material, wherein the carrier material is coated on a first surface with a first coating material and on a second surface with a second coating material, the composite material has links of coating material which run from the first surface of the carrier material to the second surface of the carrier material, and the links of coating material start from 1 percent to 90 percent of at least one of the surfaces of the carrier material.

However, the high-performance polyethylene fibers composite fabrics comprising a polymeric material known in the prior art allow very high moisture uptake when exposed to moisture, in particular water uptake in case of rain and snow fall, fog, ice etc., which negatively influences the electromagnetic properties of the radome, in particular increasing the dielectric constant and loss tangent values of the composite fabric.

The objective of the present invention is therefore to provide a method that enables making a composite fabric comprising high performance polyethylene fibres, which allows very low amount of moisture, e.g. water uptake, i.e. a composite fabric that absorbs and retains less than 5.9 wt%, preferably at most 4 wt%, preferably at most 3 wt%, more preferably at most 2 wt%, even more preferably at most 1 wt%, even preferably at most 0.5 wt%, most preferably at most 0.2 wt%, or between 0.1 wt% and at most 1 wt%, or between 0.1 wt% and at most 0.2 wt%, based on the total weight of the composite fabric, in particular water uptake, when exposed to various weather conditions, in particular to wet environment, e.g. high humidity, rain, fog, snow, damp, ice, and even during long periods of time of exposure to wet environments, and that shows better electromagnetic properties, i.e. lower dielectric constant and loss tangent values at broad frequency range, e.g. from 3.9 to 72 GHz, which is especially relevant when the composite fabric is used in radomes. The water uptake may be preferably between 0.2 wt% and lower than 5.9 wt%, or between 0.2 wt% and at most 1 wt%, based on the total weight of the composite fabric.

This objective was achieved by a method for producing a composite fabric, the method comprising the steps of: a) providing high performance polyethylene fibres; b) assembling the high performance polyethylene fibres (HPPE) to form a fabric; c) optionally, applying an aqueous suspension or solvent solution of a polymeric material to the HPPE fibres before, during or after assembling; d) optionally, at least partially drying the aqueous suspension or the solvent suspension of the polymeric material applied in step c); to obtain a fabric upon completion of steps a), b), c) and d); e) optionally, applying a temperature in the range from the melting temperature of the polymeric material to 153°C to the fabric of step c) or after step d) to at least partially melt the polymeric material; f) optionally, applying a pressure to the fabric before, during and/or after step e) to at least partially compact the fabric; and g) applying a polymeric material as used in step c) or a chemically distinct polymeric material than the polymeric material used in step c) on at least one side of the composite fabric at a temperature above the melting temperature of the polymeric material applied in step g); to obtain a composite fabric upon completion of steps a) - g); and h) compressing the composite fabric by applying a compression pressure of at least 1 bar at a temperature of between the melting temperature of the polymeric material applied in step g) and c) and the melting temperature of the HPPE fibers; wherein the polymeric material is selected from the group consisting of homopolymers of ethylene, homopolymers of propylene, copolymers of ethylene and copolymers of propylene, and/or mixtures thereof, the polymeric material having a density as measured according to ISO1183-2004 in the range from 875 to 970 kg/m^3, a melting temperature in the range from 40 to 140°C and a heat of fusion of at least 5 J/g.

It has unexpectedly been found that by applying the composite fabric manufactured according to the process of the invention, the moisture uptake, in particular water uptake, is considerably reduced, i.e. water content is less than 5.9 wt%, preferably at most 4 wt%, preferably at most 3 wt%, more preferably at most 2 wt%, even more preferably at most 1 wt%, even preferably at most 0.5 wt%, or between 0.2 and lower than 5.9 wt%, or between 0.2 and at most 1 wt%, based on the total weight of the composite fabric, when exposed to various moisture conditions, such as weather and wet environments, e.g. rain, fog, snow, freezing, even during long periods of time, while showing better electromagnetic properties, e.g. lower dielectric constant and loss tangent values at broad frequency range, e.g. from 3.9 to 72 GHz, especially when used in radome applications. Furthermore, applying the composite fabric manufactured according to the process of the invention having a higher initial tensile modulus, enables higher dimensional stability of the composite fabric under load when used in different applications.

It is true that WO2017060469 discloses a composite sheet adapted to facilitate the manufacture of ballistic resistant articles and a method for manufacturing the composite sheet comprising the steps of a) providing HPPE fibers; b) assembling the HPPE fibers to form a sheet; c) applying an aqueous suspension of the polymeric resin to the HPPE fibers before, during or after assembling; d) at least partially drying the aqueous suspension of the polymeric resin applied in step c) to obtain a composite sheet upon completion of steps a), b), c) and d); e) optionally applying a temperature in the range from the melting temperature of the resin to 153°C to the sheet of step c) before, during and/or after step d) to at least partially melt the polymeric resin; and f) optionally applying a pressure to the composite sheet before, during and/or after step e) to at least partially compact the composite sheet, wherein the polymeric resin is a homopolymer or copolymer of ethylene and/or propylene and wherein said polymeric resin has a density as measured according to ISO1183 in the range from 860 to 930 kg/m^3, a peak melting temperature in the range from 40 to 140°C and a heat of fusion of at least 5 J/g. However, this document does not disclose or suggest applying at least 30 wt% of a polymeric material in the composite fabric, or that the composite fabric retains at most 4 wt% moisture, based on the total weight of the composite fabric, when exposed to moisture.

Within the context of the present invention, a “yarn” may be a monofilament yarn, which may be a tape or a multifilament yarn, which is herein an elongated body comprising a plurality of, i.e. at least 2, fibers. Herein “fibers” are understood to be elongated bodies with length dimension much greater than their transversal dimensions, e.g. width and thickness. The term fiber includes a monofilament, a ribbon, a strip or a tape and the like, and can have a regular or an irregular cross-section. The fibers may have continuous lengths, known in the art as filaments, or discontinuous lengths, known in the art as staple fibers. A tape for the purposes of the present invention may have a cross-sectional aspect ratio of at least 5:1, more preferably at least 20:1, even more preferably at least 100:1 and yet even more preferably at least 1000:1. The width of the tape may be between 1 mm and 200 mm, preferably between 1.5 mm and 50 mm, and more preferably between 2 mm and 20 mm. Thickness of the flat tape preferably is between 10 μm and 200 μm and more preferably between 15 μm and 100 μm.

By term “composite” is herein understood a material comprising i) polymeric fibers and ii) a material in a different form, e.g. a polymeric resin impregnated through the HPPE fibers and/or coated on the HPPE fibers. The composite fabric typically has an upper surface (herein may also be referred to as “upper side”) and a lower surface (herein may also be referred to as “lower side”) opposite to the upper surface. It goes without saying that although called upper surface and lower surface, these denominations are not limiting and they are interchangeable.

The fabric used according to the present invention may be of any construction known in the art, e.g. woven, knitted, plaited, braided or a combination thereof. Knitted fabrics may be weft knitted, e.g. single- or double-jersey fabric or warp knitted. Further examples of woven and knitted fabrics as well as the manufacturing methods thereof are described in “*Handbook of Technical Textiles*”, ISBN 978-1-59124-651-0 at chapters 4, 5 and 6, the disclosure thereof being incorporated herein as reference. A description and examples of braided fabrics are described in the same Handbook at Chapter 11, more in particular in paragraph 11.4.1, the disclosure thereof being incorporated herein by reference. The areal density of fabrics is preferably between 10 and 2000 g/m^2, more preferably between 100 and 1000 g/m^2 or between 150 and 500 g/m^2. Preferably, a woven fabric is used in the hybrid fabric according to the present invention.

By “warp yarn” is generally understood the yarns that run substantially lengthwise, i.e. in the machine length direction of the fabric. In general, the length direction is only limited by the length of the warp yarns whereas the width is mainly limited by the number of individual warp yarns and the width of the weaving machine employed. The hybrid fabric according of the invention may be a woven fabric that may have multiple warp yarns with similar or different composition. By term “weft yarn” is generally understood the yarns that run in a cross-wise direction, i.e. transverse to the machine direction of the fabric. Defined by a weaving sequence of the product, the weft yarn repeatedly interlaces or interconnects with at least one warp yarn. The angle formed between the warp yarns and the weft yarns can vary from 15 to 90, for instance be about 90°, 60°, 45° or 30°.

A fabric is typically known in the art to be a three-dimensional (3D) object, wherein one dimension (the thickness) is much smaller than the two other dimensions (the length or the warp direction and the width or weft direction). In general, the length direction is only limited by the length of the warp yarns whereas the width of a fabric is mainly limited by the count of individual warp yarns and the width of the weaving machine employed. The position of the warp yarns is defined according to their position across the thickness of the fabric, whereby the thickness is delimited by an outside and an inside surface. By ‘outside’ and ‘inside’ is herein understood that the fabric comprises two distinguishable surfaces. The terminology ‘outside’ and ‘inside’ should not be interpreted as a limiting feature rather than a distinction made between the two different surfaces. It may as well be that for specific uses the surfaces will be facing the opposite way or that the fabric is folded to form a double layer fabric with two identical surfaces exposed on either side while the other surfaces are turned towards each other.

