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- Einzmann, Mirko
4600 Wels (AT)
- Goldhalm, Gisela
3363 Neufurth (AT)
- Hayhurst, Malcolm John
Bulkington, Warwickshire CV12 9RZ (GB)
- Mayer, Katharina
4813 Altmünster (AT)
- Sagerer Foric, Ibrahim
4840 Vöcklabruck (AT)

(71) Applicant: **LENZING AKTIENGESELLSCHAFT**
4860 Lenzing (AT)

(72) Inventors:
• Carlyle, Tom
Spanish Fort, AL Alabama 36527 (US)

(74) Representative: **Dilg, Haeusler, Schindelmann**
Patentanwalts-gesellschaft mbH
Leonrodstrasse 58
80636 München (DE)

(54) **NONWOVEN CELLULOSE FIBER FABRIC WITH FIBERS HAVING NON-CIRCULAR CROSS SECTION**

(57) A nonwoven cellulose fiber fabric (102), in particular directly manufactured from lyocell spinning solution (104), wherein the fabric (102) comprises a network

of substantially endless fibers (108), and wherein at least 1% of the fibers (108) has a non-circular cross sectional shape having a roundness of not more than 90%.

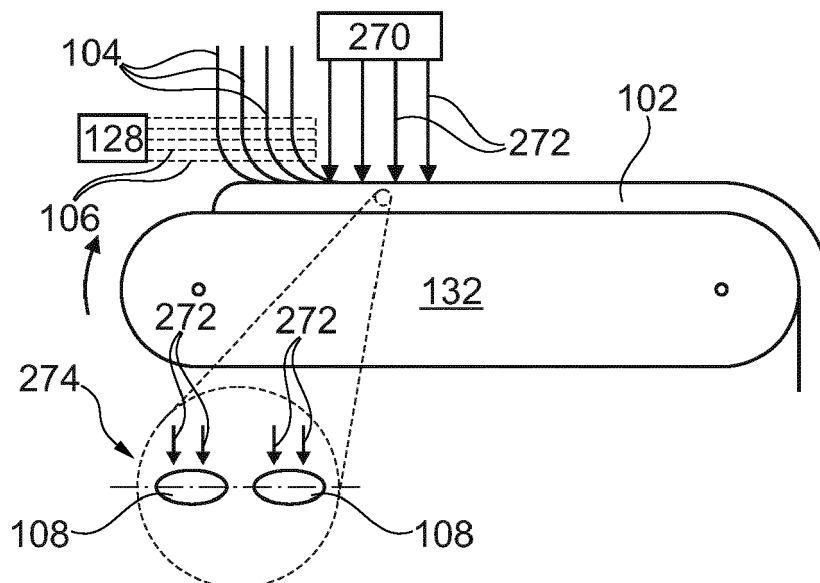


Fig. 14

Description

Field of the invention

[0001] The invention relates to a nonwoven cellulose fiber fabric, a method of manufacturing a nonwoven cellulose fiber fabric, a device for manufacturing a nonwoven cellulose fiber fabric, a product or composite, and a method of use.

Background of the invention

[0002] Lyocell technology relates to the direct dissolution of cellulose wood pulp or other cellulose-based feedstock in a polar solvent (for example n-methyl morpholine n-oxide, which may also be denoted as "amine oxide" or "AO") to produce a viscous highly shear-thinning solution which can be transformed into a range of useful cellulose-based materials. Commercially, the technology is used to produce a family of cellulose staple fibers (commercially available from Lenzing AG, Lenzing, Austria under the trademark TENCEL®) which are widely used in the textile industry. Other cellulose products from lyocell technology have also been used.

[0003] Cellulose staple fibers have long been used as a component for conversion to nonwoven webs. However, adaption of lyocell technology to produce nonwoven webs directly would access properties and performance not possible for current cellulose web products. This could be considered as the cellulosic version of the melt-blow and spunbond technologies widely used in the synthetic fiber industry, although it is not possible to directly adapt synthetic polymer technology to lyocell due to important technical differences.

[0004] Much research has been carried out to develop technology to directly form cellulose webs from lyocell solutions (*inter alia*, WO 98/26122, WO 99/47733, WO 98/07911, US 6,197,230, WO 99/64649, WO 05/106085, EP 1 358 369, EP 2 013 390). Further art is disclosed in WO 07/124521 A1 and WO 07/124522 A1.

Object and summary of the invention

[0005] It is an object of the invention to provide a cellulose-based fabric having an adjustable mechanical stability.

[0006] In order to achieve the object defined above, a nonwoven cellulose fiber fabric, a method of manufacturing a nonwoven cellulose fiber fabric, a device for manufacturing a nonwoven cellulose fiber fabric, a product or composite, and a method of use according to the independent claims are provided.

[0007] According to an exemplary embodiment of the invention, a (in particular solution-blown) nonwoven cellulose fiber fabric is provided (which is in particular directly (in particular in an *in situ* process or in a continuous process executable in a continuously operating production line) manufactured from lyocell spinning solution),

and wherein at least 1% of the fibers has a non-circular cross sectional shape (in particular along an entire fiber's longitudinal extension or only along a portion of the fiber's longitudinal extension) having a roundness of not more than 90%.

[0008] According to another exemplary embodiment, a method of manufacturing (in particular solution-blown) nonwoven cellulose fiber fabric directly from lyocell spinning solution is provided, wherein the method comprises extruding the lyocell spinning solution through orifices (which may be embodied as or which may form part of a spinneret or an extrusion unit) supported by a gas flow into a coagulation fluid atmosphere (in particular an atmosphere of dispersed coagulation fluid) to thereby form substantially endless fibers, collecting the fibers on a fiber support unit to thereby form the fabric, and adjusting process parameters so that at least 1% of the fibers has a non-circular cross sectional shape having a roundness of not more than 90%.

[0009] According to a further exemplary embodiment, a device for manufacturing (in particular solution-blown) nonwoven cellulose fiber fabric directly from lyocell spinning solution is provided, wherein the device comprises a jet with orifices configured for extruding the lyocell spinning solution supported by a gas flow, a coagulation unit configured for providing a coagulation fluid atmosphere for the extruded lyocell spinning solution to thereby form substantially endless fibers, a fiber support unit configured for collecting the fibers to thereby form the fabric, and a control unit (such as a processor configured for executing program code for manufacturing the nonwoven cellulose fiber fabric directly from the lyocell spinning solution) configured for adjusting process parameters so that at least 1% of the fibers has a non-circular cross sectional shape having a roundness of not more than 90%.

[0010] According to yet another embodiment, a nonwoven cellulose fiber fabric having the above-mentioned properties is used for at least one of the group consisting of a wipe, a filter, an absorbent hygiene product, a medical application product, a geotextile, agrotexile, clothing, a product for building technology, an automotive product, a furnishing, an industrial product, a product related to beauty, leisure, sports or travel, and a product related to school or office.

[0011] According to still another exemplary embodiment, a product or composite is provided which comprises a fabric having the above mentioned properties.

[0012] In the context of this application, the term "nonwoven cellulose fiber fabric" (which may also be denoted as nonwoven cellulose filament fabric) may particularly denote a fabric or web composed of a plurality of substantially endless fibers. The term "substantially endless fibers" has in particular the meaning of filament fibers having a significantly longer length than conventional staple fibers. In an alternative formulation, the term "substantially endless fibers" may in particular have the meaning of a web formed of filament fibers having a signifi-

cantly smaller amount of fiber ends per volume than conventional staple fibers. In particular, endless fibers of a fabric according to an exemplary embodiment of the invention may have an amount of fiber ends per volume of less than 10,000 ends/cm³, in particular less than 5,000 ends/cm³. For instance, when staple fibers are used as a substitute for cotton, they may have a length of 38 mm (corresponding to a typical natural length of cotton fibers). In contrast to this, substantially endless fibers of the nonwoven cellulose fiber fabric may have a length of at least 200 mm, in particular at least 1000 mm. However, a person skilled in the art will be aware of the fact that even endless cellulose fibers may have interruptions, which may be formed by processes during and/or after fiber formation. As a consequence, a nonwoven cellulose fiber fabric made of substantially endless cellulose fibers has a significantly lower number of fibers per mass compared to nonwoven fabric made from staple fibers of the same denier. A nonwoven cellulose fiber fabric may be manufactured by spinning a plurality of fibers and by attenuating and stretching the latter towards a preferably moving fiber support unit. Thereby, a three-dimensional network or web of cellulose fibers is formed, constituting the nonwoven cellulose fiber fabric. The fabric may be made of cellulose as main or only constituent.

[0013] In the context of this application, the term "lyocell spinning solution" may particularly denote a solvent (for example a polar solution of a material such as N-methyl-morpholine, NMMO, "amine oxide" or "AO") in which cellulose (for instance wood pulp or other cellulose-based feedstock) is dissolved. The lyocell spinning solution is a solution rather than a melt. Cellulose filaments may be generated from the lyocell spinning solution by reducing the concentration of the solvent, for instance by contacting said filaments with water. The process of initial generation of cellulose fibers from a lyocell spinning solution can be described as coagulation.

[0014] In the context of this application, the term "gas flow" may particularly denote a flow of gas such as air substantially parallel to the moving direction of the cellulose fiber or its preform (i.e. lyocell spinning solution) while and/or after the lyocell spinning solution leaves or has left the spinneret.

[0015] In the context of this application, the term "coagulation fluid" may particularly denote a non-solvent fluid (i.e. a gas and/or a liquid, optionally including solid particles) which has the capability of diluting the lyocell spinning solution and exchanging with the solvent to such an extent that the cellulose fibers are formed from the lyocell filaments. For instance, such a coagulation fluid may be water mist.

[0016] In the context of this application, the term "process parameters" may particularly denote all physical parameters and/or chemical parameters and/or device parameters of substances and/or device components used for manufacturing nonwoven cellulose fiber fabric which may have an impact on the properties of the fibers and/or the fabric, in particular on fiber diameter and/or fiber di-

ameter distribution. Such process parameters may be adjustable automatically by a control unit and/or manually by a user to thereby tune or adjust the properties of the fibers of the nonwoven cellulose fiber fabric. Physical parameters which may have an impact on the properties of the fibers (in particular on their diameter or diameter distribution) may be temperature, pressure and/or density of the various media involved in the process (such as the lyocell spinning solution, the coagulation fluid, the gas flow, etc.). Chemical parameters may be concentration, amount, pH value of involved media (such as the lyocell spinning solution, the coagulation fluid, etc.). Device parameters may be size of and/or distances between orifices, distance between orifices and fiber support unit, speed of transportation of fiber support unit, the provision of one or more optional *in situ* post processing units, the gas flow, etc.

[0017] The term "fibers" may particularly denote elongated pieces of a material comprising cellulose, for instance roughly round or non-regularly formed in cross-section, optionally twisted with other fibers. Fibers may have an aspect ratio which is larger than 10, particularly larger than 100, more particularly larger than 1000. The aspect ratio is the ratio between the length of the fiber and a diameter of the fiber. Fibers may form networks by being interconnected by merging (so that an integral multi-fiber structure is formed) or by friction (so that the fibers remain separate but are weakly mechanically coupled by a friction force exerted when mutually moving the fibers being in physical contact with one another). Fibers may have a substantially cylindrical form which may however be straight, bent, kinked, or curved. Fibers may consist of a single homogenous material (i.e. cellulose). However, the fibers may also comprise one or more additives. Liquid materials such as water or oil may be accumulated between the fibers.

[0018] In the context of this document, a "jet with orifices" (which may for instance be denoted as an "arrangement of orifices") may be any structure comprising an arrangement of orifices which are linearly arranged.

[0019] In the context of this application, the term "roundness" may particularly denote the ratio between the inscribed circle and the circumscribed circle of a cross section of a fiber, i.e. the maximum and minimum sizes for circles that are just sufficient to fit inside and to enclose the shape of the fiber's cross section. For determining roundness, a cross sectional plane perpendicular to an extension direction of the fiber may be intersected with the fiber. Thus, roundness may be denoted as the measure of how closely the cross sectional shape of a respective fiber approaches that of a circle having a roundness of 100%. For example, a cross-section of the respective fiber may have an oval (in particular elliptic) shape or may have a polygonal shape. More generally, a trajectory defining the exterior limits of a cross-section of a fiber may be any closed planar line showing a deviation from a circle. The cross-section of the respective fiber may be entirely round or may have one or more sharp edges.

[0020] According to an exemplary embodiment, a non-woven cellulose fiber fabric is provided which has substantially endless fibers showing a significant deviation from an entirely circular cylindrical shape. From a mechanical point of view, this also has the consequence that a preferred bending direction of the fibers in the presence of a mechanical load is defined by the design of the cross-section of the fiber. For instance, wherein the fiber has an elliptic cross sectional shape with two main axes (i.e. major axis and minor axis) having different lengths, bending in the presence of an exerted force will occur predominantly with the minor axis as bending line. Thus, the bending characteristics of such a fiber fabric is no longer statistical and unpredictable, but in contrast to this, increases the defined order of the nonwoven cellulose fiber fabric. Therefore, defined mechanical properties of the fabric can be adjusted in a simple way by simply influencing the cross-sectional geometry of the individual fibers. Also a mutual lay down behavior or networking behavior of the fibers may be adjusted by adjusting a deviation of some or substantially all of the fibers from a perfect circularity. Furthermore, a nonwoven cellulose fiber fabric with anisotropic mechanical properties may be manufactured when non-circular cylindrical fibers are aligned in an ordered or partially ordered way.

Detailed description of embodiments of the invention

[0021] In the following, further exemplary embodiments of the nonwoven cellulose fiber fabric, the method of manufacturing a nonwoven cellulose fiber fabric, the device for manufacturing a nonwoven cellulose fiber fabric, the product or composite, and the method of use are described.

[0022] In an embodiment, at least 3%, in particular at least 5%, more particularly at least 10%, of the fibers has a non-circular cross sectional shape having a roundness of not more than 90%. Even more particularly, it is possible that at least 10%, at least 20%, at least 30%, at least 50% or at least 80% of the fibers has a non-circular cross sectional shape having a roundness of not more than 90%, not more than 80%, not more than 70%, not more than 60%, not more than 50%, or not more than 30%. The higher the amount of fibers deviating from a circular cross sectional shape, the higher is the deviation of the manufactured fiber fabric from an isotropic mechanical behavior and the more pronounced is the adjustability of the mechanical properties of the fabric.

[0023] In an embodiment, at least 1%, at least 10%, at least 20%, at least 30%, at least 50% or at least 80% of the fibers has a non-circular cross sectional shape having a roundness of not more than 80%, in particular of not more than 70%, more particularly of not more than 50%. Even more particularly, it is possible that at least 1% of the fibers has a non-circular cross sectional shape having a roundness of not more than 60%, not more than 50%, not more than 40% or not more than 10%. The larger the amount of at least part of the fibers deviating from a cir-

cular cross sectional shape is, the higher is the deviation of the manufactured fiber fabric from an isotropic mechanical behavior and the more pronounced is the adjustability of the mechanical properties of the fabric.