A weave structure is typically characterized in the prior art by a float, a length of the float and a float ratio. The float is a portion of a weft yarn delimited by two consecutive points where the weft yarn crosses the virtual plane formed by the warp yarns. The length of the float expresses the number of warp yarns that the float passes between said two delimiting points. Typical lengths of floats may be up to 11 or higher, 11 lengths of floats indicating that the weft yarn passes 11 warp yarns before crossing the virtual plane formed by the warp yarns by passing between adjacent warp yarns. The float ratio is the proportion between the lengths of the floats of the weft yarn on either side of the plane formed by the warp yarns. The weave structure for the inside layer may be chosen independent form the outside layer.

In the context of the present invention, HPPE fibers are understood to be polyethylene fibers with improved mechanical properties such as tensile strength, abrasion resistance, cut resistance or the like. Preferably, high performance polyethylene fibers comprise or consist of polyethylene fibers with a tensile strength of at least 1.0 N/tex, more preferably at least 1.5 N/tex, more preferably at least 1.8 N/tex, even more preferably at least 2.5 N/tex and most preferably at least 3.5 N/tex, at yarn level, as measured according to the method indicated in the *Examples* section of the present application. Preferred polyethylene is high molecular weight (HMWPE) or ultrahigh molecular weight polyethylene (UHMWPE). Best results were obtained when the high-performance polyethylene fibers comprise ultra-high molecular weight polyethylene (UHMWPE) and have a tenacity of at least 2.0 N/tex, more preferably at least 3.0 N/tex at yarn level.

Preferably, the HPPE fibers comprise high molecular weight polyethylene (HMWPE) or ultra-high molecular weight polyethylene (UHMWPE) and/or a combination thereof, preferably the HPPE fibers substantially consist of HMWPE and/or UHMWPE, more preferably the HPPE fibers substantially consist of or the HPPE consist of UHMWPE because good mechanical properties, i.e. strength and modulus of the composite fabric and improved electromagnetic properties of the radomes are obtained.

In the context of the present invention the expression ‘substantially consisting of’ has the meaning of ‘may comprise a minor amount of further species’ wherein minor is up to 5 wt%, preferably of up to 2 wt% of said further species or in other words ‘comprising more than 95 wt% of’ preferably ‘comprising more than 98 wt% of’ HMWPE and/or UHMWPE.

In the context of the present invention, the polyethylene (PE) may be linear or branched, whereby linear polyethylene is preferred. Linear polyethylene is herein understood to mean polyethylene with less than 1 side chain per 100 carbon atoms, and preferably with less than 1 side chain per 300 carbon atoms; a side chain or branch generally containing at least 10 carbon atoms. Side chains may suitably be measured by FTIR. The linear polyethylene may further contain up to 5 mol% of one or more other alkenes that are copolymerisable therewith, such as propene, 1-butene, 1-pentene, 4-methylpentene, 1-hexene and/or 1-octene.

The PE is preferably of high molecular weight with an intrinsic viscosity (IV) of at least 2 dl/g; more preferably of at least 4 dl/g, most preferably of at least 8 dl/g. Such polyethylene with IV exceeding 4 dl/g are also referred to as ultra-high molecular weight polyethylene (UHMWPE). Intrinsic viscosity is a measure for molecular weight that can more easily be determined than actual molar mass parameters like number and weigh average molecular weights (Mn and Mw).

By applying the method according to the present invention, the composite fabric takes up moisture, in particular water, in an amount of preferably less than 5.9 wt%, or may be between 0.001 wt% to 5 wt%, or between 0.001 wt% to 4 wt%, or between 0.001 wt% to 3 wt%, preferably at most 4 wt%, preferably at most 3 wt%, more preferably at most 2 wt%, even more preferably at most 1 wt%, even preferably at most 0.5 wt%, more preferably at most 0.2 wt%, or between 0.2 and lower than 5.9 wt%, or between 0.2 and at most 1 wt%, based on the total weight of the composite fabric, e.g. when exposed to moisture conditions.

Moisture or water content (uptake) can be determined according to any known methods. Preferably, the moisture uptake was determined according to the method described in the section Examples herein below, i.e. by weighing the composite fabric and then at least one time submerging it into water at ambient conditions, i.e. room temperature (about 23°C) for a period of time and then weighing again the composite fabric, water uptake being then calculated as the % weight increase of the composite fabric. In particular, the composite fabric test sample may be cut before submerging it into water and before weighing, e.g. at a size of 20x20 cm with a knife belt or scissor and then about 1 cm in length of the composite fabric edge may be submerged in water, and then the composite fabric may be weighted again. After weighing the sample, the same edge of the sample can be again submerged (1cm) in water to a total time of submerging of 14 days. The water uptake is being then calculated by % weight increase of the composite fabric after 14 days of submerging it into water.

According to the method of the present invention, the HPPE fibers are preferably assembled in a fabric before, during or after adding the polymeric material, and may also be referred herein to “assembled HPPE fibers”.

The HPPE fibers may be obtained by various processes, for example by a melt spinning process, a gel spinning process or a solid-state powder compaction process.

A known method that can be used for the production of the HPPE fibers in the composite fabric according to the present invention is a solid-state powder process comprising the feeding the polyethylene as a powder between a combination of endless belts, compression-molding the polymeric powder at a temperature below the melting point thereof and rolling the resultant compression-molded polymer followed by solid state drawing. Such a method is for instance described in US 5,091,133, which is incorporated herein by reference. If desired, prior to feeding and compression-molding the polymer powder, the polymer powder may be mixed with a suitable liquid compound having a boiling point higher than the melting point of said polymer. Compression molding may also be carried out by temporarily retaining the polymer powder between the endless belts while conveying them. This may for instance be done by providing pressing platens and/or rollers in connection with the endless belts.

Another method that may be used for the production of the HPPE fibers used in the present invention comprises feeding the polyethylene to an extruder, extruding a molded article at a temperature above the melting point thereof and drawing the extruded fibers below its melting temperature. If desired, prior to feeding the polymer to the extruder, the polymer may be mixed with a suitable liquid compound, for instance to form a gel, such as is preferably the case when using ultrahigh molecular weight polyethylene.

In yet another known method, the HPPE fibers used in the present invention may be prepared by a gel spinning process. A suitable gel spinning process is described in for example GB-A-2042414, GB-A-2051667, EP 0205960A, CN103255489A and WO01/73173A1, all documents being incorporated herein by reference. In short, the gel spinning process comprises preparing a solution of a polyethylene of high intrinsic viscosity, the solvent being e.g. decline or a white mineral oil, extruding the solution into a solution-fiber at a temperature above the dissolving temperature, cooling down the solution-fiber below the gelling temperature, thereby at least partly gelling the polyethylene of the fiber, and drawing the fiber before, during and/or after at least partial removal of the solvent.

In the described methods to prepare HPPE fibers applied according to the present invention, drawing, preferably uniaxial drawing, of the produced fibers may be carried out by means known in the art. Such means comprise extrusion stretching and tensile stretching on suitable drawing units. To attain increased mechanical tensile strength and stiffness, drawing may be carried out in multiple steps.

In case of the preferred UHMWPE fibers, drawing is typically carried out uniaxially in a number of drawing steps. The first drawing step may for instance comprise drawing to a stretch factor (also called draw ratio) of at least 1.5, preferably at least 3.0. Multiple drawing may typically result in a stretch factor of up to 9 for drawing temperatures up to 120°C, a stretch factor of up to 25 for drawing temperatures up to 140°C, and a stretch factor of 50 or above for drawing temperatures up to and above 150°C. By multiple drawing at increasing temperatures, stretch factors of about 50 and more may be reached. HPPE fibers with tensile strengths of 2 N/tex to 3 N/tex and more may be so obtained.

Preferably, the composite fabric according to the present invention has a construction containing at least two monolayers of the HPPE fibers according to the present invention, the fibers in each monolayer being unidirectionally (UD) oriented in at least two fiber directions. Such construction is typically a non-woven type of construction and may be also referred interchangeably herein to as a multiaxial sheet or a non-woven multiaxial sheet. The term monolayer refers to one layer of fibers comprising the HPPE fibers and at least 30 wt% polymeric material, based on the total weight of the composite fabric. The monolayer is typically a unidirectional monolayer, i.e. containing fibers oriented in one fiber direction. The term unidirectional monolayer refers in general to a layer of unidirectionally oriented fibers, i.e. fibers that are essentially oriented in parallel. Preferably, the fiber direction in each monolayer is rotated with respect to the fiber direction in an adjacent monolayer. Several monolayers may be preassembled before their use in the composite sheet. For that purpose, a set of from 2 to 10 monolayers, preferably from 2 to 5, more preferably 2 monolayers may be stacked such that the fiber direction in each monolayer is rotated with respect to the fiber direction in an adjacent monolayer, that may be followed by consolidation. Consolidation may be done according to the prior art, e.g. by using a stitching yarn or by the use of pressure and temperature to form a preassembled sheet, or sub-sheet. Pressure for consolidation generally ranges from 1 to 10 bar while temperature during consolidation typically is in the range from 60 to 140 °C.

Preferably, the fiber monolayers in the multiaxial sheet can be at any orientation relative to other fiber monolayers, for instance the fibers in one monolayer can be oriented at an angle of from 0° to 90° relative to the fibers in an adjacent monolayer(s). Preferably, the multiaxial sheet contains or consists of at least four monolayers of HPPE fibers with orientations at angles of 0°, 90°, -45°, and +45° (each monolayer may have an offset of up to -5°, or up to +5°) relative to the adjacent monolayer, i.e. the multiaxial sheet contains or consists of a first unidirectional monolayer comprising the HPPE fibers being oriented in parallel to each other, a second unidirectional monolayer comprising the HPPE fibers being oriented in parallel to each other, a third unidirectional monolayer comprising fibers oriented in parallel to each other, wherein the first unidirectional monolayer is positioned such that the fibers in the first UD monolayer are oriented 90° relative to the fibers of the second UD monolayer; and wherein the third unidirectional monolayer is positioned such that the fibers in the third UD monolayer are oriented 45° relative to fibers of the second UD monolayer. More preferably, the multiaxial sheet contains or consists of two UD monolayers containing the HPPE fibers according to the present invention, wherein the first unidirectional monolayer comprise HPPE fibers oriented in parallel to each other, and a second unidirectional monolayer comprise HPPE fibers oriented in parallel to each other, wherein the first unidirectional monolayer is positioned such that the HPPE fibers in the first UD monolayer are oriented at an angle of from 0° to 90°, preferably at angles of -45° and +45° (each angle value may have an offset of +5° or up to -5°, e.g. the HPPE fibers in the first UD monolayer are oriented at an angle of -48° and +48°) relative to the HPPE fibers in the second adjacent UD monolayer. Further details of matrix systems and monolayers with multiaxial constructions may be found, for example, in U.S. Patent No. 5,470,632 and WO2011163643, both documents being incorporated herein by reference in its entirety. Using such a preferred multiaxial sheet in the composite fabric according to the invention is additionally advantageous due to the fact that such a multiaxial sheet is free of undulations under load, i.e. it shows uniform elongation of the fiber in different fiber directions, e.g. of about 3% elongation compared with the initial elongation of the HPPE fibers measured by EN12311 2/A, as described also in the Examples section herein below, and shows excellent mechanical properties, i.e. high stiffness and high modulus in multiaxial sheet directions, especially high initial modulus, i.e. which is the elastic modulus between 0.3 and 1 % elongation, during use at high loads and enables better overall dimensional stability of the structure wherein the composite fabric is applied for.

The flexural modulus in both HPPE fibre directions in one monolayer of the multiaxial sheet is larger than 8 GPa, preferably larger than 9 GPa, more preferably larger than 10 GPa, as measured by the method mentioned in the *Examples* section of this patent application.

The amount of fiber in one monolayer of the multiaxial sheet is generally between 1 and 120 grams per square meter. The amount of fiber may also be referred to as the fiber density of a layer. Preferably the amount of fiber in one monolayer of the multiaxial sheet is between 2 and 30 grams per square meter, and more preferably between 3 and 20 grams per square meter. It has been found that fiber densities in these ranges help to maintain flexibility of the multilayer composite fabric according to the present invention.

The composite fabric may furthermore comprise at least one film, or cover sheet, being a polymeric film with a thickness of preferably from 1 to 150 micrometer, more preferably from 2 to 50 micrometer. The film or cover sheet may comprise polyethylene, especially ultrahigh molecular weight polyethylene, low density polyethylene, polypropylene, thermoplastic polyester or polycarbonate, biaxially-oriented films made from polyethylene, polypropylene, polyethylene terephthalate or polycarbonate. However, it is an additional advantage of the composite fabric of the present invention that it fulfils the advantages of the present invention even without such film or cover sheet.

Preferably, the composite fabric of the present invention contains at most 70 wt% of UHMWPE, preferably at most 50 wt% of UHMWPE and more preferably at most 30 wt% UHMWPE, whereby the wt% are expressed as weight of UHMWPE to the total weight of the composite fabric. In a yet preferred embodiment, the UHMWPE present in the composite fabric is comprised in the HPPE fibers of said composite fabric.

Preferably, areal density of the composite fabric according to the present invention is at least 100 g/m^2 and at most 1000 g/m^2, more preferably from 200 to 800 g/m^2, most preferably at least 500 g/m^2 and at most 800 g/m^2. The areal density of one monolayer without the polymeric material may be from 80 to 120 g/m^2.

The composite fabric according to the present invention may contain one single polymeric material, i.e. one single type or (substantially) the same type of polymeric material (i.e. from the same chemical class), preferably at least one of polyethylene homopolymer or ethylene-based (co)polymer, as defined herein, that is hetero-atom free or may contain at least two chemically distinct polymeric materials, preferably two chemically distinct polymeric materials. In case at least two chemically distinct polymeric materials are used according to the present invention, “chemically distinct” means herein that at least one of these polymeric materials may comprises (co)polymers comprising a monomer having a hetero atom and at least one of these polymeric materials may comprises (co)polymers comprising a monomer that is free of hetero atoms.

The polymeric material may comprise at least one material selected from a group consisting of polyethylene homopolymer, ethylene-propylene co-polymers, other ethylene copolymers with co-monomers such as 1-butene, isobutylene, as well as with hetero atom containing monomers such as acrylic acid, methacrylic acid, vinyl acetate, maleic anhydride, ethyl acrylate, methyl acrylate; generally, α-olefin and cyclic olefin homopolymers and copolymers, or blends thereof. Preferably, the polymeric material is a copolymer of ethylene or propylene which may contain as co-monomers one or more olefins having 2 to 12 C-atoms, in particular ethylene, propylene, isobutene, 1-butene, 1-hexene, 4-methyl-1-pentene, 1-octene, acrylic acid, methacrylic acid or vinyl acetate. In the absence of co-monomer in any of the polymeric material, a wide variety of polyethylene or polypropylene may be used amongst which high density polyethylene (HDPE), linear low-density polyethylene (LLDPE), very low-density polyethylene (VLDPE), low density polyethylene (LDPE), isotactic polypropylene, atactic polypropylene, syndiotactic polypropylene or blends thereof.

Furthermore, the polymeric material in the composite fabric according to the present invention may be a functionalized polyethylene or a functionalized polypropylene or copolymers thereof. Such functionalized polymers are often referred to as functional copolymers or grafted polymers, whereby the grafting refers to the chemical modification of the polymer backbone mainly with ethylenically unsaturated monomers comprising heteroatoms and whereas functional copolymers refer to the copolymerization of ethylene or propylene with ethylenically unsaturated monomers. Preferably, the ethylenically unsaturated monomer comprises oxygen and/or nitrogen atoms. Most preferably, the ethylenically unsaturated monomer comprises a carboxylic acid group or derivatives thereof resulting in an acylated polymer, specifically in an acetylated polyethylene or polypropylene. Preferably, the carboxylic reactants are selected from the group consisting of acrylic, methacrylic, cinnamic, crotonic, and maleic, amine, fumaric, and itaconic reactants. Said functionalized polymers typically comprise between 1 and 10 wt% of carboxylic reactant or more. The presence of such functionalization in the polymeric material, particularly resin, may substantially enhance the dispersability of the resin and/or allow a reduction of further additives present for that purpose such as surfactants. Preferably, ethylene acrylic acid (EAA) copolymer, such as the commercially available EAA copolymers sold under the tradename Michemprime®, is comprised in the polymeric material in the composite fabric according to the present invention as this copolymer enhances adhesion to HPPE fibers.

The polymeric material has a density as measured according to ISO1183-2004 in the range from 875 to 970 kg/m^3, preferably from 860 to 930 kg/m^3, yet preferably from 870 to 920 kg/m^3, more preferably from 870 to 910 kg/m^3. The inventors identified that polymeric materials with densities within said preferred ranges provide an improved balance between the mechanical properties of the composite fabric and the processability of the suspension, especially the dried suspension during the process of the invention.