[0024] The percentage of the fibers having a non-circular cross-sectional shape with a corresponding roundness value may be adjusted for example by adjusting a number and/or shape of the orifices through which the lyocell spinning solution, which forms the fibers after coagulation, is ejected. Additionally or alternatively, the percentage of the fibers having a non-circular cross-sectional shape with a corresponding roundness value may be adjusted for example by adjusting a number of filaments of the lyocell spinning solution being subject to a mechanical impact for changing the cross-sectional shape before coagulation.

[0025] In an embodiment, smoothness, respectively the specific hand, of the fabric measured with a "Handle-O-Meter" on the basis of the nonwoven standard WSP90.3 is in a range between 2 mNm²/g and 70 mNm²/g. By varying the process parameters of the described manufacturing method, smoothness may hence be varied over a broad range. When designing fibers with non-circular cross-section or non-circular cylindrical geometry, this may already ensure sufficient and defined stability of the fabric. The smoothness of the surface - even a very high degree of smoothness - may then be freely adjusted without any danger that stability of the fabric may suffer from this.

[0026] The mentioned smoothness of a fabric may be measured with a "Handle-O-Meter" (as commercially available by Thwing-Albert Instrument Co., Philadelphia, PA) on the basis of the nonwoven standard WSP90.3. For determining smoothness of the fabric, a pivoting arm of the "Handle-O-Meter" is lowered and presses a sample (for instance having square dimensions of 10 cm x 10 cm) of fabric into an adjustable parallel slit. The force is measured which is required in order to press the sample into the slit. During this procedure, a bending force and a friction force are exerted on the sample. The average value from the measurements in CD direction and in MD direction correspond to an average force which is required to press the sample through the slit. The ratio between the average force (for instance given in mN) and basis weight of the fabric (for instance given in g/m²) gives a smoothness value, measured as specific hand, in mNm²/g which is indicative for the smoothness of the fabric material.

[0027] In an embodiment, the fibers have a copper content of less than 5 ppm and/or have a nickel content of less than 2 ppm. The ppm values mentioned in this application all relate to mass (rather than to volume). Apart from this, the heavy metal contamination of the fibers or the fabric may be not more than 10 ppm for each individual chemical element. Due to the use of a lyocell spinning solution as a basis for the formation of the endless fiber-based fabric (in particular when involving a solvent such as N-methyl-morpholine, NMMO), the contamination of

the fabric with heavy metals such as copper or nickel (which may cause allergic reactions of a user) may be kept extremely small. Due to the concept of direct merging of fibers under certain conditions adjustable by process control, no extra material (such as a glue or the like) needs to be introduced in the process for interconnecting the fibers. This keeps contaminations of the fabric very low.

[0028] In an embodiment, at least part of (in particular at least 10%, more particularly at least 20% of) the fibers are integrally merged at merging positions. In the context of this application, the term "merging" may particularly denote an integral interconnection of different fibers at the respective merging position which results in the formation of one integrally connected fiber structure composed of the previously separate fiber preforms. Merging may be denoted as a fiber-fiber connection being established during coagulation of one, some or all of the merged fibers. Interconnected fibers may strongly adhere to one another at a respective merging position without a different additional material (such as a separate adhesive) so as to form a common structure. Separation of merged fibers may require destruction of the fiber network or part thereof. According to the described embodiment, a nonwoven cellulose fiber fabric is provided in which some or all of the fibers are integrally connected to one another by merging. Merging may be triggered by a corresponding control of the process parameters of a method of manufacturing the nonwoven cellulose fiber fabric. In particular, coagulation of filaments of lyocell spinning solution may be triggered (or at least completed) after the first contact between these filaments being not yet in the precipitated solid fiber state. Thereby, interaction between these filaments while still being in the solution phase and then or thereafter converting them into the solid phase by coagulation allows to properly adjust the merging characteristics. A degree of merging is a powerful parameter which can be used for fine-tuning the properties of the manufactured fabric. In particular, mechanical stability of the network is the larger the higher the density of merging positions is. By an inhomogeneous distribution of merging positions over the volume of the fabric, it is also possible to adjust regions of high mechanical stability and other regions of low mechanical stability. For instance, separation of the fabric into separate parts can be precisely defined to happen locally at mechanical weak regions with a low number of merging positions. In a preferred embodiment, merging between fibers is triggered by bringing different fiber preforms in form of lyocell spinning solution in direct contact with one another prior to coagulation. By such a coagulation process, single material common precipitation of the fibers is executed, thereby forming the merging positions.

[0029] In an embodiment, the merging points or merging positions consist of the same material as the merged fibers. Thus, the merging positions may be formed by cellulose material resulting directly from the coagulation of lyocell spinning solution. This not only renders the sep-

arate provision of a fiber connection material (such as an adhesive or a binder) dispensable, but also keeps the fabric clean and made of a single material. Formation of fibers having a non-circular cross-section and formation of fibers being interconnected by merging can be done by one single common process. The reason for this is that both the formation of merging positions (such as merging points or merging lines) between fibers and the formation of fibers having a cross-section deviating from a perfectly circular diameter can be carried out by exerting a mechanical force on filaments of lyocell spinning solution prior to the completion of coagulation. Nevertheless, filaments of lyocell spinning solution may be influenced mechanically while they are still in a liquid phase. Descriptively speaking, applying a mechanical pressure on filaments of still liquid or viscous (typically being present in a honey-like consistency) lyocell spinning solution on the one hand may promote a deformation of cylindrical filaments into a (for instance oval (in particular elliptic)) non-circular shape to thereby reduce roundness. Simultaneously, the application of such a mechanical pressure on filaments of still liquid or viscous lyocell spinning solution and being in physical contact with one another may trigger formation of merging positions between the fibers upon coagulation.

[0030] In an embodiment, different ones of the fibers are located at least partially in different distinguishable (i.e. showing a visible separation or interface region in between the layers) layers. For example, varying mechanical properties among the layers and at an interface between the layers may be adjusted by a respective adjustment of the roundness value of the fibers of the respective layer.

[0031] More specifically, fibers of different layers are integrally merged at at least one merging position between the layers. Hence, different ones of the fibers being located at least partially in different distinguishable layers (which may be identical or which may differ concerning one or more parameters such as merging factor, fiber thickness, etc.) may be integrally connected at at least one merging position. For instance, two (or more) different layers of a fabric may be formed by serially aligning two (or more) jets with orifices through which lyocell spinning solution is extruded for coagulation and fiber formation. When such an arrangement is combined with a moving fiber support unit (such as a conveyor belt with a fiber accommodation surface), a first layer of fibers is formed on the fiber support unit by the first jet, and the second jet forms a second layer of fibers on the first layer when the moving fiber support unit reaches the position of the second jet. The process parameters of this method may be adjusted so that merging points are formed between the first layer and the second layer. In particular, fibers of the second layer under formation being not yet fully cured or solidified by coagulation may for example still have exterior skin or surface regions which are still in the liquid lyocell solution phase and not yet in the fully cured solid state. When such pre-fiber structures come into

contact with one another and fully cure into the solid fiber state thereafter, this may result in the formation of two merged fibers at an interface between different layers. The higher the number of merging positions, the higher is the stability of the interconnection between the layers of the fabric. Thus, controlling merging allows to control rigidity of the connection between the layers of the fabric. Merging can be controlled, for example, by adjusting the degree of curing or coagulation before pre-fiber structures of a respective layer reach the fiber support plate on an underlying layer of fibers or pre-fiber structures. By merging of fibers of different layers at an interface there between, undesired separation of the layers may be prevented. In the absence of merging points between the layers, peeling off one layer from the other layer of fibers may be made possible. According to an exemplary embodiment of the invention, it is possible to adjust to the degree of adhesion between the fibers and/or between the layers gradually between "unmerged fibers or layers" and "fully merged fibers or layers". As a result, a partial adhesion in particular between different layers may be controlled and adjusted for functionalizing the fabric for a product manufactured on the basis of the fabric. For instance, a package may be manufactured using such a (in particular multilayer) fabric which provides a slight adhesion force so that a packaged good can be properly handled through the weakly adhering parts thereof.

[0032] For determining the aforementioned merging factor (which may also be denoted as area merging factor) of fabric, the following determination process may be carried out: A square sample of the fabric may be optically analyzed. A circle, which has a diameter which has to stay fully inside the square sample, is drawn around each merging position of fibers crossing at least one of the diagonals of the square sample. The size of the circle is determined so that the circle encompasses the merging area between the merged fibers. An arithmetic average of the values of the diameter of the determined circles is calculated. The merging factor is calculated as ratio between the averaged diameter value and the diagonal length of the square sample, and may be given in percent.

[0033] In an embodiment, at least part of the fibers is twisted. Twisting fibers is a further powerful tool of designing the mechanical strength of the fiber network. For instance, a twisted fiber may have a higher mechanical stability than an entirely straight fiber. Also forming twisted fiber groups (for instance twisted merged fibers) may significantly increase the mechanical stability of the fabric in a similar way as a rope of twisted filaments has a significantly higher mechanical stability than a corresponding number of single filaments. Twisted fibers may be manufactured for instance by turning or rotating filaments of lyocell spinning solution during their stretching phase, i.e. before coagulation or precipitation.. Particularly the application of vorticity, i.e. a turbulent flow around the filaments of lyocell spinning solution prior to coagulation can be used for forming twisted fibers.

[0034] In an embodiment, the fibers are aligned anisotropically within the fabric to thereby define, on the average, at least one preferential alignment direction along which a larger portion of fibers is aligned compared to other directions. In such an embodiment, the adjustment of the fiber shape to deviate from a circular cross-section may be carried out for a group of or for all of the fibers of the fabric so that, when the fibers are laying down on the fiber support unit, they are aligned on the average or preferably along one or more predominant directions as a consequence of their preferred bending axes defined by the deviation of the respective fiber rounding from one. By taking this measure, a certain degree of order may be introduced in the fabric which results in non-isotropic properties of the manufactured fabric.

[0035] In an embodiment, adjusting the process parameters comprises exerting a deforming force to filaments of the lyocell spinning solution before the coagulation is completed. Descriptively speaking, when a compression force is applied to a viscous and thus still flowable filament of the lyocell spinning solution before conversion to a solid phase, the filaments may be deformed from a for instance cylindrical cross sectional shape to a for instance oval (in particular elliptic) cross-sectional shape. The fiber deforming force can be applied in a direction perpendicular to a longitudinal extension of the fiber or fiber portion under analysis. When coagulation is then carried out while the filament of the lyocell spinning solution is in this deformed shape, fibers with a roundness of less than one are obtained.

[0036] In an embodiment, the force is exerted by directing a shaping fluid (which may be a liquid and/or a gas) to the filaments of the lyocell spinning solution before the coagulation is completed. Such a shaping fluid may be a shaping gas (such as air) or a shaping liquid (such as water). When a shaping gas is employed, a precisely definable mechanical force is applicable to the not yet coagulated filaments without already triggering coagulation. When a shaping liquid is used, an also precisely definable mechanical force is applicable to the not yet coagulated filaments which simultaneously also triggers coagulation by dilution of the lyocell spinning solution with the (in particular aqueous) liquid. In such an embodiment, deformation and coagulation may be carried out simultaneously.

[0037] In an embodiment, the mentioned pressure increase by a gaseous or a liquid (i.e. fluidic) flow may be configured so that the individual fluidic flows are antiparallel at a certain position, and the fiber under formation is in between. As a result, a local asymmetric pressure increase is created which impacts the fiber. At the same time, this phenomenon does not further influence the process of manufacturing fibers.

[0038] In an embodiment, at least some of the orifices are non-circular, in particular are oval (in particular elliptic) or polygonal. Preferably, the openings in a jet plate of the fiber formation unit defining the orifices may have a shape with substantially the same roundness (in par-

ticular of not more than 90%) as the fibers composed of precipitated lyocell spinning solution ejected through these respective orifices. In one embodiment, a first part of the orifices has a circular opening, whereas a second part of the orifices has a non-circular opening. Thus, the design of the shape of the orifices allows to some extent to define also the shape of the manufactured fibers.

[0039] In an embodiment, adjusting the process parameters for adjusting merging comprises forming at least part of the merging positions after the lyocell spinning solution has left the orifices and before the lyocell spinning solution has reached the fiber support unit. This may be achieved for example by triggering an interaction between strands of lyocell spinning solution extruded through different ones of the orifices while moving downwardly. For example, the gas flow may be adjusted in terms of strength and direction so that different strands or filaments of the (not yet fully coagulated) spinning solution are forced to get into interaction with one another in a lateral direction before reaching the fiber support unit. It is also possible that the gas flow is operated to be close or in the regime of turbulent flow so as to promote a mutual interaction between the various preforms of the fibers. Therefore, the individual preforms of the fibers may be brought in contact with one another prior to coagulation, thereby forming merging positions.

[0040] In an embodiment, adjusting the process parameters for adjusting merging comprises forming at least part of the merging positions after the lyocell spinning solution has reached the fiber support unit by triggering coagulation of at least part of the fibers when laying on the fiber support unit. In such an embodiment, the process of coagulation may be delayed intentionally (which may be adjusted by a corresponding operation of the coagulation unit, in particular by correspondingly adjusting the properties and the position of supply of the coagulation fluid). More specifically, the process of coagulation may be delayed until the spinning solution has reached the fiber support plate. In such an embodiment, the preforms of the fibers, still prior to coagulation, are deposited on the fiber support plate and thereby get into contact with other preforms of the fiber, also still prior to coagulation. Spinning solution of different strands or preforms may thereby be forced to flow into contact with one another, and only thereafter coagulation may be triggered or completed. Thus, coagulation following initial contact between different preforms of fibers being still in the non-coagulated state is an efficient measure of forming merging positions.

[0041] In an embodiment, adjusting the process parameters for adjusting merging comprises serially arranging multiple jets with orifices along a movable fiber support unit, depositing a first layer of fibers on the fiber support unit, and depositing a second layer of fibers on the first layer before coagulation of at least part of the fibers at an interface between the layers has been completed. For each layer to be formed, the process parameters of operating the corresponding jet may be adjusted

so as to obtain a layer specific coagulation behavior. Layer specific coagulation behavior of the different layers may be adjusted so that merging positions are formed within the respective layer and preferably between adjacent layers. More specifically, process control may be adjusted so that merging positions are formed between two adjacent layers by promoting coagulation of both layers only after initial contact between spinning solution related to the different layers.