The polymeric material is a semi-crystalline polymer, i.e. have a peak melting temperature in the range from 40 to 140°C and a heat of fusion of at least 5 J/g, measured in accordance with ASTM E793-85 (1989) and ASTM E794-85 (1989), considering the second heating curve at a heating rate of 10 K/min, on a dry sample. Preferably, the polymeric material has a heat of fusion of at least 10 J/g, preferably at least 15 J/g, more preferably at least 20 J/g, even more preferably at least 30 J/g and most preferably at least 50 J/g. The heat of fusion of the polymeric material is not specifically limited by an upper value, other than the theoretical maximum heat of fusion for a fully crystalline polyethylene or polypropylene of about 300 J/g. The polymeric material is a semi-crystalline product with a peak melting temperature in the specified ranges. Accordingly, is a reasonable upper limit for the polymeric material a heat of fusion of at most 200 J/g, preferably at most 150 J/g. Preferably, a peak melting temperature of the polymeric material is in the range from 50 to 130°C, preferably in the range from 60 to 120°C. Such preferred peak melting temperatures provide a more robust processing method to produce the composite fabric of the invention in that the conditions for drying and/or compaction of the composite fabric do need less attention while composite fabrics with good properties are produced. The polymeric material may have more than one peak melting temperatures. In such case, at least one of said melting temperatures falls within the above ranges. A second and/or further peak melting temperature of the polymeric material may fall within or outside the temperature ranges. Such may for example be the case when the polymeric material is a blend of polymers or at least one of the polymeric materials is a blend of polymers.

The polymeric material may have a modulus that may vary in wide ranges. For instance, the modulus may vary from 50 MPa to 500 MPa, related to the specific demands during the use of the composite fabric according to the invention in different applications.

Preferably, the composite fabric comprises the HPPE fibers and at least 30 wt%, based on the total weight of the composite fabric, of at least two polymeric materials, preferably at least 30 wt%, based on the total weight of the composite fabric, of two polymeric materials, wherein the first polymeric material is a homopolymer of ethylene or propylene, an ethylene copolymer with a co-monomer free of hetero atoms or a propylene copolymer with a co-monomer free of hetero atoms, or an ethylene copolymer with a hetero atom containing co-monomer or a propylene copolymer with a hetero atom containing co-monomer, and the second polymeric material is a homopolymer of ethylene or propylene, an ethylene copolymer with a co-monomer free of hetero atoms or a propylene copolymer with a co-monomer free of hetero atoms. Most preferably, the polymeric material consists of a first polymeric material that is a polymeric resin of an ethylene acrylic acid copolymer, ethylene methacrylic acid copolymer, ethylene acrylonitrile copolymer or derivatives thereof and the second polymeric material that is a copolymer of ethylene and 1-butene, 1-hexane and or 1-octene. An amount of less than 30 wt% polymeric material, based on the total weight of the composite fabric, results in a too thin composite fabric that has low robustness and can be easily damaged.

Preferably, the density of the first polymeric material is in the range from 930 to 970 kg/m^3 and the density of the second polymeric material is in the range from 875 to 910 kg/m^3.

Preferably, the first polymeric material is substantially (i.e. more than 98% coating the surface of the fibers) coating the HPPE fibers and the second polymeric material is substantially coating (more than 98% coating the surface of the fibers) the first polymeric material. More preferably, the first polymeric material is in direct contact with the surface of the HPPE fibers forming the coated HPPE fibers, and the first polymeric material may be applied on the HPPE fibers as a coating obtained from an aqueous or solvent suspension.

The composite fabric according to the invention comprises at least 30 wt%, based on the total weight of the composite fabric, of a polymeric material that may also be referred herein as polymeric matrix. The amount of the polymeric material in the composite fabric of the present invention is at least 30 wt% and at most 95 wt%, preferably higher than 50 wt% and at most 90 wt%, more preferably between 55 and 90 wt%, most preferably between 60 and 90 wt%, even most preferably between 65 and 90 wt%, based on the total weight of the composite based on the total weight of the composite fabric. The amount of the polymeric material is preferably higher than 35 wt%; 40 wt%; 50 wt%; 55 wt%; or than 60 wt% and lower than 90 wt%; or 80 wt% or than of 70 wt%. In case the composite fabric of the invention comprises HPPE fibres and at least two polymeric materials, and in particular at least two chemically distinct polymeric materials, and preferably two polymeric materials, and more preferably two chemically distinct polymeric materials, then the first polymeric material may be present in an amount of from 0.1 to 15 wt%, preferably of from 2 to 10 wt%, more preferably between 2 and 5 wt%, based on the total amount of polymeric material in the composite fabric.

The composite fabric of the present invention contains, i.e. absorbs and retains or takes up moisture, e.g. water during exposure to wet environmental conditions of less than 5.9 wt%, preferably at most 4 wt%, preferably at most 3 wt%, more preferably at most 2 wt%, even more preferably at most 1 wt%, even preferably at most 0.5 wt%, more preferably at most 0.2 wt%, or between 0.1 and lower than 5.9 wt%, or between 0.1 and at most 1 wt%, based on the total weight of the composite fabric. This very low amount of moisture in the composite fabric according to the present invention when exposed to moisture, wet environments makes the composite fabric suitable for use in different applications, such as radomes, i.e. radome walls, architectural structures, inflatable structures, protective structures, such as a sleeve or liners for oil tanks.

The total sum of the wt% of the components in the composite fabric according to the present invention, i.e. of the HPPE fibers content; of the content of the at least one polymeric material and of the moisture content; and optionally of the conventional additives content should not exceed 100%, wherein the weight percentage is the weight of each component in the total weight of the composite fabric.

It is generally known that synthetic fibers are naturally prone to static build-up and thus typically require the application of a fiber surface finish compound, also known in the art as spin finish, in order to facilitate further processing of the fibers into useful composites. Fiber spin finishes are generally employed to reduce static build-up, and in the case of untwisted and unentangled fibers, to aid in maintaining fiber cohesiveness. Spin finishes typically are also known to lubricate the surface of the fiber, protecting the fiber from the equipment and protecting the equipment from the fiber. The art discloses many types of fiber surface spin finishes for use in various industries, e.g. U.S. patents 5,275,625, 5,443,896, 5,478,648, 5,520,705, 5,674,615, 6,365,065, 6,426, 142, 6,712,988, 6,770,231, 6,908,579 and 7,021,349.

The HPPE fibers may contain spin finish compound on the surface of the fibers or the fibers are preferably substantially free of spin finish compound, i.e. the fibers contain virtually no spin finish compound on the surface of the fibers, i.e. the HPPE fibers may contain from 0 to at most 0.05 wt%, preferably to at most 0.01 wt%, based on the weight of the fiber, of a spin finish compound on their surface and/or in their structure.

The composite fabric according to the invention may have a dielectric constant of lower than 3.20, preferably lower than 3, more preferably lower than 2.7, yet more preferably lower than 2.60, and most preferably lower than 2.20, most preferably between 2.0 and 2.4, more preferably between 2.1 and 2.3, at a broad range frequency of between at least 0.5 GHz and at most 130 GHz, preferably between between 1 GHz and 72 GHz, and between 39.5 GHz and 72 GHz, as measured according to the method described in the *Examples* section herein below.

The composite fabric according to the invention may have a loss tangent of lower than 0.023, preferably lower than 0.02, more preferably lower than lower than 0.015, yet more preferably lower than 0.01, yet more preferably lower than 0.008, yet more preferably lower than 0.001, yet more preferably lower than 0.0009 at a broad range frequency of between at least 0.5 GHz and at most 130 GHz, preferably between 1 GHz and 72 GHz, and between 39.5 GHz and 72 GHz, as measured according to the method described in the *Examples* section herein below.

Preferably, the method for manufacturing the composite fabric of the invention comprises the steps of:

a) providing HPPE fibres;
b) assembling the HPPE fibres to form a fabric that is preferably a multiaxial construction having at least two adjacent monolayers of the HPPE fibres, with the HPPE fibres in each monolayer being unidirectionally oriented in at least two fiber directions;
c) applying an aqueous suspension or solvent solution of a polymeric material to the HPPE fibres before, during or after assembling;
d) at least partially drying the aqueous suspension or the solvent suspension of the polymeric material applied in step c);
   to obtain a fabric upon completion of steps a), b), c) and d);
e) optionally, applying a temperature in the range from the melting temperature of the polymeric material to 153°C to the fabric of step c) or after step d) to at least partially melt the polymeric material;
f) optionally, applying a pressure to the fabric before, during and/or after step e) to at least partially compact the fabric; and

g) applying a polymeric material as used in step c) or applying a second polymeric material that is a polymeric material that is chemically distinct than the polymeric material used in step c) on at least one side of the fabric at a temperature above the melting temperature of the polymeric material;

to obtain a composite fabric upon completion of steps a) - g);

h) compressing the composite fabric by applying a compression pressure of at least 1 bar at a temperature of between the melting temperature of the polymeric material applied in step g) and c) and the melting temperature of the HPPE fibers;

wherein the polymeric material applied in step c) and d) is selected from the group consisting of homopolymers of ethylene, homopolymers of propylene, ethylene copolymers and propylene copolymers, and/or mixtures thereof, the polymeric material having a density as measured according to ISO1183-2004 in the range from 875 to 970 kg/m^3, a melting temperature in the range from 40 to 140°C and a heat of fusion of at least 5 J/g.

In case at least two chemically distinct polymeric materials are applied in the method according to the invention, the polymeric material applied in step c) may be also referred herein as the first polymeric material and the polymeric material applied in step g) may be also referred herein as the second polymeric material.

The fabric obtained in step b) may be stitched in zero direction relative to orientation of fibers or in the machine direction with a thread which can be a polyester or other polymer that may have different titres.

Preferably, the concentration of (first) polymeric material in step c) in the aqueous suspension or solvent solution, preferably in the aqueous suspension, is between 4 and 60 wt%, preferably between 5 and 50 wt%, most preferably between 6 and 40 wt%, based on the total weight of aqueous suspension.

According to the method of the present invention, the aqueous suspension or solvent solution is preferably applied to the HPPE fibers as a coating and this coating may also impregnate into the HPPE fibers. Such application of suspension or solution takes place before, during or after the HPPE fibers are assembled into a fabric, but most preferably after HPPE fibers are assembled. By aqueous suspension is understood that particles of the polymeric material are suspended in water acting as non-solvent. The concentration of the (first) polymeric material in step c) of the method may widely vary and is mainly limited by the capability to formulate a stable suspension of the polymeric material in water. A typical range of concentration is between 0.5 and 60 vol% of (first) polymeric material applied in step c) in water, based on the total volume of aqueous suspension. Preferred concentrations are between 1 and 40 vol%, more preferably between 1 and 30 vol%, most preferably between 3 and 20 vol%. Further preferred concentrations of the (first) polymeric material applied in step c) in the suspension or solution is at least 1; 2; 3; 5; 10; 15 or 20 vol%, based on the total volume of suspension or solution and at most 30; 35; 40 or 50 vol% (first) polymeric material applied in step c) in the total volume of suspension or solution. Such preferred higher concentrations of (first) polymeric material applied in step c) may have the advantage of providing a composite fabric with higher concentration while reducing the time and energy required for the removal of the water or solvent from the fabric.

Conventional additives such as ionic or non-ionic surfactants, tackyfying resins, stabilizers, such as UV stabilizers, flame-retardant, anti-oxidants, colorants or other additives modifying the properties of the suspension, may be added in an amount of from 0.001 to 8 wt%, or from 0.001 to 5 wt%, based on the total weight of the composite fabric, in any of the method steps and are present in the composite fabric. Preferably, the aqueous suspension is substantially free of additives that may act as solvents for the (first) polymeric material applied in step c). Such suspension may also be referred to as solvent-free. By solvent is herein understood a liquid in which at room temperature the (first) polymeric material is soluble in an amount of more than 1 wt% whereas a non-solvent is understood a liquid in which at room temperature the (first) polymeric material applied in step c) is soluble in an amount of less than 0.1 wt%. The concentrations of the (first) polymeric material applied in step c) in the solvent solution may have the same values as the concentrations of the (first) polymeric material applied in step c) as mentioned herein for the aqueous suspension.

The application of the suspension or solution to the HPPE fibers may be done by methods known in the art and may depend amongst others on the moment the suspension or solution is added to the HPPE fibers, the concentration and viscosity of the suspension or solution. The suspension or solution may for example be applied to the HPPE fibers by spraying, dipping, brushing, transfer rolling or the like, especially depending on the intended amount of (first) polymeric material added in step c). The amount of suspension or solution present in the composite fabric may vary widely in function of the intended application of the composite fabric and can be adjusted by the employed method but also the properties of the suspension.

Once the polymeric solution or suspension is applied to the HPPE fibers, the coated and/or impregnated HPPE fibers formed thereof, preferably the assembly comprising the coated and/or impregnated fibers is at least partially dried. Such drying step involves the removal, e.g. the evaporation of at least a fraction of the water or solvent present in the assembly. Preferably the majority (e.g. more than 98 %), more preferably essentially all water or solvent is removed during the drying step, optionally in combination with other components present in the coated or impregnated assembled fabric. Drying, i.e. the removal of water or solvent from the suspension, may be done by methods known in the art. Typically the evaporation of water involves an increase of the temperatures of the fabric close to or above the boiling point of water. The temperature increase may be assisted or substituted by a reduction of the pressure and or combined with a continuous refreshment of the surrounding atmosphere. Typical drying conditions are temperatures below melting temperature of the HPPE fibers, e.g. of between 40 and 150°C, preferably between 50 and 140°C.

Preferably, the method of the invention may optionally comprise a step wherein the fabric is heated to a temperature in the range from the melting temperature of the (first) polymeric material to 153°C to the fabric of step c) or after the partially drying of the HPPE fibers to at least partially melt the (first) polymeric material of step c). Heating of the HPPE fibers may be carried out by keeping the fabric for a dwell time in an oven set at a heating temperature, subjecting the impregnated fabric to heat radiation or contacting the layer with a heating medium such as a heating fluid, a heated gas stream or a heated surface. Preferably, the temperature is at least 2°C, preferably at least 5°C, most preferably at least 10°C above the peak melting temperature of the (first) polymeric material of step c). The upper temperature is at most 153°C, preferably at most 150°C, more preferably at most 145°C and most preferably at most 140°C, to prevent detrioration of the (strength) properties of the fibers. The dwell time is preferably between 2 and 200 seconds, more preferably between 3 and 60 seconds, most preferably between 4 and 30 seconds. The heating of the fabric of this step may overlap or may be combined with the drying step. It may prove to be practical to apply a temperature gradient to the impregnated fabric whereby the temperature is raised from about room temperature to the maximum temperature of the heating step over a period of time whereby the impregnated fabric will undergo a continuous process from drying of the suspension to at least partial melting of the (first) polymeric material applied in step c).

The same polymeric material as used in step c) or a chemically distinct polymeric material than the polymeric material used in step c) is applied on at least one side, preferably on both sides of the fabric, i.e. on the upper surface area and on the lower surface area of the fabric, at a temperature above the melting temperature of the polymeric material that is applied in the method according to the present invention in step g).

Preferably, the amount of the (second) polymeric material in step g) is higher than the amount of the (first) polymeric material applied in step c). The (second) polymeric material applied in step g) of the method of the invention in amounts of from 30 wt% to 80 wt%, preferably of from 40 wt% to 70 wt%, based on the total weight of the composite fabric.

Application of the polymeric material(s) applied in step g) in order to obtain a composite fabric is preferably done in melt by using for instance a melt coating process. Such a step g) is for instance known from documents US9555442B2, WO2011045321 and WO2011045325, incorporated herein by reference. The polymeric material of step g) may be for instance deposited as a molten polymeric material at a temperature above its melting temperature that may be between 90°C and 180°C, on at least one surface, preferably on both surfaces of the fabric. Deposition may be carried out by applying any methods known in the art, for instance as by coating, laminated as film, impregnated or sprayed to form a layer on the surface of fabric obtained in step f). After deposition, the fabric may be impregnated with at least part of the molten polymeric material layer by e.g. drawing the fabric into a gap between at least two calendaring rollers at a temperature of between the melting temperature of the polymeric material and the melting temperature as determined by DSC of the HPPE fibers, said gap having a width smaller than the thickness of the fabric, with the width of the gap is chosen to apply an impregnation pressure on the fabric of at least 20 bars. The steps of applying molten polymeric material in step f) of the method of the present invention may be repeated such that a fabric encapsulated in the polymeric material may be obtained. Melting the polymeric material can be carried out according to known methods in the art, for example in an extruder. Preferably, the polymeric material in step f) is molten at a temperature of between 120°C and 150°C. After the impregnation step, the composite fabric obtained may be cooled in a cooling step, e.g. with a stream of cold air or by contacting said fabric with a cooled roller, to a temperature below 50°C, more preferably to a temperature of between 10°C and 30°C.

The method of the invention may preferably comprise an additional step of cutting the composite fabric obtained after completion of step g) and before applying step h). The composite fabric cut at this step at size and shape as desired may take up even less moisture, e.g. at most 3 wt%, more preferably at most 2 wt%, even more preferably at most 1 wt%, even preferably at most 0.05 wt%, based on the total weight of the composite fabric, when the composite fabric is exposed to moisture conditions. The cutting step may be performed with any device known in the prior art and typically to bring the size and shape of the composite fabric as desired, typically depending on the application where the composite fabric may be used.