[0042] In an embodiment, the method further comprises further processing the fibers and/or the fabric after collection on the fiber support unit but preferably still *in situ* with the formation of the nonwoven cellulose fiber fabric with endless fibers. Such *in situ* processes may be those processes being carried out before the manufactured (in particular substantially endless) fabric is stored (for instance rolled by a winder) for shipping to a product manufacture destination. For instance, such a further processing or post processing may involve hydroentanglement. Hydroentanglement may be denoted as a bonding process for wet or dry fibrous webs, the resulting bonded fabric being a nonwoven. Hydroentanglement may use fine, high pressure jets of water which penetrate the web, hit a fiber support unit (in particular a conveyor belt) and bounce back causing the fibers to entangle. A corresponding compression of the fabric may render the fabric more compact and mechanically more stable. Additionally or alternatively to hydroentanglement, steam treatment of the fibers with a pressurized steam may be carried out. Additionally or alternatively, such a further processing or post processing may involve a needling treatment of the manufactured fabric. A needle punching system may be used to bond the fibers of the fabric or web. Needle punched fabrics may be produced when barbed needles are pushed through the fibrous web forcing some fibers through the web, where they remain when the needles are withdrawn. If sufficient fibers are suitably displaced the web may be converted into a fabric by the consolidating effect of these fibers plugs. Yet another further processing or post processing treatment of the web or fabric is an impregnating treatment. Impregnating the network of endless fibers may involve the application of one or more chemicals (such as a softening agent, a hydrophobic agent, an antistatic agent, etc.) on the fabric. Still another further processing treatment of the fabric is calendering. Calendering may be denoted as a finishing process for treating the fabric and may employ a calender to smooth, coat, and/or compress the fabric.

[0043] A nonwoven cellulose fiber fabric according to an exemplary embodiment of the invention may also be combined (for instance *in situ* or in a subsequent process) with one or more other materials, to thereby form a composite according to an exemplary embodiment of the invention. Exemplary materials, which can be combined with the fabric for forming such a composite may be selected from a group of materials comprising, but not being limited to, the following materials or combinations thereof: fluff pulp, a fiber suspension, a wetlaid nonwoven, an

airlaid nonwoven, a spunbond web, a meltblown web, a carded spunlaced or needlepunched web or other sheet like structures made of various materials. In an embodiment, the connection between the different materials can be done by (but not limited to) one or a combination of the following processes: merging, hydroentanglement, needle punching, hydrogen bonding, thermobonding, gluing by a binder, laminating, and/or calendering.

[0044] In the following, exemplary advantageous products comprising, or uses of, a nonwoven cellulose fiber fabric according to exemplary embodiments of the invention are summarized:

Particular uses of the webs, either 100% cellulose fiber webs, or for example webs comprising or consisting of two or more fibers, or chemically modified fibers or fibers with incorporated materials such as anti-bacterial materials, ion exchange materials, active carbon, nano particles, lotions, medical agents or fire retardants, or bicomponent fibers may be as follows:

The nonwoven cellulose fiber fabric according to exemplary embodiments of the invention may be used for manufacturing wipes such as baby, kitchen, wet wipes, cosmetic, hygiene, medical, cleaning, polishing (car, furniture), dust, industrial, duster and mops wipes.

[0045] It is also possible that the nonwoven cellulose fiber fabric according to exemplary embodiments of the invention is used for manufacturing a filter. For instance, such a filter may be an air filter, a HVAC, air condition filter, flue gas filter, liquid filters, coffee filters, tea bags, coffee bags, food filters, water purification filter, blood filter, cigarette filter; cabin filters, oil filters, cartridge filter, vacuum filter, vacuum cleaner bag, dust filter, hydraulic filter, kitchen filter, fan filter, moisture exchange filters, pollen filter, HEVAC/HEPA/ULPA filters, beer filter, milk filter, liquid coolant filter and fruit juices filters.

[0046] In yet another embodiment, the nonwoven cellulose fiber fabric may be used for manufacturing absorbent hygiene products. Examples thereof are an acquisition layer, a coverstock, a distribution layer, an absorbent cover, sanitary pads, topsheets, backsheets, leg cuffs, flushable products, pads, nursing pads, disposal underwear, training pants, face masks, beauty facial masks, cosmetic removal pads, washcloths, diapers, and sheets for a laundry dryer releasing an active component (such as a textile softener).

[0047] In still another embodiment, the nonwoven cellulose fiber fabric may be used for manufacturing a medical application product. For instance, such medical application products may be disposable caps, gowns, masks and shoe cover, wound care products, sterile packaging products, coverstock products, dressing materials, one way clothing, dialyses products, nasal strips, adhesives for dental plates, disposal underwear, drapes,

wraps and packs, sponges, dressings and wipes, bed linen, transdermal drug delivery, shrouds, underpads, procedure packs, heat packs, ostomy bag liners, fixation tapes and incubator mattresses.

[0048] In yet another embodiment, the nonwoven cellulose fiber fabric may be used for manufacturing geotextiles. This may involve the production of crop protection covers, capillary matting, water purification, irrigation control, asphalt overlay, soil stabilisation, drainage, sedimentation and erosion control, pond liners, impregnation based, drainage channel liners, ground stabilisation, pit linings, seed blankets, weed control fabrics, greenhouse shading, root bags and biodegradable plant pots. It is also possible to use the nonwoven cellulose fiber fabric for a plant foil (for instance providing a light protection and/or a mechanical protection for a plant, and/or providing the plant or soil with dung or seed).

[0049] In another embodiment, the nonwoven cellulose fiber fabric may be used for manufacturing clothing. For example, interlinings, clothing insulation and protection, handbag components, shoe components, belt liners, industrial headwear/foodwear, disposable workwear, clothing and shoe bags and thermal insulation may be manufactured on the basis of such fabric.

[0050] In still another embodiment, the nonwoven cellulose fiber fabric may be used for manufacturing products used for building technology. For instance, roofing and tile underlay, underslating, thermal and noise insulation, house wrap, facings for plaster board, pipe wrap, concrete moulding layers, foundations and ground stabilisation, vertical drainages, shingles, roofing felts, noise abatement, reinforcement, sealing material, and damping material (mechanical) may be manufactured using such fabric.

[0051] In still another embodiment, the nonwoven cellulose fiber fabric may be used for manufacturing an automotive product. Examples are a cabin filter, boot liners, parcel shelves, heat shields, shelf trim, moulded bonnet liners, boot floor covering, oil filter, headliners, rear parcel shelves, decorative fabrics, airbags, silencer pads, insulation materials, car covers, underpadding, car mats, tapes, backing and tufted carpets, seat covers, door trim, needled carpet, and auto carpet backing.

[0052] Still another field of application of fabric manufactured according to exemplary embodiments of the invention are furnishings, such as furniture, construction, insulator to arms and backs, cushion thickening, dust covers, linings, stitch reinforcements, edge trim materials, bedding constructions, quilt backing, spring wrap, mattress pad components, mattress covers, window curtains, wall coverings, carpet backings, lampshades, mattress components, spring insulators, sealings, pillow ticking, and mattress ticking.

[0053] In yet another embodiment, the nonwoven cellulose fiber fabric may be used for manufacturing industrial products. This may involve electronics, floppy disc liners, cable insulation, abrasives, insulation tapes, conveyor belts, noise absorbent layers, air conditioning, bat-

tery separators, acid systems, anti-slip matting stain removers, food wraps, adhesive tape, sausage casing, cheese casing, artificial leather, oil recovery booms and socks, and papermaking felts.

[0054] Nonwoven cellulose fiber fabric according to exemplary embodiments of the invention is also appropriate for manufacturing products related to leisure and travel. Examples for such an application are sleeping bags, tents, luggage, handbags, shopping bags, airline headrests, CD-protection, pillowcases, and sandwich packaging.

[0055] Still another field of application of exemplary embodiment of the invention relates to school and office products. As examples, book covers, mailing envelopes, maps, signs and pennants, towels, and flags shall be mentioned.

Brief description of the drawings

[0056] The invention will be described in more detail hereinafter with reference to examples of embodiment but to which the invention is not limited:

Figure 1 illustrates a device for manufacturing nonwoven cellulose fiber fabric which is directly formed from lyocell spinning solution being coagulated by a coagulation fluid according to an exemplary embodiment of the invention.

Figure 2 to Figure 4 show experimentally captured images of nonwoven cellulose fiber fabric according to an exemplary embodiment of the invention in which merging of individual fibers has been accomplished by a specific process control.

Figure 5 and Figure 6 show experimentally captured images of nonwoven cellulose fiber fabric according to an exemplary embodiment of the invention in which swelling of fibers has been accomplished, wherein Figure 5 shows the fiber fabric in a dry non-swollen state and Figure 6 shows the fiber fabric in a humid swollen state.

Figure 7 shows an experimentally captured image of nonwoven cellulose fiber fabric according to an exemplary embodiment of the invention in which formation of two superposed layers of fibers has been accomplished by a specific process implementing two serial bars of nozzles.

Figure 8 shows a schematic drawing indicating that a defined bending of fibers can be promoted when adjusting roundness of a cross-section of the fiber to deviate from a circular cross-section.

Figure 9 shows an experimentally captured image of nonwoven cellulose fiber fabric according to an exemplary embodiment of the invention illustrating

fibers having a cross-sectional shape deviating from a circular shape.

Figure 10 shows an experimentally captured image of nonwoven cellulose fiber fabric according to an exemplary embodiment of the invention in which fibers having a cross-sectional shape deviating from a circular shape are partially twisted.

Figure 11 shows an experimentally captured image of nonwoven cellulose fiber fabric according to an exemplary embodiment of the invention composed of three stacked layers with different diameters of fibers.

Figure 12 shows how a roundness of fibers having a cross-section deviating from a circular cross-section can be calculated as a ratio between the radii of an inscribed circle and a circumscribed circle of the cross-section of the fiber according to an exemplary embodiment of the invention.

Figure 13 illustrates a device for manufacturing nonwoven cellulose fiber fabric according to another exemplary embodiment of the invention in which the process is controlled so as to trigger formation of merging positions between fibers.

Figure 14 illustrates a part of a device for manufacturing nonwoven cellulose fiber fabric according to yet another exemplary embodiment of the invention in which the process is controlled so as to trigger formation of fibers having a roundness deviating from a circular roundness by exerting a lateral force to the oblong endless fibers during coagulation.

Figure 15 illustrates a part of a device for manufacturing nonwoven cellulose fiber fabric according to still another exemplary embodiment of the invention having orifices being shaped to form fibers having a roundness deviating from a circular roundness and results in a mechanical reinforcement of the fabric.

Figure 16 is a schematic illustration of nonwoven cellulose fiber fabric according to an exemplary embodiment of the invention illustrating fibers having a cross-sectional shape deviating from a circular shape so that, as a result, the fibers are arranged on the average along a preferential direction.

Detailed description of the drawings

[0057] The illustrations in the drawings are schematic. In different drawings similar or identical elements are provided with the same reference labels.

[0058] **Figure 1** illustrates a device 100 according to an exemplary embodiment of the invention for manufacturing nonwoven cellulose fiber fabric 102 which is di-

rectly formed from lyocell spinning solution 104. The latter is at least partly coagulated by a coagulation fluid 106 to be converted into partly-formed cellulose fibers 108. By the device 100, a lyocell solution blowing process according to an exemplary embodiment of the invention may be carried out. In the context of the present application, the term "lyocell solution-blowing process" may particularly encompass processes which can result in essentially endless filaments or fibers 108 of a discrete length or mixtures of endless filaments and fibers of discrete length being obtained. As further described below, nozzles each having an orifice 126 are provided through which cellulose solution or lyocell spinning solution 104 is ejected together with a gas stream or gas flow 146 for manufacturing the nonwoven cellulose fiber fabric 102 according to an exemplary embodiment of the invention.

[0059] As can be taken from Figure 1, wood pulp 110, other cellulose-based feedstock or the like may be supplied to a storage tank 114 via a metering unit 113. Water from a water container 112 is also supplied to the storage tank 114 via metering unit 113. Thus, the metering unit 113, under control of a control unit 140 described below in further detail, may define relative amounts of water and wood pulp 110 to be supplied to the storage tank 114. A solvent (such as N-methyl-morpholine, NMMO) accommodated in a solvent container 116 may be concentrated in a concentration unit 118 and may then be mixed with the mixture of water and wood pulp 110 or other cellulose-based feedstock with definable relative amounts in a mixing unit 119. Also the mixing unit 119 can be controlled by the control unit 140. Thereby, the water-wood pulp 110 medium is dissolved in the concentrated solvent in a dissolving unit 120 with adjustable relative amounts, thereby obtaining lyocell spinning solution 104. The aqueous lyocell spinning solution 104 can be a honey-viscous medium composed of (for instance 5 mass % to 15 mass %) cellulose comprising wood pulp 110 and (for instance 85 mass % to 95 mass %) solvent.

[0060] The lyocell spinning solution 104 is forwarded to a fiber formation unit 124 (which may be embodied as or which may comprise a number of spinning beams or jets 122). For instance, the number of orifices 126 of the jets 122 may be larger than 50, in particular larger than 100. In one embodiment, all orifices 126 of a fiber formation unit 124 (which may comprise a number of spinnerets or jets 122) may have the same size and/or shape. Alternatively, size and/or shape of different orifices 126 of one jet 122 and/or orifices 126 of different jets 122 (which may be arranged serially for forming a multilayer fabric) may be different.

[0061] When the lyocell spinning solution 104 passes through the orifices 126 of the jets 122, it is divided into a plurality of parallel strands of lyocell spinning solution 104. A vertically oriented gas flow, i.e. being oriented substantially parallel to spinning direction, forces the lyocell spinning solution 104 to transform into increasingly long and thin strands which can be adjusted by changing the process conditions under control of control unit 140.

The gas flow may accelerate the lyocell spinning solution 104 along at least a part of its way from the orifices 126 to a fiber support unit 132.

[0062] While the lyocell spinning solution 104 moves through the jets 122 and further downward, the long and thin strands of the lyocell spinning solution 104 interact with non-solvent coagulation fluid 106. The coagulation fluid 106 is advantageously embodied as a vapor mist, for instance an aqueous mist. Process relevant properties of the coagulation fluid 106 are controlled by one or more coagulation units 128, providing the coagulation fluid 106 with adjustable properties. The coagulation units 128 are controlled, in turn, by control unit 140. Preferably, respective coagulation units 128 are provided between the individual nozzles or orifices 126 for individually adjusting properties of respective layers of fabric 102 being produced. Preferably, each jet 122 may have two assigned coagulation units 128, one from each side. The individual jets 122 can thus be provided with individual portions of lyocell spinning solution 104 which may also be adjusted to have different controllable properties of different layers of manufactured fabric 102.

[0063] When interacting with the coagulation fluid 106 (such as water), the solvent concentration of the lyocell spinning solution 104 is reduced, so that the cellulose of the former e.g. wood pulp 110 (or other feedstock) is at least partly coagulated as long and thin cellulose fibers 108 (which may still contain residual solvent and water).

[0064] During or after initial formation of the individual cellulose fibers 108 from the extruded lyocell spinning solution 104, the cellulose fibers 108 are deposited on fiber support unit 132, which is here embodied as a conveyor belt with a planar fiber accommodation surface. The cellulose fibers 108 form a nonwoven cellulose fiber fabric 102 (illustrated only schematically in Figure 1). The nonwoven cellulose fiber fabric 102 is composed of continuous and substantially endless filaments or fibers 108.

[0065] Although not shown in Figure 1, the solvent of the lyocell spinning solution 104 removed in coagulation by the coagulation unit 128 and in washing in a washing unit 180 can be at least partially recycled.

[0066] While being transported along the fiber support unit 132, the nonwoven cellulose fiber fabric 102 can be washed by washing unit 180 supplying wash liquor to remove residual solvent and may then be dried. It can be further processed by an optional but advantageous further processing unit 134. For instance, such a further processing may involve hydro-entanglement, needle punching, impregnation, steam treatment with a pressurized steam, calendering, etc.

[0067] The fiber support unit 132 may also transport the nonwoven cellulose fiber fabric 102 to a winder 136 on which the nonwoven cellulose fiber fabric 102 may be collected as a substantially endless sheet. The nonwoven cellulose fiber fabric 102 may then be shipped as roll-good to an entity manufacturing products such as wipes or textiles based on the nonwoven cellulose fiber fabric 102.

[0068] As indicated in Figure 1, the described process may be controlled by control unit 140 (such as a processor, part of a processor, or a plurality of processors). The control unit 140 is configured for controlling operation of the various units shown in Figure 1, in particular one or more of the metering unit 113, the mixing unit 119, the fiber formation unit 124, the coagulation unit(s) 128, the further processing unit 134, the dissolution unit 120, the washing unit 118, etc. Thus, the control unit 140 (for instance by executing computer executable program code, and/or by executing control commands defined by a user) may precisely and flexibly define the process parameters according to which the nonwoven cellulose fiber fabric 102 is manufactured. Design parameters in this context are air flow along the orifices 126, properties of the coagulation fluid 106, drive speed of the fiber support unit 132, composition, temperature and/or pressure of the lyocell spinning solution 104, etc. Additional design parameters which may be adjusted for adjusting the properties of the nonwoven cellulose fiber fabric 102 are number and/or mutual distance and/or geometric arrangement of the orifices 126, chemical composition and degree of concentration of the lyocell spinning solution 104, etc. Thereby, the properties of the nonwoven cellulose fiber fabric 102 may be properly adjusted, as described below. Such adjustable properties (see below detailed description) may involve one or more of the following properties: diameter and/or diameter distribution of the fibers 108, amount and/or regions of merging between fibers 108, a purity level of the fibers 108, properties of a multilayer fabric 102, optical properties of the fabric 102, fluid retention and/or fluid release properties of the fabric 102, mechanical stability of the fabric 102, smoothness of a surface of the fabric 102, cross-sectional shape of the fibers 108, etc.

[0069] Although not shown, each spinning jet 122 may comprise a polymer solution inlet via which the lyocell spinning solution 104 is supplied to the jet 122. Via an air inlet, a gas flow 146 can be applied to the lyocell spinning solution 104. Starting from an interaction chamber in an interior of the jet 122 and delimited by a jet casing, the lyocell spinning solution 104 moves or is accelerated (by the gas flow 146 pulling the lyocell spinning solution 104 downwardly) downwardly through a respective orifice 126 and is laterally narrowed under the influence of the gas flow 146 so that continuously tapering cellulose filaments or cellulose fibers 108 are formed when the lyocell spinning solution 104 moves downwardly together with the gas flow 146 in the environment of the coagulation fluid 106.

[0070] Thus, processes involved in the manufacturing method described by reference to Figure 1 may include that the lyocell spinning solution 104, which may also be denoted as cellulose solution is shaped to form liquid strands or latent filaments, which are drawn by the gas flow 146 and significantly decreased in diameter and increased in length. Partial coagulation of latent filaments or fibers 108 (or preforms thereof) by coagulation fluid

106 prior to or during web formation on the fiber support unit 132 may also be involved. The filaments or fibers 108 are formed into web like fabric 102, washed, dried and may be further processed (see further processing unit 134), as required. The filaments or fibers 108 may for instance be collected, for example on a rotating drum or belt, whereby a web is formed.

[0071] As a result of the described manufacturing process and in particular the choice of solvent used, the fibers 108 have a copper content of less than 5 ppm and have a nickel content of less than 2 ppm. This advantageously improves purity of the fabric 102.

[0072] The lyocell solution blown web (i.e. the nonwoven cellulose fiber fabric 102) according to exemplary embodiments of the invention preferably exhibits one or more of the following properties:

- (i) The dry weight of the web is from 5 to 300 g/m², preferably 10-80 g/m²
- (ii) The thickness of the web according to the standard WSP120.6 respectively DIN29073 (in particular in the latest version as in force at the priority date of the present patent application) is from 0.05 to 10.0 mm, preferably 0.1 to 2.5 mm
- (iii) The specific tenacity of the web in MD according to EN29073-3, respectively ISO9073-3 (in particular in the latest version as in force at the priority date of the present patent application) ranges from 0.1 to 3.0 Nm²/g, preferably from 0.4 to 2.3 Nm²/g
- (iv) The average elongation of the web according to EN29073-3, respectively ISO9073-3 (in particular in the latest version as in force at the priority date of the present patent application) ranges from 0.5 to 100%, preferably from 4 to 50%.
- (v) The MD/CD tenacity ratio of the web is from 1 to 12
- (vi) The water retention of the web according to DIN 53814 (in particular in the latest version as in force at the priority date of the present patent application) is from 1 to 250%, preferably 30 to 150%
- (vii) The water holding capacity of the web according to DIN 53923 (in particular in the latest version as in force at the priority date of the present patent application) ranges from 90 to 2000%, preferably 400 to 1100%.
- (viii) Metal residue levels of copper content of less than 5 ppm and nickel content of less than 2 ppm, in particular measured according to EN 15587-2 for decomposition and EN17294-2 for ICP-MS.

[0073] Most preferably, the lyocell solution-blown web exhibits all of said properties (i) to (viii) mentioned above.

[0074] As described, the process to produce the nonwoven cellulose fiber fabric 102 preferably comprises:

- (a) Extruding a solution comprising cellulose dissolved in NMMO (see reference numeral 104) through the orifices 126 of at least one jet 122, thereby forming filaments of lyocell spinning solution 104

(b) Stretching said filaments of lyocell spinning solution 104 by a gaseous stream (see reference numeral 146)

(c) Contacting said filaments with a vapor mist (see reference numeral 106), preferably containing water, thereby at least partly precipitating said fibers 108. Consequently, the filaments or fibers 108 are at least partly precipitated before forming web or nonwoven cellulose fiber fabric 102.

(d) Collecting and precipitating said filaments or fibers 108 in order to form a web or nonwoven cellulose fiber fabric 102

(e) Removing solvent in wash line (see washing unit 180)

(f) Optionally bonding via hydro-entanglement, needle punching, etc. (see further processing unit 134)

(g) Drying and roll collection

[0075] Constituents of the nonwoven cellulose fiber fabric 102 may be bonded by merging, intermingling, hydrogen bonding, physical bonding such as hydroentanglement or needle punching, and/or chemical bonding.

[0076] In order to be further processed, the nonwoven cellulose fiber fabric 102 may be combined with one or more layers of the same and/or other materials, such as (not shown) layers of synthetic polymers, cellulosic fluff pulp, nonwoven webs of cellulose or synthetic polymer fibers, bicomponent fibers, webs of cellulose pulp, such as airlaid or wetlaid pulp, webs or fabrics of high tenacity fibers, hydrophobic materials, high performance fibers (such as temperature resistant materials or flame retardant materials), layers imparting changed mechanical properties to the final products (such as Polypropylene or Polyester layers), biodegradable materials (e.g. films, fibers or webs from Polylactic acid), and/or high bulk materials.

[0077] It is also possible to combine several distinguishable layers of nonwoven cellulose fiber fabric 102, see for instance Figure 7.

[0078] The nonwoven cellulose fiber fabric 102 may essentially consist of cellulose alone. Alternatively, the nonwoven cellulose fiber fabric 102 may comprise a mixture of cellulose and one or more other fiber materials. The nonwoven cellulose fiber fabric 102, furthermore, may comprise a bicomponent fiber material. The fiber material in the nonwoven cellulose fiber fabric 102 may at least partly comprise a modifying substance. The modifying substance may be selected from, for example, the group consisting of a polymeric resin, an inorganic resin, inorganic pigments, antibacterial products, nanoparticles, lotions, fire-retardant products, absorbency-improving additives, such as superabsorbent resins, ion-exchange resins, carbon compounds such as active carbon, graphite, carbon for electrical conductivity, X-ray contrast substances, luminescent pigments, and dye stuffs.

[0079] Concluding, the cellulose nonwoven web or nonwoven cellulose fiber fabric 102 manufactured direct-

ly from the lyocell spinning solution 104 allows access to value added web performance which is not possible via staple fiber route. This includes the possibility to form uniform lightweight webs, to manufacture microfiber products, and to manufacture continuous filaments or fibers 108 forming a web. Moreover, compared to webs from staple fibers, several manufacturing procedures are no longer required. Moreover, nonwoven cellulose fiber fabric 102 according to exemplary embodiments of the invention is biodegradable and manufactured from sustainably sourced raw material (i.e. wood pulp 110 or the like). Furthermore, it has advantages in terms of purity and absorbency. Beyond this, it has an adjustable mechanical strength, stiffness and softness. Furthermore, nonwoven cellulose fiber fabric 102 according to exemplary embodiments of the invention may be manufactured with low weight per area (for instance 10 to 30 g/m²). Very fine filaments down to a diameter of not more than 5 μm, in particular not more than 3 μm, can be manufactured with this technology. Furthermore, nonwoven cellulose fiber fabric 102 according to an exemplary embodiment of the invention may be formed with a wide range of web aesthetics, for instance in a flat crispy film-like way, in a paper-like way, or in a soft flexible textile-like way. By adapting the process parameters of the described process, it is furthermore possible to precisely adjust stiffness and mechanical rigidity or flexibility and softness of the nonwoven cellulose fiber fabric 102. This can be adjusted for instance by adjusting a number of merging positions, the number of layers, or by after-treatment (such as needle punch, hydro-entanglement and/or calendering). It is in particular possible to manufacture the nonwoven cellulose fiber fabric 102 with a relatively low basis weight of down to 10 g/m² or lower, to obtain filaments or fibers 108 with a very small diameter (for instance of down to 3 to 5 μm, or less), etc.

[0080] Figure 2, Figure 3 and Figure 4 show experimentally captured images of nonwoven cellulose fiber fabric 102 according to an exemplary embodiment of the invention in which merging of individual fibers 108 has been accomplished by a corresponding process control. The oval markers in Figure 2 to Figure 4 show such merging regions where multiple fibers 108 are integrally connected to one another. At such merging points, two or more fibers 108 may be interconnected to form an integral structure.

[0081] Figure 5 and Figure 6 show experimentally captured images of nonwoven cellulose fiber fabric 102 according to an exemplary embodiment of the invention in which swelling of fibers 108 has been accomplished, wherein Figure 5 shows the fiber fabric 102 in a dry non-swollen state and Figure 6 shows the fiber fabric 102 in a humid swollen state. The pore diameters can be measured in both states of Figure 5 and Figure 6 and can be compared to one another. When calculating an average value of 30 measurements, a decrease of the pore size by swelling of the fibers 108 in an aqueous medium up to 47% of their initial diameter could be determined.

[0082] Figure 7 shows an experimentally captured image of nonwoven cellulose fiber fabric 102 according to an exemplary embodiment of the invention in which formation of two superposed layers 200, 202 of fibers 108 has been accomplished by a corresponding process design, i.e. a serial arrangement of multiple spinnerets. The two separate, but connected layers 200, 202 are indicated by a horizontal line in Figure 7. For instance, an n-layer fabric 102 ($n \geq 2$) can be manufactured by serially arranging n spinnerets or jets 122 along the machine direction.

[0083] Specific exemplary embodiments of the invention will be described in the following in more detail:

[0084] Figure 8 shows a schematic drawing which will be used for explaining that a defined bending of fibers 108 can be promoted when adjusting roundness of a cross-section of the fiber 108 to deviate from a circular cross-section.

[0085] In order to explain the mentioned phenomenon, a fiber 108 is shown in Figure 8 in a straight force free state (upper illustration) and in a state where the fiber 108 undergoes bending (lower illustration). When the fiber 108 has a perfect circular cylindrical cross-section, even an extremely small bending force may initiate bending of the fiber 108 along a non-predictable bending axis. Thus, in a practical application, it is impossible to predict or define a direction, along which a bunch of fibers 108 with perfect circular cylindrical cross-section will undergo bending. When however the fiber 108 is provided with a roundness deviating significantly from the value of one (i.e. a cross-section of the fiber 108 deviates from a perfect circle, for instance being shaped as an oval (in particular elliptic)), a preferred bending axis is thereby defined along which the bending is enabled in a simpler way (or by smaller forces) than in a direction perpendicular thereto. For instance, bending of a fiber 108 with oval-elliptic cross-section will be possible with smaller forces with the shorter minor axis as bending line as compared to the longer major axis as bending line.

[0086] Applying the described phenomenon to the fiber design of a fabric 102 according to an exemplary embodiment of the invention, designing fibers 108 of such a fabric 102 with a circular cross-section allows to predictably define preferred bending axes of the fibers 108. When the filaments of lyocell spinning solution 104 are laid down on a fiber support unit 132 for forming fibers 108 by coagulation, they will be aligned with a certain degree of order along the fiber accommodating surface of the fiber support unit 132 in a predictable manner and not merely statistical. As a consequence, the mechanical properties of the fabric 102 may be precisely defined by defining the cross-section of the fibers 108 to deviate from a circular symmetric geometry. Thus, predictability may be introduced in the nonwoven cellulose fiber fabric 102 as a consequence of the definition of the pronounced non-circular roundness of the fibers 108. Concluding, by adjusting a deviation of at least some of the fibers 108 of a nonwoven cellulose fiber fabric 102 according to an

exemplary embodiment of the invention from a cylindrical geometry by a corresponding adjustment of the manufacturing process allows to precisely define the mechanical properties of the fabric 102, in particular allows to obtain a fabric 102 having a high mechanical robustness.

[0087] Figure 9 shows an experimentally captured image of nonwoven cellulose fiber fabric 102 according to an exemplary embodiment of the invention illustrating fibers 102 having a cross-sectional shape deviating from a circular shape.

[0088] Preferably, at least 10% of the fibers 108 has a non-circular cross sectional shape having a roundness of not more than 50% along at least a portion of the fiber's 108 longitudinal extension. With such a strong deviation of a remarkable subset of fibers 108 from a circular cylindrical geometry, some degree of regularity may be defined in the fabric 102. This allows to fine-tune the mechanical properties of the obtained fabric 102. The smoothness of the fabric 102 measured with a "Handle-O-Meter" on the basis of the nonwoven standard WSP90.3 may be freely adjusted within a broad range between 2 mNm²/g and 70 mNm²/g, since a desired mechanical robustness can be precisely defined already by the non-circular roundness design of at least some of the fibers 108.