The method according to the present invention further comprises a step h) of compressing the composite fabric obtained in step g) by applying a compression pressure of at least 1 bar at a temperature of between the melting temperature of the polymeric material applied in step g) and optionally in step c) and the melting temperature of the HPPE fibers. It was observed that by applying this step h) in the method of the invention, the moisture uptake in the composite fabric is very low, e.g. less than 5.9 wt%, preferably at most 4 wt%, preferably at most 3 wt%, more preferably at most 2 wt%, even more preferably at most 1 wt%, even preferably at most 0.05 wt%, based on the total weight of the composite fabric, when exposed to moisture conditions.

The temperature used at step h) of the method of the invention is preferably between 80°C and 150°C, more preferably between 80°C and 130°C, most preferably between 100 and 150ºC. Preferably, when a fabric containing UHMWPE fibers is used, said temperature is between 80°C and 145°C, more preferably between 80°C and 130°C, most preferably between 90°C and 125°C.

The compression pressure is preferably between at least 1 bar and at most 25 bar, more preferably between at least 1 bar and at most 20 bar, even more preferably between at least 1 bar and at most 15 bar, and most preferably between at least 1 bar and at most 10 bar. Higher compression pressures may result in low quality of esthetic appearance of the obtained composite fabric. The compression pressure may be applied from 1 to 30 min or higher, preferably between 5 and 15 min, more preferably between 10 and 15 min, at a preferred temperature of from 110 to 135ºC.

Preferably, in step h) the pressure is applied only on the edges of the composite fabric.

Preferably, the composite fabric is compressed by applying the compression pressure in step h) in a direction perpendicular to a plane defined by the lateral dimensions of the composite fabric, e.g. the plane containing the dimensions of width and thickness of the composite fabric in case of a rectangular sheet or the plane containing the circumference of the composite fabric in case of a round sheet.

The compression pressure in step h) may be applied by using conventional pressing means, a calander, a hydraulic press, a vacuum packing process, an autoclave, an oven, and/or any combination of these methods. Preferably, a vacuum packing process in combination with any of a hydraulic press or an autoclave process or oven heating is applied in step h), as the moisture uptake of the composite fabric further decrease, e.g. to less than 3 wt%, or even less than 2 wt%, based on the total weight of the composite fabric. In case a calander is used, the compression pressure may be applied by drawing the composite fabric in a gap between at least two calendaring rollers, with the compression pressure that can be set routinely by adjusting the width of said gap between said calendaring rollers such that said width is less than the thickness of the composite fabric before is drawn into the gap.

Preferably, step h) is carried out by a vacuum packing process in combination with a hydraulic press or an autoclave process or oven heating, at a pressure of at least 1 bar, preferably at least 1 bar and at most 30 bar, more preferably at least 1 bar and at most 25 bar. The preferred temperature is between 90 and 130°C in case UHMWPE fibers are used, and the time of applying the pressure may be between 1 and 30 min. The vacuum packing process typically include removing air from inside a film package, e.g. a bag of plastic material, such as a LDPE/PA, prior to sealing the composite fabric obtained in step g), by using any conventional means, e.g. a Henkovac machine. Pressing in a hydraulic press, which may be done after vacuum packing, may be carried out for a period of time of between 1 and 5 min and at a pressure of between 5 and 30 bar, preferably between 10 and 25 bar and the temperature may be between 90 and 130°C in case UHMWPE fibers are used. Pressing in an autoclave, which may be done after vacuum packing, may be carried out for a period of time of between 1 and 20 min, preferably between 1 and 15 min, at a pressure of between 5 and 30 bar, preferably between 10 and 25 bar and the temperature may be between 90 and 130°C in case UHMWPE fibers are used. Heating in an oven, which may be done after vacuum packing, may be carried out for a period of time of between 1 and at most 20 min, preferably between 10 and at most 15 min, at a temperature that may be between 90 and 130°C in case UHMWPE fibers are used. By applying such a vacuum packing process in combination with said processes, the moisture content further decreases, e.g. to even below 2 wt%, preferably below 1 wt%, more preferably below 0.5 wt%, or between 0.1 wt% to at most 1 wt% or between 0.2 wt% to at most 1 wt%, based on the total weight of the composite fabric.

During step h), a release polymeric film, e.g. a silicone paper may be preferably positioned on both sides of the composite fabric to prevent sticking of the composite fabric.

Upon completion of step h), a step i) of cooling to room temperature of the compressed composite fabric may be typically carried out by applying any method known in the art. e.g. by cooling with a stream of cold air, to a temperature below 50°C, more preferably to a temperature of between 10°C and 30°C. The fabric is preferably afterwards directly used, without cutting.

The AD of the final composite fabric is preferably between 0.2 and 3 kg/m^2, more preferably between 0.2 and 2 kg/m^2, most preferably 0.5 and 0.7 kg/m^2.

The invention also relates to a composite fabric that comprises or consists of HPPE fibers and at least one polymeric material, wherein the amount of the polymeric material is at least 30 wt%, based on the total weight of the composite fabric; the polymeric material being selected from a group consisting of a homopolymers of ethylene, homopolymers of propylene, ethylene copolymers and propylene copolymers, and/or mixtures thereof, the polymeric material having a density as measured according to ISO1183-2004 in the range from 875 to 970 kg/m^3, a melting temperature in the range from 40 to 140°C and a heat of fusion of at least 5 J/g, preferably the composite fabric is a multiaxial construction having at least two adjacent monolayers of HPPE fibres, the HPPE fibres in each monolayer being unidirectionally oriented in at least two fiber directions. The composite fabric contains or takes up less than 5.9 wt%, preferably at most 4 wt%, preferably at most 3 wt%, more preferably at most 2 wt%, even more preferably at most 1 wt%, even preferably at most 0.5 wt%, most preferably at most 0.2 wt%, or between 0.1 wt% and at most 1 wt%, or between 0.1 wt% and at most 0.2 wt%, based on the total weight of the composite fabric, when exposed to moisture conditions. Such composite fabric is subject to the preferred embodiments and potential advantages as discussed above or below in respect of the composite fabric or method, whereas the preferred embodiments for the method potentially apply vice versa for the preferred composite fabric.

Moreover, the present invention directs to a composite fabric obtainable by or obtained by the method according to the present invention. Such composite fabric comprises or consists of HPPE fibers and at least one polymeric material, wherein the amount of the polymeric material is at least 30 wt%, based on the total weight of the composite fabric; the polymeric material being selected from a group consisting of a homopolymers of ethylene, homopolymers of propylene, ethylene copolymers and propylene copolymers, and/or mixtures thereof, the polymeric material having a density as measured according to ISO1183-2004 in the range from 875 to 970 kg/m^3, a melting temperature in the range from 40 to 140°C and a heat of fusion of at least 5 J/g, preferably the composite fabric is a multiaxial construction having at least two adjacent monolayers of HPPE fibres, the HPPE fibres in each monolayer being unidirectionally oriented in at least two fiber directions. The composite fabric contains or takes up less than 5.9 wt%, preferably at most 4 wt%, preferably at most 3 wt%, more preferably at most 2 wt%, even more preferably at most 1 wt%, even preferably at most 0.5 wt%, most preferably at most 0.2 wt%, or between 0.1 wt% and at most 1 wt%, or between 0.1 wt% and at most 0.2 wt%, based on the total weight of the composite fabric when exposed to moisture conditions. Such composite fabric is subject to the preferred embodiments and potential advantages as discussed above or below in respect of the preferred method, whereas the preferred embodiments for the composite fabric potentially apply vice versa for the preferred process.

The present invention also relates to an article comprising the composite fabric according to the present invention, that may be manufactured by the method or the preferred method according to the present invention. Preferably, the article is a radome, more preferably a radome wall or an architectural structure, an inflatable structure, a protective structure, such as a sleeve or liners for oil tanks. By applying the composite fabric according to the present invention, radomes having excellent electromagnetic properties and contain or take up less than 5.9 wt%, preferably at most 4 wt%, preferably at most 3 wt%, more preferably at most 2 wt%, even more preferably at most 1 wt%, even preferably at most 0.5 wt%, most preferably at most 0.2 wt%, or between 0.1 wt% and at most 1 wt%, or between 0.1 wt% and at most 0.2 wt%, based on the total weight of the composite fabric are obtained when exposed to moisture conditions. A design of a radome adapted for an array antenna is disclosed e.g. in US 4 833 837 and US 4 783 666 included herein by reference and more in particular in the Figures and figures' explanations thereof. Additional applications of the composite fabric of the invention include cargo and container covers, ground covers, roofing, and building covers, reservoir, pond, canal, and pit liners, sails, tarpaulins, awnings, sails, bags, inflated structures, tents and the like.