[0089] As a result of the manufacturing process of the fabric 102 described above referring to Figure 1, the fibers 108 have only a very small copper content of less than 5 ppm and have only a very small nickel content of less than 2 ppm. Therefore, the fabric 102 can be manufactured with a very small contamination of heavy metals, which ensures biocompatibility of the fabric 102 and prevents allergic reactions when the fabric 102 comes into physical contact with a human skin.

[0090] Figure 10 shows an experimentally captured image of nonwoven cellulose fiber fabric 102 according to an exemplary embodiment of the invention in which fibers 108 having a cross-sectional shape deviating from a circular shape are partially twisted.

[0091] In the embodiment of Figure 10, some of the fibers 108 are twisted. Consequently, these fibers 108 form a somewhat helical structure along at least a part of their longitudinal extension. Such a fiber twisting provides the obtained nonwoven cellulose fiber fabric 102 with a mechanical robustness while at the same time allowing some elastic adjustment of the fabric 100. In particular, the combination of fibers 108 having a roundness deviating from one, being twisted and being merged with one another at merging positions 204 provides the fabric 102 with some degree of flexibility.

[0092] Figure 11 shows an experimentally captured image of nonwoven cellulose fiber fabric 102 according to another exemplary embodiment of the invention composed of three stacked layers 202, 200, 200 with different diameters of fibers 108. According to Figure 11, an intermediate sandwich layer 200 has significantly smaller diameters of fibers 108 than the two exterior layers 200, 202 above and below.

[0093] The multilayer fabric 102 shown in Figure 11 is particularly appropriate for applications such as medical applications, agricultural textiles, etc. For instance, an active substance may be stored in the inner layer 200 showing a high capillary action. The exterior layers 200, 202 may be designed in terms of rigidity and surface haptic. This is advantageous for cleaning and medical applications. For agricultural applications, the fiber layer design may be specifically configured in terms of evaporation properties and/or root penetration.

[0094] In another application, the multilayer fabric 102 shown in Figure 11 may be used as facial mask, wherein the central layer 200 may have a specifically pronounced fluid retaining capability. The cover layers 200, 202 may be configured for adjusting fluid release properties. The diameters of the fibers 108 of the respective layer 200, 202 may be used as a design parameter for adjusting these functions.

[0095] Hence, the fibers 108 shown in Figure 11 are located in three different distinguishable layers 200, 202. Fibers 108 of different layers 200, 202 are integrally merged at merging positions 204 between the layers 200, 202. Moreover, at least some of the fibers 108 are provided with a non-circular cross-section having a roundness of not more than 90% which provides some degree of order in the respective layer 200, 202 and reinforces the fabric 102.

[0096] Figure 12 shows how a value of roundness of fibers 108 having a cross-section deviating from a circular cross-section can be calculated as the ratio between the radii of an inscribed circle 280 and a circumscribed circle 282 of the cross-section of the fiber 108 according to an exemplary embodiment of the invention.

[0097] The minimum circumscribed circle 282 is defined as the smallest circle which encloses whole of the roundness profile of the cross-section of the fiber 108 illustrated in Figure 12. The maximum inscribed circle 280 is defined as the largest circle that can be inscribed inside the roundness profile of the cross-section of the fiber 108 illustrated in Figure 12. In the context of the present application, roundness can be defined as a ratio between a radius r of the inscribed circle 280 divided by a radius R of the circumscribed surface 282. Roundness may be indicated by a resulting percentage value. In the present example, $R \approx 2r$ and the roundness of the fiber 108 is therefore approximately 0.5 or 50%. For comparison, a circular cylindrical fiber 108 fulfills the condition $R=r$ and has a roundness of one or 100%.

[0098] Figure 13 illustrates a part of a device 100 for manufacturing nonwoven cellulose fiber fabric 102 composed of two stacked layers 200, 202 of endless cellulose fibers 108 according to an exemplary embodiment of the invention. In view of the movable fiber accommodation surface of the conveyor belt-type fiber support unit 132, the upstream jet 122 on the left-hand side of Figure 13 produces layer 202 of fibers 108. Layer 200 of other fibers 108 is produced by the downstream jet 122 (on the right hand side of Figure 13) and is attached to an upper main

surface of the previously formed layer 202 so that a double layer 200, 202 of fabric 102 is obtained.

[0099] According to Figure 13, the control unit 140 (controlling the jets 122 and the coagulation units 128) is configured for adjusting process parameters so that at least part of the fibers 108 are integrally merged at merging positions 204 between layers 200, 202.

[0100] Although not shown in Figure 13, it is possible to further process the fibers 108 after collection on the fiber support unit 132, for instance by hydro-entanglement, needling, and/or impregnating.

[0101] Still referring to the embodiment illustrated in Figure 13, one or more further nozzle bars or jets 122 may be provided and may be arranged serially along a transport direction of fiber support unit 132. The multiple jets 122 may be arranged so that further layer 200 of fibers 108 may be deposited on top of the previously formed layer 202, preferably before the coagulation or curing process of the fibers 108 of the layer 202 and/or of the layer 200 is fully completed, which may trigger merging. When properly adjusting the process parameters, this may have advantageous effects in terms of the properties of a multilayer fabric 102:

Intended merging between fibers 108 of the fabric 102 according to Figure 13 can be triggered so as to further increase the mechanical stability of the fabric 102. In this context, merging may be a supported contact point adhesion of contacting filaments of fibers 108, in particular prior to the completion of a coagulation process of one or both of the fibers 108 being merged. For instance, merging may be promoted by increasing a contact pressure between two filaments of lyocell spinning solution 104 to be merged by a fluid flow (for instance a flow of air or water). By taking this measure, the cohesion on the one hand between different filaments or fibers 108 of one of the layers 200, 202 and/or on the other hand between the layers 200, 202 may be increased.

[0102] The device 100 according to Figure 13, which is configured for the manufacture of multilayer fabric 102, implements a high number of process parameters which can be used for adjusting merging factor, designing shape and/or diameter or diameter distribution of the fibers 108 as well as of fiber layers 200, 202. This is the result of the serial arrangement of multiple jets 122, each of which being operable with individually adjustable process parameters. When orifices 126 of the multiple jets 122 are shaped differently and in a non-circular way, it is also possible to form a fabric 102 of fibers 108 which have a cross section deviating from a circle. Such fibers 108 may be oval, elliptic oblong, rectangular, triangular, polygonal, with sharp and/or round edges, etc.

[0103] With device 100 according to Figure 13, it is in particular possible to manufacture a fabric 102 composed of at least two layers 200, 202 (preferably more than two layers). By the defined layer separation of a multilayer

fabric 102, it is also possible to later separate the multi-layer fabric 102 into the different individual layers 200, 202 or into different multilayer sections. According to exemplary embodiments of the invention, both *intra-layer* adhesion of the fibers 108 of one layer 200, 202 as well as *inter-layer* adhesion of the fibers 108 between adjacent layers 200, 202 (for instance by merging and/or by friction generating contact) may be properly and individually adjusted. A corresponding separate control for each layer 200, 202 individually may be in particular obtained when the process parameters are adjusted so that coagulation or curing of the fibers 108 of one layer 202 is already completed when the other layer 200 of fibers 108 is placed on top thereof.

[0104] For instance, adjusting the process parameters for adjusting merging according to Figure 13 comprises serially arranging multiple jets 122 with orifices 126 along a movable fiber support unit 132, depositing first layer 202 of fibers 108 on the fiber support unit 132, and depositing second layer 200 of fibers 108 on the first layer 202 before coagulation of some or all of the fibers 108 at an interface between the layers 200, 202 has been completed. Thus, different ones of the fibers 108 of the fabric 102 may be located in different distinguishable layers 200, 202 which can however be merged by forming merging positions 204. In other words, fibers 108 of different layers 200, 202 may be integrally merged at one or more merging position 204 between the layers 200, 202.

[0105] Figure 14 illustrates a part of a device 100 for manufacturing nonwoven cellulose fiber fabric 102 according to yet another exemplary embodiment of the invention in which the process is controlled by a control unit 140 so as to trigger formation of fibers 108 having a roundness deviating from a circular roundness by exerting a lateral force to the fibers 108 during coagulation.

[0106] More specifically, a spinning solution deformation unit 270 is provided in the device 100 which is configured for exerting a deforming force to filaments of the lyocell spinning solution 104 before the coagulation is completed. Such a deforming force may deform the filaments from a circular cross section into a non-circular cross section. As can be taken from a detail 274 showing a part of the fabric 102 prior to the completion of coagulation of the fibers 108, the solution deformation force is exerted by directing a flow of shaping fluid 272 to the filaments of the lyocell spinning solution 104 before the coagulation is completed. The shaping fluid 272 can be a gas flow and/or a liquid flow being directed from the spinning solution deformation unit 272 to the filaments of lyocell spinning solution 104 before the fibers 108 are precipitated therefrom. The pressure applied by the shaping fluid 272 to the filaments of lyocell spinning solution 104 deforms the filaments from a for instance substantially circular cross-sectional shape into an elliptic or flat shape, as shown in detail 274. When the pressure applied by the shaping fluid 272 to the filaments of lyocell spinning solution 104 is maintained until coagulation or

precipitation is completed, the fibers 108 will be automatically formed in a corresponding shape with non-circular cross-section. When the shaping fluid 272 comprises or consists of water, the application of shaping pressure may be synergistically combined with the precipitation of coagulation of the fibers 108 from the lyocell spinning solution 104 triggered at least partially by the then aqueous shaping fluid 272.

[0107] Figure 15 illustrates a part of a device 100 for manufacturing nonwoven cellulose fiber fabric 102 according to still another exemplary embodiment of the invention having orifices 126 being shaped to form fibers 108 having a roundness deviating from a circular roundness.

[0108] Additionally or alternatively to the provisions taking according to Figure 14 for defining a roundness of less than one for at least part of the fibers 108 of the fabric 102, the orifices 126 of the jets 122 of Figure 15 are provided with a non-circular shape. In the shown embodiment, alternating rows of elliptical orifices 126 are foreseen having the respective major axis either oriented along a common align axis 236 (i.e. the horizontal direction according to Figure 15, compare the odd rows of orifices 126) or oriented along parallel align axes 238 (i.e. the vertical direction according to Figure 15, compare the even rows of orifices 126). However, a person skilled in the art will clearly understand that the shown patterns of orifices 126 are only exemplary, and many other patterns of non-circular orifices 126 can be implemented according to other exemplary embodiments of the invention.

[0109] Figure 16 shows a schematic illustration of nonwoven cellulose fiber fabric 102 according to an exemplary embodiment of the invention illustrating fibers 108 having a cross-sectional shape deviating from a circular shape so that, as a result, the fibers 108 are arranged or aligned on the average along or around a preferential direction 290. In other words, the fibers 108 are aligned anisotropically within the fabric 102 to thereby define, on the average, one preferential alignment direction 290 along which a larger portion of fibers 108 is aligned compared to other directions. According to Figure 16, several fibers 108 of the fabric 102 are shown which all have a non-circular elliptic cross-section. As a consequence, the fibers 108 preferably bend around alignment direction 290 when being deposited on the fiber support unit 132. As can be taken from Figure 16, some of the fibers 108 are merged at merging positions 204 prior to coagulation, whereas other fibers 108 cross each other at crossing position 264 without being merged, i.e. experiencing only a mutual friction force.

[0110] More generally, the provision of a nonwoven cellulose fiber fabric 102 having non-round endless fibers 108 allows to increase both rigidity and homogeneity. Although each individual process according to which one fiber 108 is laid down on a fiber support unit 132 has a statistical impact, a predictable preferred lay down direction of the fibers 108 may be defined by configuring at least part of the fibers 108 with a non-circular cross-section.

tion. A corresponding increase of at least one of homogeneity and rigidity may be obtained by manufacturing at least a part of the fibers 108 with a sufficiently small roundness. This is particularly powerful for increasing stability of the fabric 102 when at the same time merging between at least part of the fibers 108 is triggered. By adjusting the properties of the fibers 108 of the fabric 102 according to an exemplary embodiment of the invention in terms of roundness value(s) or cross-sectional shape, a functionalization of the fabric 102 with regard to a specific application becomes possible. In particular, this makes it possible to design a fabric 102 with a higher mechanical robustness at a given grammage or to obtain a lower grammage at a given mechanical robustness. Such a reinforced mechanical stability may be obtained in one or both perpendicular directions in a plane of the fabric 102 corresponding to a fiber accommodation plane of the fiber support unit 132. Highly advantageously, such a fabric 102 according to an exemplary embodiment of the invention may be manufactured in accordance with a lyocell spinning solution architecture, so that a very low contamination of the obtained fabric 102 with heavy metal impurities may be guaranteed. Consequently, the obtained nonwoven cellulose fiber fabric 102 has a very high degree of purity so that the obtained fabric 102 or products manufactured on the basis thereof are not prone of causing allergic reactions of a user.

[0111] According to a preferred embodiment, one or more nozzle bars or jets 122 for creating filaments of lyocell spinning solution 104 are implemented, wherein these filaments are then stretched, swirled and laid down on a fiber accommodation surface of a fiber support unit 132. The formation of merging positions 204 between two or more fibers 108 may be triggered or promoted by air vorticity or turbulence during this stretching process and/or when the filaments of not yet coagulated lyocell spinning solution 104 are laid down on the fiber support unit 132.

[0112] Such merging processes can occur at different points of time during coagulation of the chemical process of formation of endless fibers 108. They may also be adjusted with varying intensity and can be promoted using different media (such as water or air). By a corresponding adjustment, coagulation and/or shaping of the filaments may be controlled, as well as an adhesion at the mentioned contact or merging positions 204. As a result, a large variety of merging effects can be adjusted: on the one hand it is possible to form a fabric 102 with a very low tendency of adhesion of merging; on the other hand, it is possible to control the process so that extremely strong merging is obtained so that the fibers 108 lose their shape and tend to assume an areal film like structure.

[0113] During the lay-down process of the fibers 108 or not yet fully coagulated preforms thereof, statistical or random processes may be involved. This may conventionally result in an arbitrary structure of the endless filaments or fibers 108. In particular when the transport

velocity of the transport apparatus (i.e. the fiber support unit 132) is significantly smaller than the velocity of the filaments moving down on the fiber accommodation surface of the fiber support unit 132, an arbitrary orientation of the filaments of fibers 108 may take place. In other words, a non-predictable or pseudo-random lay down direction of the filaments or fibers 108 may occur due to a counterforce applied from the fiber support unit 132 to the filaments when the latter move down on the fiber support unit 132.

[0114] This phenomenon has been described above referring to Figure 8.

[0115] However, such purely statistical of random lay down behavior of fibers 108 may be overcome by exemplary embodiments of the invention by configuring at least part of the fibers 108 with a non-circular cross-section in accordance with a roundness value of 90% or lower, as described above referring to Figure 8. When a fiber 108 deviates to a sufficient degree from a circular cylindrical cross-section one or more predominant lay down directions for the fibers 108 or for correspondingly designed and oriented groups of fibers 108 may be defined, thereby increasing homogeneity and predictability of the characteristics of the fabric 102. Descriptively speaking and referring to an elliptic cross-section of a fiber 108, such an elliptic fiber 108 will preferably bend down or kink in the direction of the smaller cross-sectional dimension (i.e. along the minor axis of the ellipse). As a result of this phenomenon, a control of the cross-sectional shape of the manufactured fibers 108 deviating from a circular shape allows to define one or more preferred alignment directions of the fibers 108 in the fabric 102.

[0116] In order to create fibers 108 with roundness below 90%, preferably below 50%, it is for instance possible to blow air or to produce a water jet exerting a pressure on not yet coagulated preforms of the fibers 108. It is also possible to apply such a pressure onto two opposing surfaces of the preforms of the fibers 108 for flattening the latter. For instance, when the pressure is applied from 0° and 180° directions, a preferred flattening or ovalization of the fibers 108 occurs along a 90°-270°-axis.

[0117] In order to create fibers 108 with roundness below 90%, preferably below 50%, it is additionally or alternatively possible to provide orifices 126 of the jet 122 having an oval (or more generally non-circular) nozzle cross-section.

[0118] In the framework of the described mechanisms for forming fibers 108 having a non-circular cross-section, one or more of the following options can be applied:

- a) At a high transport velocity of the fiber support unit 132, the transportation of the fabric 102 in MD direction results in an implicit focusing of the average fiber alignment (as can be derived from a vector addition of the transport velocity and the lay down velocity). In particular when the transport velocity is in the same order of magnitude or even larger than the lay down velocity, an efficient orientation of the fiber

alignment of the fabric 102 in MD direction can be achieved. By defined cross-sectional control of the laid down fibers 108 in CD direction due to a stretching or flattening modification of the cross-section of the fibers 108 compared to a circular cross-section and increased fiber orientation in CD direction would be obtained at the transport velocity of zero. Hence, it is possible to determine an average or intermediate value at a transport velocity and a CD lay down reinforcement at which no preferential alignment direction of the fibers 108 is obtained. In other words, under such conditions it is even possible to obtain a perfect homogeneity. It should however be mentioned that in some embodiments, the laydown velocity may be higher, in particular magnitudes higher, than the transport velocity.

b) It is presently believed that already a modification of a relatively low number of fibers 108 according to the principle described under a) yields the result that further neighbored fibers 108 are also oriented preferably in CD direction. This can be explained with the analogy of a forest in the presence of a wind-storm. The first tree(s) which break(s) trigger(s) a domino-like forest aisle along the breaking direction.

c) By a modification of a cross-sectional shape of fibers 108, a friction-based clamping effect can be created in a fabric 102 according to an exemplary embodiment of the invention. This results in a self-inhibition like in a conical tool receptacle. This effect can already be obtained with relatively small deviations of a cross-sectional shape of fibers 108 compared to a circular cross-section. The transition of a circular cross-section to an oval cross-section may be capable of forming such a self-inhibiting system in relation to another fiber 108 (also having a non-circular cross-section or having a circular cross-section).

[0119] Again referring to the embodiment illustrated in Figure 13, one or more further nozzle bars or jets 122 may be provided and may be arranged serially along a transport direction of fiber support unit 132. The multiple jets 122 may be arranged so that further layer 200 of fibers 108 may be deposited on top of the previously formed layer 202, preferably before the coagulation or curing process of the fibers 108 of the layer 202 and/or of the layer 200 is fully completed, which may trigger inter-layer merging. When properly adjusting the process parameters, this may have advantageous effects in terms of the properties of a multilayer fabric 102:

On the one hand, the first deposited layer 202 may be laid on a transport band such as a conveyor belt as fiber support unit 132. In such an embodiment, the fiber support unit 132 may be embodied as an ordered structure of a release mechanism and air

suction openings (not shown). In the statistical distribution of filaments of fibers 108, this may have the effect that a higher material concentration can be found in the regions in which no airflow is present. Such a (in particular microscopic) material density variation can be considered as a perforation from a mechanical point of view which functions as a distortion (in particular due to its tendency of suppressing patterns) of the homogeneity of the nonwoven cellulose fiber fabric 102. At the position where the gas flow or a liquid flow (for instance water) penetrates through the nonwoven cellulose fiber fabric 102, pores may be formed in the nonwoven cellulose fiber fabric 102. By such a fluid flow (wherein the fluid can be a gas or a liquid), the tensile strength of the manufactured nonwoven cellulose fiber fabric 102 may be increased. Without wishing to be bound to a specific theory, it is presently believed that the second layer 200 can be considered as a reinforcement of the first layer 202, which compensates the homogeneity reduction of the layer 202. This increase of the mechanical stability can be further improved by fiber diameter variation (in particular *inter*-fiber diameter variation and/or *intra*-fiber longitudinal diameter variation of the individual fibers 108). When exerting deeper (in particular punctual) pressure (for instance provided by air or water), the cross-sectional shape of a fiber 108 can be further intentionally distorted, which may advantageously result in a further increased mechanical stability.

[0120] On the other hand, intended merging between fibers 108 of the fabric 102 according to Figure 13 can be triggered so as to further increase the mechanical stability of the fabric 102. In this context, merging may be a supported contact point adhesion of contacting filaments of fibers 108, in particular prior to the completion of a coagulation process of one or both of the fibers 108 being merged. For instance, merging may be promoted by increasing a contact pressure by a fluid flow (for instance a flow of air or water). By taking this measure, the strength of the coagulation on the one hand between filaments or fibers 108 of one of the layers 200, 202 and/or on the other hand between the layers 200, 202 may be increased.

[0121] The device 100 according to Figure 13, which is configured for the manufacture of multilayer fabric 102, implements a high number of process parameters which can be used for designing shape and/or diameter or diameter distribution of the fibers 108 as well as of fiber layers 200, 202. This is the result of the serial arrangement of multiple jets 122, each of which being operable with individually adjustable process parameters.

[0122] The high mechanical robustness of the fabric 102 according to an exemplary embodiment of the invention also results from the following properties of the described manufacturing process: Firstly, the use of endless fibers 108 made of cellulose material, since endless

fibers 108 (in comparison to staple fibers) has less disturbing transitions so that an individual fiber 108 has a higher loading capacity. Secondly, such fibers 108 may be manufactured highly pure, since the process related heavy metal content of a corresponding fabric 102 is very small. Thirdly, a specific design of carrier grid, supports web or other carrier structures (web support system) which may be implemented in a spunlace manufacturing method allows the control of the rigidity of the fabric 102. In particular, the stability of the fabric 102 may be significantly increased by (for instance air and/or water induced) merging, allowing to obtain bionic like structures with a high load capability.

[0123] By an appropriate process control it is possible to provide the individual filaments with a drill which can also be maintained in the readily manufactured fabric 102. Thereby, twisted fibers 108 may be formed which may have an increased stretchability by a corresponding spring effect. At the same time, elasticity of the fabric 102 comprising twisted fibers 108 can be limited. This can be used to further increase the stability of the fabric 102. In particular upon bending of a fiber 108, it has the effect that elasticity is reduced with increased bending radius. When implementing appropriate airflow vorticity or turbulences, it is possible to design fabric 102 of twisted fibers 108 with further increased stability.

[0124] On a smooth flat fiber accommodation surface of the fiber support unit 132, oval fibers 108 or filaments come to rest preferably on their broadside. This has a strong impact on the properties of the manufactured fabric 102, because this involves an ordering effect. In particular, this allows to manufacture a fabric 102 having a relatively small thickness and a relatively high density.

[0125] Preferably, the fabric 102 according to an exemplary embodiment of the invention is composed of both circular fibers 108 and non-circular fibers 108. A corresponding fabric 102 can be manufactured by using mixed jets 122 with circular and non-circular orifices 126 and/or by a permanent, cyclic or repeated modification of the process parameters.

[0126] In exemplary embodiments of the invention, at least 2, in particular at least 3, more particularly at least 4, preferably up to 10, serially arranged jets 122 may be implemented for manufacturing fabric 102. Each of the jets 122 may comprise multiple orifices 126. Each of the jets 122 may selectively have circular and/or non-circular orifices 126.

[0127] By adjusting coagulation and/or the conditions of the stretching of the filaments of lyocell spinning solution 104 it is furthermore possible to manufacture a fabric 102 in which in a cross-sectional view the non-circular fiber sections are oriented perpendicular or at least substantially perpendicular with regard to a surface of the fabric 102. This results in a stable adhesion and solidification of the fabric 102.

[0128] This allows to obtain one or more of the following advantages: manufacture of high bulk fabric 102 at a relatively low grammage; recognizable layer structures with

adjustable property profile; adjustable property of fabric 102 at an upper and a lower main surface; horizontally aligned oval fibers 108 allow to obtain a high tensile strength at reduced longitudinal and lateral elongation; grammage can be adjusted over a wide range, for instance from 8 g/m² up to 250 g/m².

[0129] In another exemplary embodiment of the invention, the nonwoven cellulose fiber fabric 102 is used for a biodegradable product. After biodegradation, no binder material or adhesive material remains. In particular, no significant amount of heavy metals forms part of such a biodegradable product. Undesired abrasion of microparticles from the fabric 102 may be prevented by a corresponding design of the process.

[0130] According to an exemplary embodiment of the invention, a defined deviation from a circular cross-section of an endless fiber 108 can be obtained in such a manner that the cross-sectional shape changes along the longitudinal extension of such a fiber 108. This can also be accomplished by bending a fiber 108 beyond its elastic limit, so that a transition from an elastic bending regime to a plastic bending regime occurs. This effect can be reinforced by a subsequent fixing of the bent fibers 108 (for instance by hydroentangling). When tearing the nonwoven cellulose fiber fabric 102, this has the consequence that at certain loop or eyelet structures through which another endless fiber 108 is guided during tearing the diameter does not fit any longer and self-inhibition results already at small shape changes. This increases the tearing robustness of the fabric 102 as a whole. This is relevant in particular in terms of the implementation of endless fibers 108 in which this self-inhibiting effect promoted by a deviation of the roundness from one is stronger than with shorter staple fibers.

[0131] Highly advantageously, a deviation of a cross-section of fibers 108 from a circular cross-section may be combined with a fiber diameter variation (in particular an *intra*-fiber thickness variation and/or an *inter*-fiber thickness variation). This combination allows to obtain a specifically pronounced increase of the mechanical stability of the fabric 102.

[0132] Summarizing, in particular one or more of the following adjustments may be made according to exemplary embodiments of the invention:

- a low homogeneous fiber diameter may allow to obtain a high smoothness of the fabric 102
- multilayer fabric 102 with low diameter fibers and relatively small velocity may allow to obtain a high fabric caliper at a low fabric density
- equal absorption curves of the functionalized layers can allow to obtain a homogeneous humidity and fluid accommodation behavior, as well as a homogeneous behavior in terms of fluid release
- it is also possible to differently functionalize single layers 200, 202 so that products with anisotropic properties are obtained (for instance for wicking, oil accommodation, water accommodation, cleanabili-

ty, roughness).

[0133] Finally, it should be noted that the above-mentioned embodiments illustrate rather than limit the invention, and that those skilled in the art will be capable of designing many alternative embodiments without departing from the scope of the invention as defined by the appended claims. In the claims, any reference signs placed in parentheses shall not be construed as limiting the claims. The words "comprising" and "comprises", and the like, do not exclude the presence of elements or steps other than those listed in any claim or the specification as a whole. The singular reference of an element does not exclude the plural reference of such elements and vice-versa. In a device claim enumerating several means, several of these means may be embodied by one and the same item of software or hardware. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage.

Claims

1. A nonwoven cellulose fiber fabric (102), in particular directly manufactured from lyocell spinning solution (104), wherein the fabric (102) comprises a network of substantially endless fibers (108), and wherein at least 1% of the fibers (108) has a non-circular cross sectional shape having a roundness of not more than 90%.
2. The fabric (102) according to claim 1, comprising at least one of the following features:
 - wherein at least 3%, in particular at least 5%, of the fibers (108) has a non-circular cross sectional shape having a roundness of not more than 90%;
 - wherein at least 1% of the fibers (108) has a non-circular cross sectional shape having a roundness of not more than 80%, in particular of not more than 70%.
3. The fabric (102) according to claim 1 or 2, comprising at least one of the following features:
 - wherein a smoothness, measured as specific hand, of the fabric (102) is in a range between 2 mNm²/g and 70 mNm²/g;
 - wherein the fibers (108) have a copper content of less than 5 ppm and/or have a nickel content of less than 2 ppm;
 - wherein at least part of the fibers (108) are integrally merged at merging positions (204).
4. The fabric (102) according to any of claims 1 to 3, wherein different ones of the fibers (108) are located

at least partially in different distinguishable layers (200, 202).

5. The fabric (102) according to claim 4, comprising at least one of the following features:
 - wherein fibers (108) of different layers (200, 202) are integrally merged at at least one merging position (204) between the layers (200, 202);
 - wherein fibers (108) of different layers (200, 202) have the same physical properties;
 - wherein fibers (108) of different layers (200, 202) have different physical properties.
6. The fabric (102) according to any of claims 1 to 5, wherein at least part of the fibers (108) is twisted.
7. The fabric (102) according to any of claims 1 to 6, wherein the fibers (108) are aligned anisotropically within the fabric (102) to thereby define, on the average, at least one preferential alignment direction (290) along which a larger portion of fibers (108) is aligned compared to other directions.
8. A method of manufacturing nonwoven cellulose fiber fabric (102) directly from lyocell spinning solution (104), wherein the method comprises
 - extruding the lyocell spinning solution (104) through at least one jet (122) with orifices (126) supported by a gas flow (146) into a coagulation fluid (106) atmosphere to thereby form substantially endless fibers (108);
 - collecting the fibers (108) on a fiber support unit (132) to thereby form the fabric (102);
 - adjusting process parameters so that at least 1% of the fibers (108) has a non-circular cross sectional shape having a roundness of not more than 90%.
9. The method according to claim 8, wherein adjusting the process parameters comprises exerting a force to filaments of the lyocell spinning solution (104) before the coagulation is completed.
10. The method according to claim 9, wherein the force is exerted by directing a shaping fluid to the filaments of the lyocell spinning solution (104) before the coagulation is completed.
11. The method according to any of claims 8 to 10, wherein the method further comprises further processing the fibers (108) and/or the fabric (102) *in situ* after collection on the fiber support unit (132), in particular by at least one of the group consisting of hydro-entanglement, needle punching, impregnation, steam treatment with a pressurized steam, and calendering.