Furthermore, the present invention also directs to an antenna system comprising an antenna device and a radome comprising the composite fabric according to the present invention. By antenna is understood in the present invention a device capable of emitting, radiating, transmitting and/or receiving electromagnetic radiation. Examples of typical antennas include air surveillance radar antennas and satellite communication station antennas. Preferably, the antenna device is chosen from the group consisting of an antenna array; a microwave antenna; a dual or multiple frequency antenna preferably operating at frequencies above 39.5 GHz; a radar antenna; a planar antenna; and a broadcast antenna.

The invention also relates to a method of transmitting and/or receiving electromagnetic waves, wherein the composite fabric according to the present invention is placed in the path of said electromagnetic waves, for example as a radome. For example, a protective structure comprising the composite fabric according to the present invention is utilized to house and/or protect lasers, masers, diodes and other electromagnetic wave generation and/or receiving devices. Preferably, a protective structure as herein described is utilized in conjunction with devices operating with radio frequency waves such as those between about 1 GHz and 130 GHz, preferably between about 1 GHz and 100 GHz, more preferably between 1 GHz and 72 GHz. Protective structures could be useful for protecting electrical equipment used to monitor parts of a human or animal body or organs thereof, to monitor weather patterns, to monitor air or ground traffic or to detect the presence of aircraft, boats or other vehicles around e.g. military facilities including warships.

The present invention also directs to the use of the composite fabric (in a process) for decreasing moisture uptake of a radome wall. The invention may also relate to the use of the composite fabric as described herein for increasing electromagnetic performance of a radome.

The invention will be further explained by the following examples and comparative experiment, however first the methods used in determining the various parameters useful in defining the present invention are hereinafter presented.

EXAMPLES

METHODS

- Tex: yarn's or filament's titer of HPPE fibers was measured by weighing 100 meters of yarn or filament, respectively. The tex of the yarn or filament was calculated by dividing the weight (expressed in milligrams) by 100;
- Heat of fusion and peak melting temperature of the polymeric material(s) have been measured according to standard DSC methods ASTM E 794-85 (1989) and ASTM E 793-85 (1989), respectively at a heating rate of 10K/min for the second heating curve and performed under nitrogen on a dehydrated sample.
- The density of the polymeric material(s) is measured according to ISO 1183-2004.
- IV: Intrinsic Viscosity of HPPE fibers is determined according to method ASTM D1601(2004) at 135°C in decalin, the dissolution time being 16 hours, with BHT (Butylated Hydroxy Toluene) as anti-oxidant in an amount of 2 g/l solution, by extrapolating the viscosity as measured at different concentrations to zero concentration.
- Tensile properties of HPPE fibers: tensile strength (or strength) and tensile modulus (or E-modulus) are defined and determined on multifilament yarns as specified in ASTM D885M-2014, using a nominal gauge length of the fiber of 500 mm, a crosshead speed of 50 %/min and Instron 2714 clamps, of type "Fiber Grip D5618C". On the basis of the measured stress-strain curve the modulus is determined as the gradient between 0.3 and 1 % strain. For calculation of the modulus and strength, the tensile forces measured are divided by the titre, as determined above; values in GPa are calculated assuming a density of 0.975 g/cm^3 for the HPPE.
- Tensile strength and tensile modulus at break of the polymeric material(s) were measured according ISO 527-2.
- Areal density (AD) of the composite fabric was determined by measuring the weight of a sample of preferably 0.4 m × 0.4 m with an error of 0.1 g.
- Tensile properties (i.e. tensile strength and tensile/elastic modulus) of the composite fabric were measured according to EN12311 2/A (2000), at a temperature of about 23°C and under ambient conditions and a sample average

thickness of 0.78 mm. The thickness of the samples was measured at various places on the samples, the average being reported. The sample was cut in length direction of the fibers, in dimensions of 5 cm in width and 1 m in length. 5 such samples were measured and the average was determined for each of the tensile properties. The measurements were done on a Zwick (type 8654) grip machine. A preload of 10 N was used on the fabric at the start of the measurement. Tensile test speed was 100 mm/min. The measurement has ended after the maximum force has been reached. An optical sensor was used to measure the strain during the measurement. Tensile modulus was calculated on stress-strain curve, by taking the steepest slope of the curve (strain[%] on X axis and stress[N] on y axis), which was between 0.3 and 1 % strain.

- The electromagnetic properties, e.g. dielectric constant and loss tangent, were determined for frequencies of 1.8 GHz to 10 GHz with the well-known Split Post Dielectric Resonator (SPDR) technique. For frequencies of above 10 GHz, e.g. of between 20 GHz and 130 GHz, the Open Resonator (OR) technique was used to determine said electromagnetic properties, wherein a classical Fabry-Perot resonator setup having a concave mirror and a plane mirror was utilized. For both techniques plane samples were used, i.e. samples not having any curvature in the plane defined by their width and length. In the case of SPDR technique, the thickness of the sample was chosen as large as possible being limited only by the setup design, i.e. the maximum height of the resonator. For the OR technique, the thickness of the sample was chosen to be an integer of about $\lambda/2$, wherein λ is the wavelength at which the measurement is carried out. Since in the case of the SPDR technique, for each frequency at which the dielectric properties are measured a separate setup has to be utilized, the SPDR technique was carried out at the frequencies of 1.8 GHz; 3.9 GHz and 10 GHz. The setups corresponding to these frequencies are commercially available and were acquired from QWED (Poland) but are also sold by Agilent. The software delivered with these setups was used to compute the electromagnetic properties. For the OR technique, measurements were made at 35 GHz, 35.9 GHz and 50 GHz and the setup was built in accordance with the instructions given in Chapter 7.1.17 of "*A Guide to characterization of dielectric materials at RF and Microwave frequencies*" by Clarke, R N, Gregory, A P, Cannell, D, Patrick, M, Wylie, S, Youngs, I, Hill, G, Institute of Measurement and Control / National Physical

Laboratory, 2003, ISBN: 0904457389, and all the references cited in that chapter, i.e. references 1 – 6, and in particular reference [3] R N Clarke and C B Rosenberg, "*Fabry-Perot and Open-resonators at Microwave and Millimetre-Wave Frequencies, 2 – 300 GHz*", *J. Phys. E: Sci. Instrum.*, **15**, pp 9 – 24, 1982.

- Water (uptake) content was measured by dipping the test sample (i.e. composite fabric) into water, at ambient conditions, i.e. room temperature (about 23°C) for a time of 14 days. The sample was cut before the water uptake test with a belt knife at a size of 20x20 cm (the width x the length of the test sample), and then the sample was weighted. A sample of 1x20cm (i.e. 1 cm under water and 20 cm wide sample) was then submerged in water for 14 days. The sample was then dried and measured to determine the weight increase as a function of time. The same edge of the sample was submerged in water again to a maximum of 14 days. Water content was then calculated by % weight increase of the sample.

MATERIALS

Material 1: A polymeric material was purchased as suspension from Michelman under the trade name of Michem® Prime 5931 and is a 28 wt% of an aqueous suspension of an acrylate modified polyolefin (i.e. ethylene acrylic acid (EAA) copolymer) with a melting peak at 78°C and a heat of fusion of 29 J/g (this acrylate modified polyolefin is considered in the Examples below the first polymeric material).

Material 2: A polymeric material was commercially purchased from Borealis in pellet form under the tradename of Queo^{TM}0203, that is an ethylene based 1-octene plastomer with about 18% octene, with a density of 0.902 g/cm^3, a peak melting point of 96°C and a heat of fusion of 100 J/g (second polymeric material).

Material 3: A yarn containing gel spun UHMWPE fibers containing a spin finish compound on the fibers surface, commercially available as Dyneema® SK78 yarn of 176 tex and having a tenacity of 3.3 N/tex.

Material 4: A spin finish free gel spun HPPE (UHMWPE) yarn of 176 tex and having a tenacity of 3.3 N/tex. These fibers were manufactured according to Example 1 of

WO2009043597, with no spin finish compound being added in the process of making the fibers.

Comparative Example 1 (CE1)

A fabric being a biaxial fabric was made as following. Two unidirectional mono-layer (4 yarn/cm) of gel spun UHMWPE fibers containing a spin finish compound on the fibers surface (Material 3) were formed by laying the fibers on top of each other in a multiaxial machine to form a biaxial fabric, at ambient conditions, and room temperature, about 23°C, in a +45, +45° sequence resulting in a biaxial fabric with an aerial density of 200 g/m^2. The biaxial fabric was then stitched with a 100 denier polyester thread in zero direction relative to machine direction. The flexural modulus in both UHMWPE fibre directions in one monolayer of the biaxial fabric was 9 GPa, measured between 0.3 and 1% strain.

The biaxial fabric so obtained was then coated with a diluted suspension of EAA (Material 1). The concentration of EAA in water was 2 vol%, related to the total volume of the biaxial fabric. The dilution was chosen such that about 2 vol% aqueous dispersion was added to the Dyneema® SK78 yarn. The fabric was then dried in an oven at 130°C, such that all water evaporated and the EAA reached the melting point, and then cooled to room temperature. The amount of EAA was about 1 vol%, relative to the total volume of the biaxial fabric.