12. A device (100) for manufacturing nonwoven cellulose fiber fabric (102) directly from lyocell spinning solution (104), wherein the device (100) comprises:
- at least one jet (122) with orifices (126) configured for extruding the lyocell spinning solution (104) supported by a gas flow (146);
 - a coagulation unit (128) configured for providing a coagulation fluid (104) atmosphere for the extruded lyocell spinning solution (104) to thereby form substantially endless fibers (108);
 - a fiber support unit (132) configured for collecting the fibers (108) to thereby form the fabric (102);
 - a control unit (140) configured for adjusting process parameters so that at least 1% of the fibers (108) has a non-circular cross sectional shape having a roundness of not more than 90%.
13. The device (100) according to claim 12, wherein at least part of the orifices (126) are non-circular, in particular are oval, more particularly are elliptical.
14. A method of using a nonwoven cellulose fiber fabric (102) according to any of claims 1 to 7 for at least one of the group consisting of a wipe, a dryer sheet, a filter, a hygiene product, a medical application product, a geotextile, agrotextile, clothing, a product for building technology, an automotive product, a furnishing, an industrial product, a product related to beauty, leisure, sports or travel, and a product related to school or office.
15. A product or composite, comprising a fabric (102) according to any of claims 1 to 7.

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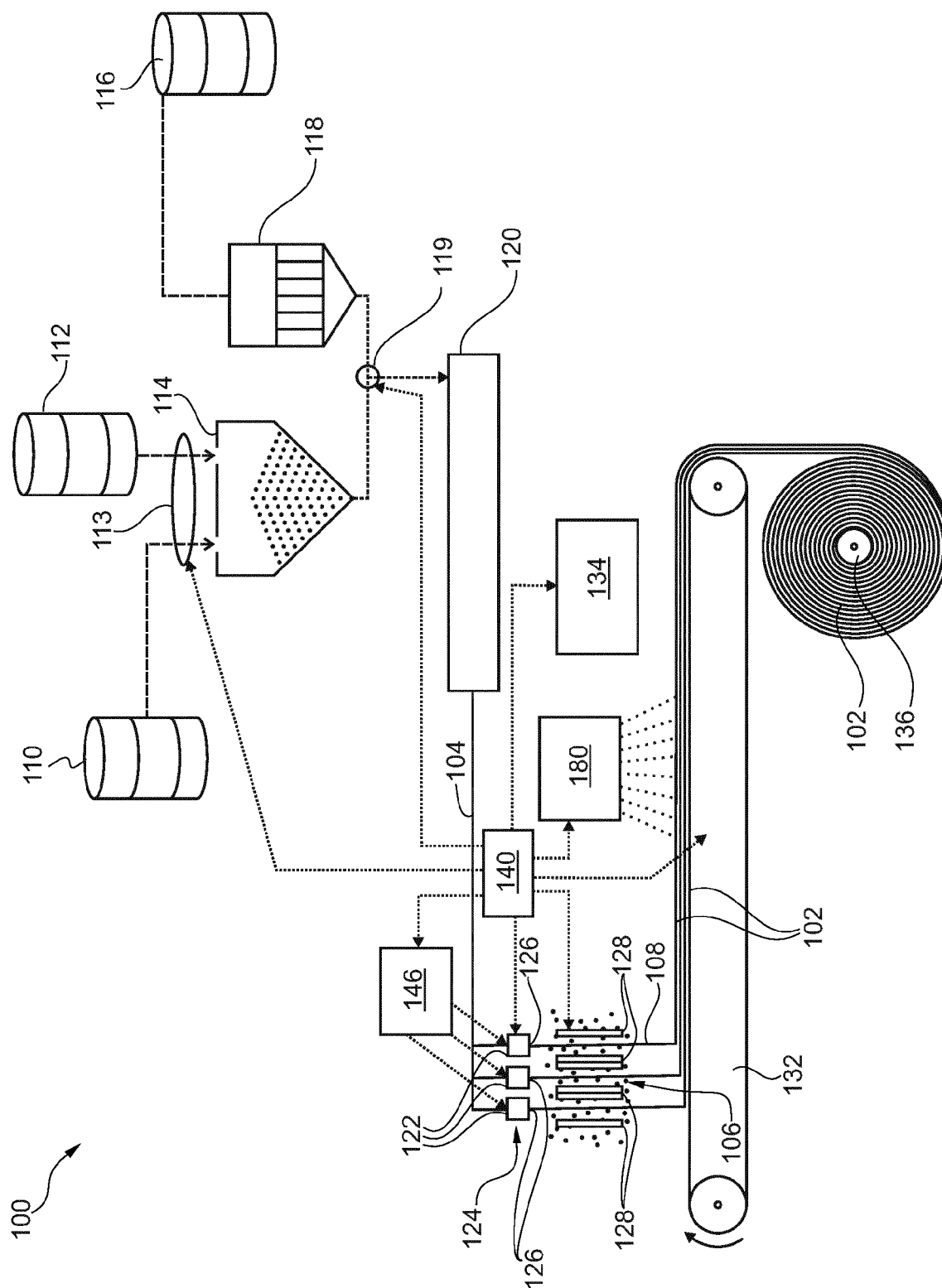