The so obtained biaxial fabric was then coated with Material 2, first on one surface, then on the other surface, according to Example 4 of document US9555442. The biaxial fabric was thus preheated to 90°C over several heated rollers (T of 120°C) and then continuously fed to the coating calander and there coated with the coating material (i.e. Material 2). The coating material was fed into the nip of the coating calandar in molten state at a temperature of 155°C on the side of the first surface of the biaxial fabric. The rollers of the coating calander were heated to a temperature of 117°C or 127°C. The linear pressure in the nip of the coating calander was approx. 3.2 kN/mm. While running the sheet and coating material through the nip of the coating calander, the fabric was coated on its first surface with the web of the coating material, wherein at the same time the coating material was pressed into the sheet structure. The coating layers had a weight per unit area of 150 g/m and of 187 g/m so that a total weight of the resulting composite biaxial fabric of 530 g/m. After the cooling of the fabric coated on one side, this was again fed to the process and coated on its second side with the coating material while being guided through the nip of the coating calander. The coating was followed by an embossing operation in which the coated carrier material was guided through an embossing calander under pressure and at increased temperature. The pressure in the embossing calander was also approx. 3.2 kN/mm, the rollers of the embossing calander had a temperature of approx. 120°C.

The amount of Material 2 was about 62 wt% in the obtained composite biaxial fabric, based on the total weight of the composite biaxial fabric. The total amount of the EAA and Material 2 in the obtained composite fabric was about 64 wt%, based on the total weight of the composite biaxial fabric. The AD of the obtained composite biaxial fabric was 530 kg/m^2. The results obtained with CE1 are presented in Table 1.

<u>Comparative Example 2 (CE. 2)</u>

Comparative Example 1 was repeated with the difference that spin finish free gel spun UHMWPE yarn (Material 4) was used instead of the yarn containing gel spun UHMWPE fibers containing a spin finish compound on the fibers surface (Material 3). The results of measurements of the sample obtained with CE.2 are shown in Table 1.

<u>Example 1 (Ex. 1)</u>

Comparative Example 1 was repeated with the difference that an additional post-treatment step (step h) was applied to the composite fabric obtained in CE1. The fabric obtained in CE1 was first cut to the required size and shape (i.e. 20x20 cm) and then was vacuum packed in a plastic bag and vacuum sealed with a vacuum sealing machine Henkovac for 1 min at 120°C and 20 bar in a hydraulic press WN Anlagenbau. A silicon release paper was used between the fabric and the press mold. The results of measurements of the sample obtained with Example 1 are shown in Table 1.

The same results as for Ex. 1 shown in Table 1 were also obtained when, instead of using the hydraulic press after cutting the fabric obtained in CE1, the cut fabric was vacuum packed and then pressed for 15 min at 120°C and 8 bar in an autoclave; or vacuum packed and then heated for 15 min and 1 bar in an oven at 120°C.

Table 1

Sample	**Water uptake, wt%**	**Dielectric constant***	**Loss tangent***
CE1	10.4	2.14	0.0014
CE2	5.9	2.11	0.0007
Ex. 1	0.2	2.14	0.0014

*measured before carrying out water uptake experiment at 5 GHz with the SPDR method as described herein

CLAIMS

1. A method for manufacturing a composite fabric comprising the steps of:
   a) providing HPPE fibres;
   b) assembling the HPPE fibres to form a fabric;
   c) optionally, applying an aqueous suspension or solvent solution of a polymeric material to the HPPE fibres before, during or after assembling;
   d) optionally, at least partially drying the aqueous suspension or the solvent suspension of the polymeric material applied in step c);

   to obtain a fabric upon completion of steps a), b), c) and d);

   e) optionally, applying a temperature in the range from the melting temperature of the polymeric material to 153°C to the fabric of step c) or after step d) to at least partially melt the polymeric material;
   f) optionally, applying a pressure to the fabric before, during and/or after step e) to at least partially compact the fabric; and
   g) applying a polymeric material as used in step c) or a chemically distinct polymeric material than the polymeric material used in step c) on at least one side of the fabric at a temperature above the melting temperature of the polymeric material applied in step g);

   to obtain a composite fabric upon completion of steps a) - g); and

   h) compressing the composite fabric by applying a compression pressure of at least 1 bar at a temperature of between the melting temperature of the polymeric material applied in step g) and c) and the melting temperature of the HPPE fibers;

   wherein the polymeric material is selected from the group consisting of homopolymers of ethylene, homopolymers of propylene, copolymers of ethylene and copolymers of propylene, and/or mixtures thereof, the polymeric material having a density as measured according to ISO1183-2004 in the range from 875 to 970 kg/m^3, a melting temperature in the range from 40 to 140°C and a heat of fusion of at least 5 J/g.
2. The method according to any one of any one of the preceding claims, further comprising an additional step of cutting the composite fabric obtained after completion of step g) and before applying step h).

3. The method according to claims 1 or 2, wherein the fabric is a multiaxial construction having at least two monolayers of HPPE fibers, the HPPE fibers in each monolayer being unidirectionally oriented in at least two fiber directions.
4. The method according to claim 3, wherein the multiaxial sheet contains two monolayers of HPPE fibres, wherein a unidirectional monolayer is positioned such that the HPPE fibres in the unidirectional monolayer are oriented at an angle of +45°, -45° relative to the HPPE fibres of the adjacent unidirectional monolayer.
5. The method according to any one of claims 3 or 4, wherein the flexural modulus in both HPPE fibre directions in a monolayer of the composite fabric is larger than 8 GPa, preferably larger than 9 GPa, more preferably larger than 10 GPa, as measured by method EN12311-2/A (2000).
6. The method according to any one of the preceding claims, wherein the composite fabric comprises a first polymeric material and a second polymeric material that are substantially the same or chemically distinct.
7. The method according to claim 6, wherein the first polymeric material is a homopolymer of ethylene or propylene, an ethylene copolymer with a co-monomer free of hetero atoms or a propylene copolymer with a co-monomer free of hetero atoms, a copolymer of ethylene with a hetero atom containing co-monomer or a copolymer of propylene with a hetero atom containing co-monomer, and wherein the second polymeric material is a homopolymer of ethylene or propylene, a copolymer of ethylene with a co-monomer free of hetero atoms or a copolymer of propylene with a co-monomer free of hetero atoms.
8. The method according to any one of claim 6 or 7, wherein the first polymeric material is a polymeric resin of an ethylene acrylic acid copolymer, ethylene methacrylic acid copolymer, ethylene acrylonitrile copolymer or derivatives thereof and the second polymeric material is a copolymer of ethylene and 1-butene, 1-hexane and or 1-octene.
9. The method according to claim any one of the preceding claims, wherein the HPPE fibres are substantially spin finish free.
10. The method according to any one of the preceding claims, wherein the amount of the polymeric material is higher than 50 wt% and at most 90 wt%, based on the total weight of the composite fabric.

11. The method according to any one of the preceding claims, wherein the HPPE fibres comprise ultrahigh molecular weight polyethylene (UHMWPE), preferably the HPPE fibres substantially consist of UHMWPE.
12. A composite fabric obtainable according to any of claims 1 to 11, comprising HPPE fibres and at least one polymeric material, wherein:
    the amount of the polymeric material is at least 30 wt%, based on the total weight of the composite fabric;
    the polymeric material is selected from a group consisting of a homopolymers of ethylene, homopolymers of propylene, copolymers of ethylene and copolymers of propylene, and/or mixtures thereof, the polymeric material having a density as measured according to ISO1183-2004 in the range from 875 to 970 kg/m^3, a melting temperature in the range from 40 to 140°C and a heat of fusion of at least 5 J/g.
13. An article comprising the composite fabric according to claims 12.
14. A radome according to claim 13.
15. An antenna system comprising an antenna device and a radome according to claim 14.

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2018/085484

A. CLASSIFICATION OF SUBJECT MATTER
INV. C08J5/04 C08J5/06 H01Q1/42
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C08J H01Q

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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X	WO 2016/041954 A1 (DSM IP ASSETS BV [NL]) 24 March 2016 (2016-03-24) cited in the application page 2, lines 23-33; claims 1,4,7,8,14; example page 6, line 25 - page 7, line 1 page 9, lines 16-23 page 11, lines 1-6 page 14, line 28 - page 15, line 29 page 16, lines 25-29 -----	1-15
X	WO 2011/045321 A1 (DSM IP ASSETS BV [NL]; WIENKE DIETRICH [NL]; MARISSEN ROELOF [NL]; JAC) 21 April 2011 (2011-04-21)	1-11
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☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"P" document published prior to the international filing date but later than the priority date claimed

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"&" document member of the same patent family

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International application No
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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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