Fig. 1

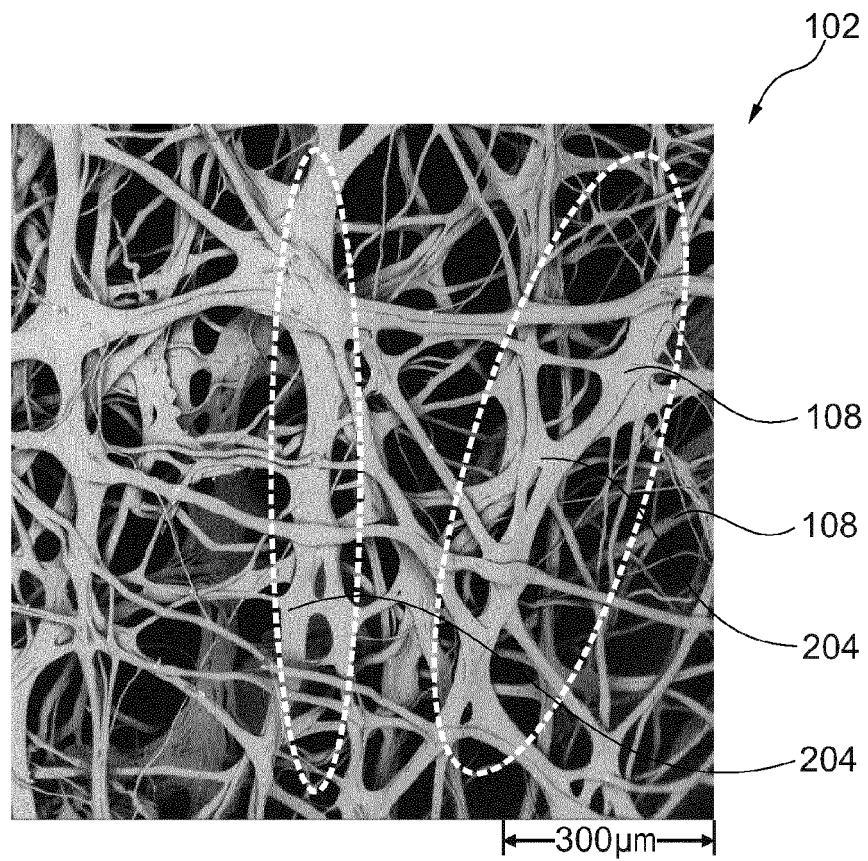


Fig. 2

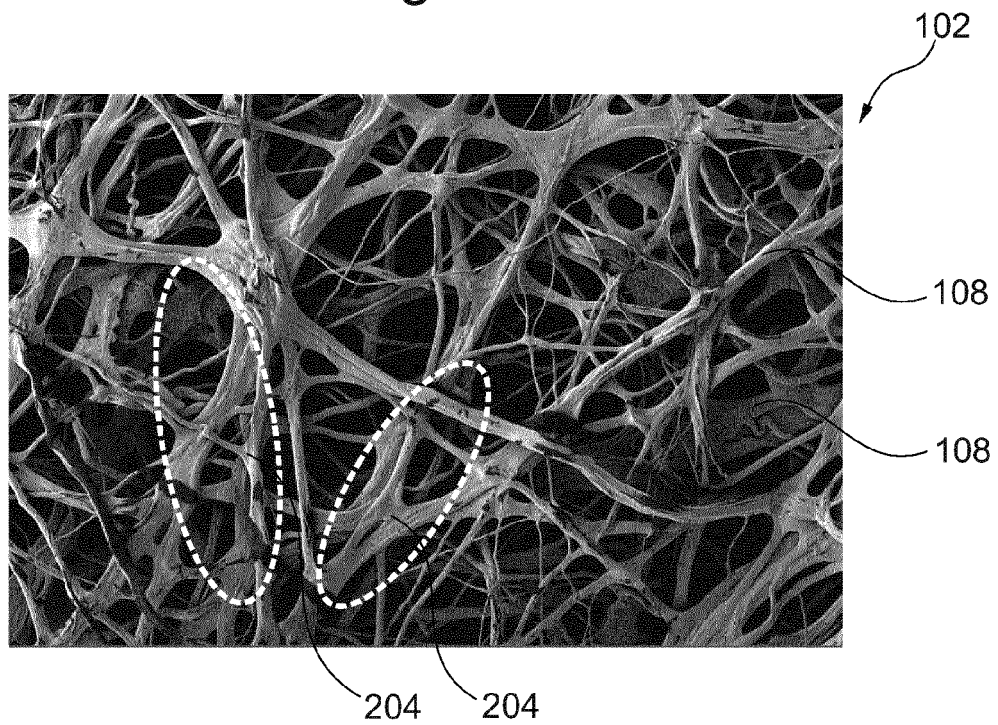


Fig. 3

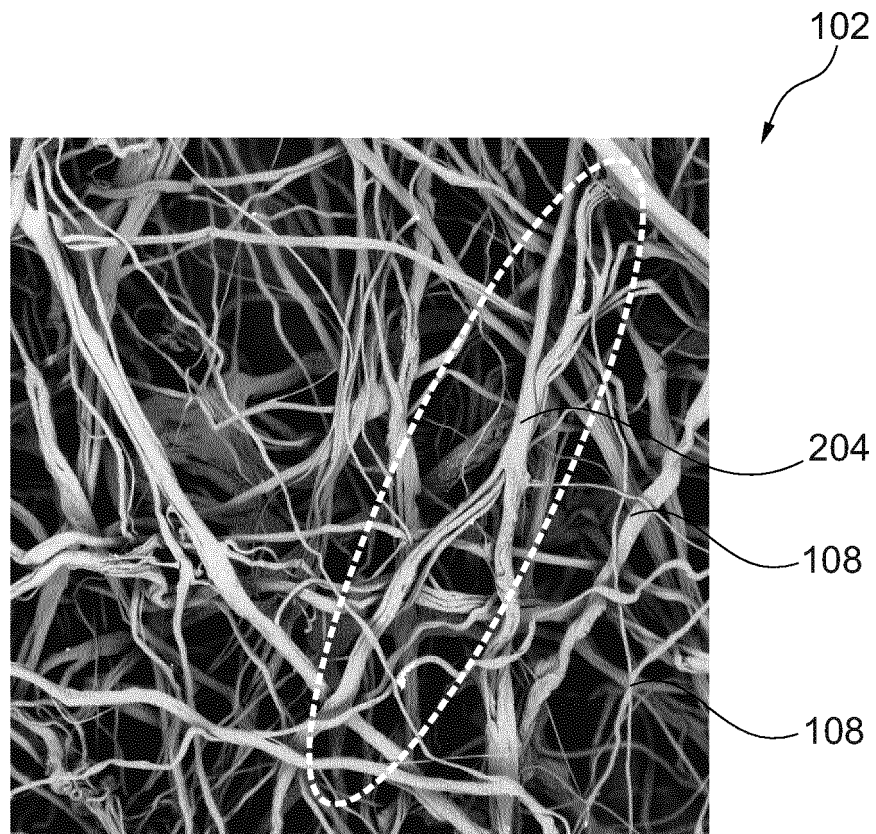


Fig. 4

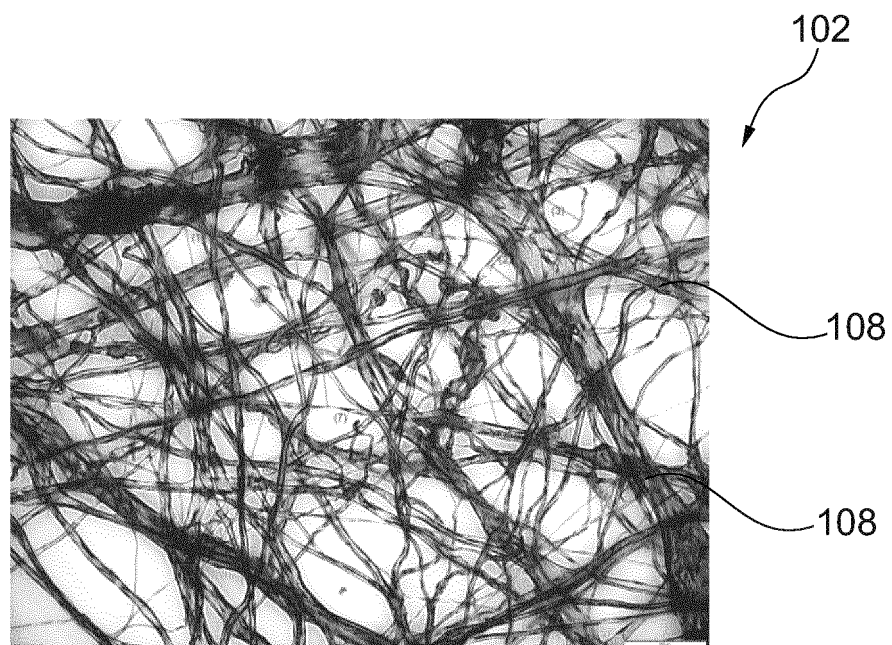


Fig. 5

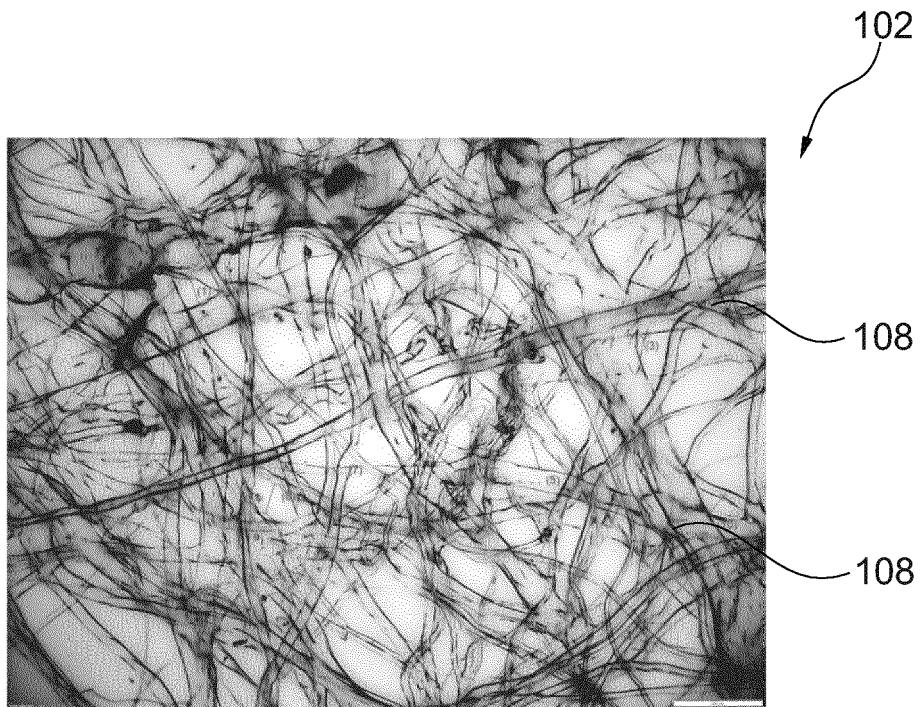


Fig. 6

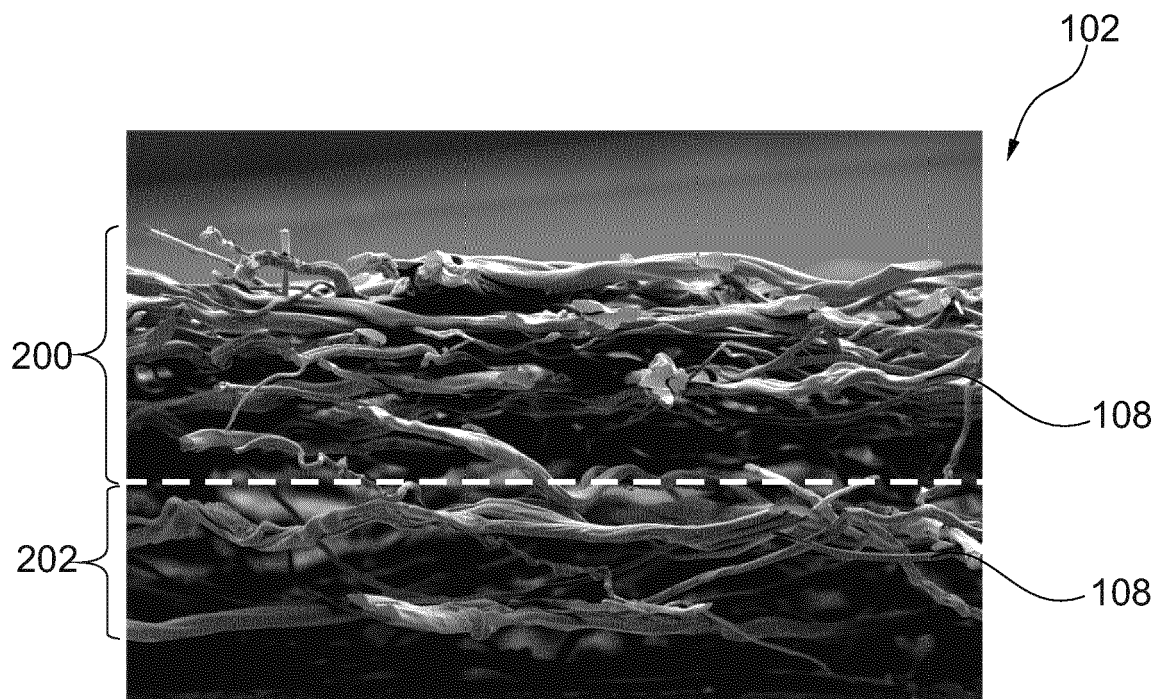


Fig. 7

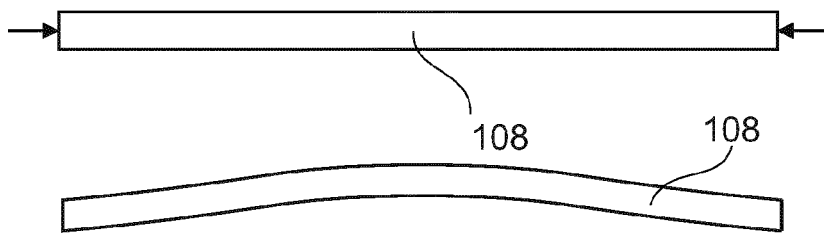


Fig. 8

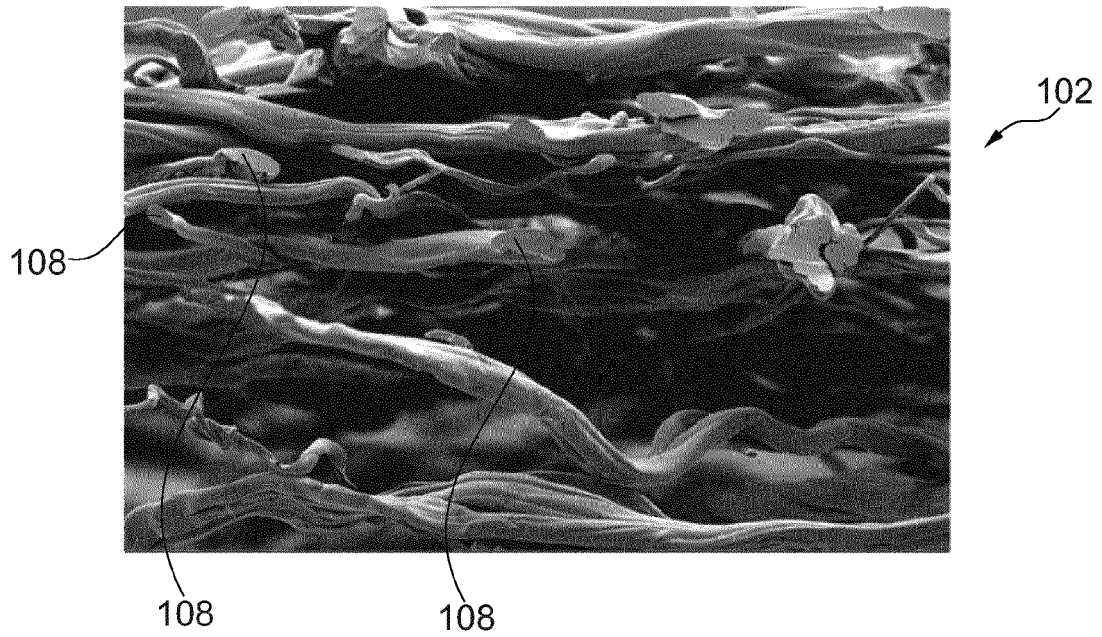


Fig. 9



Fig. 10

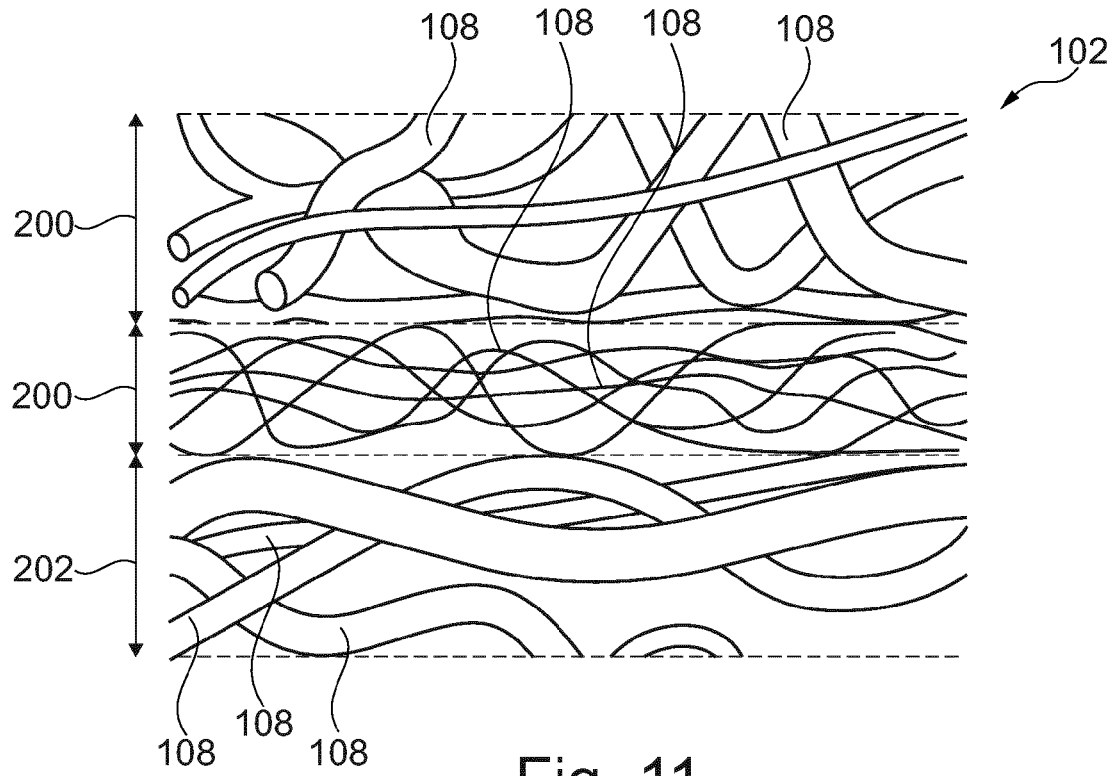


Fig. 11

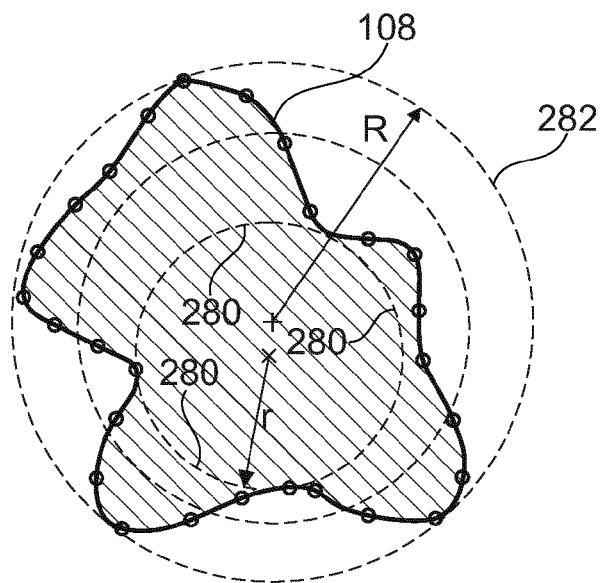


Fig. 12

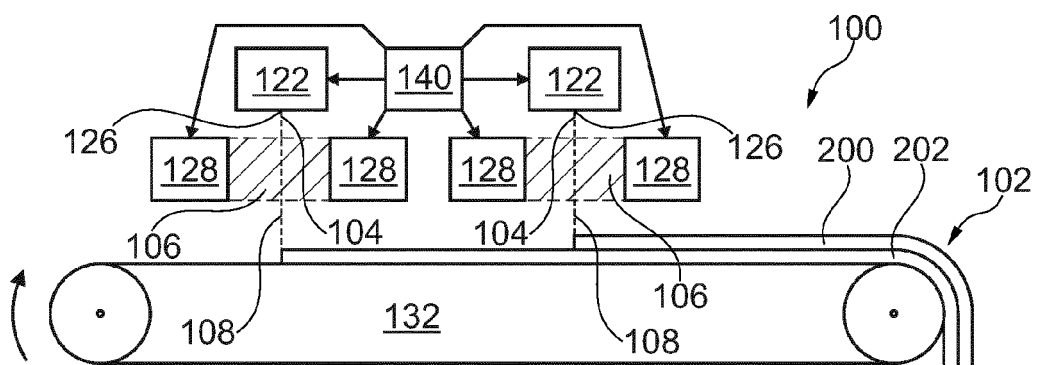


Fig. 13

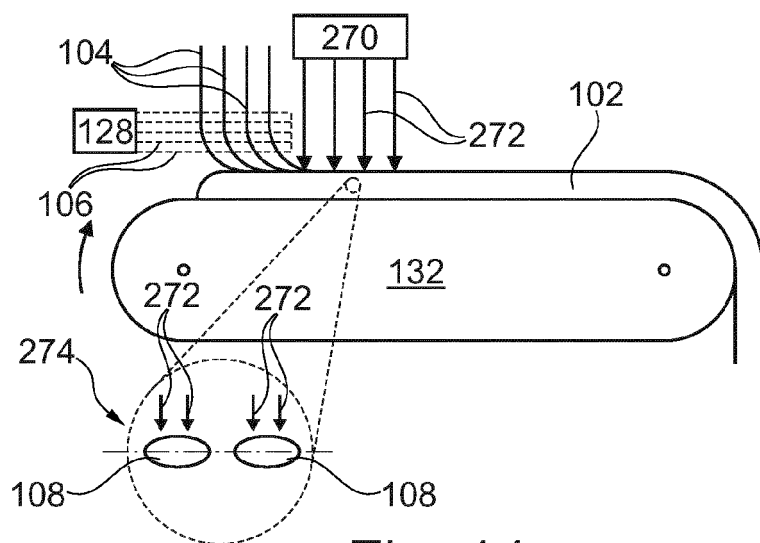


Fig. 14

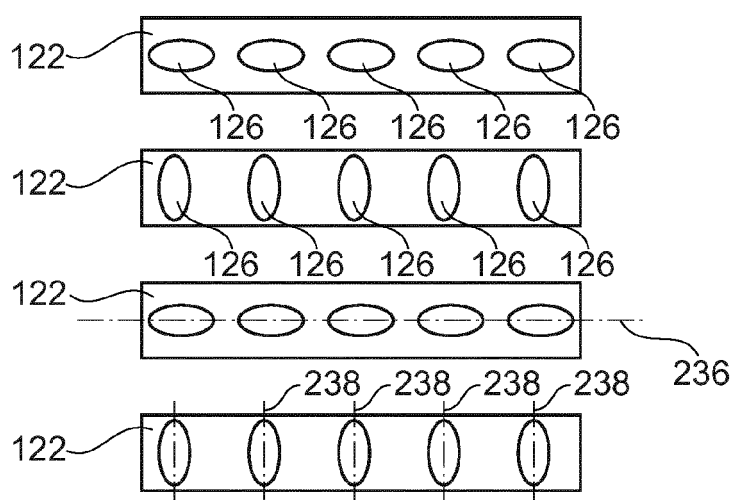


Fig. 15

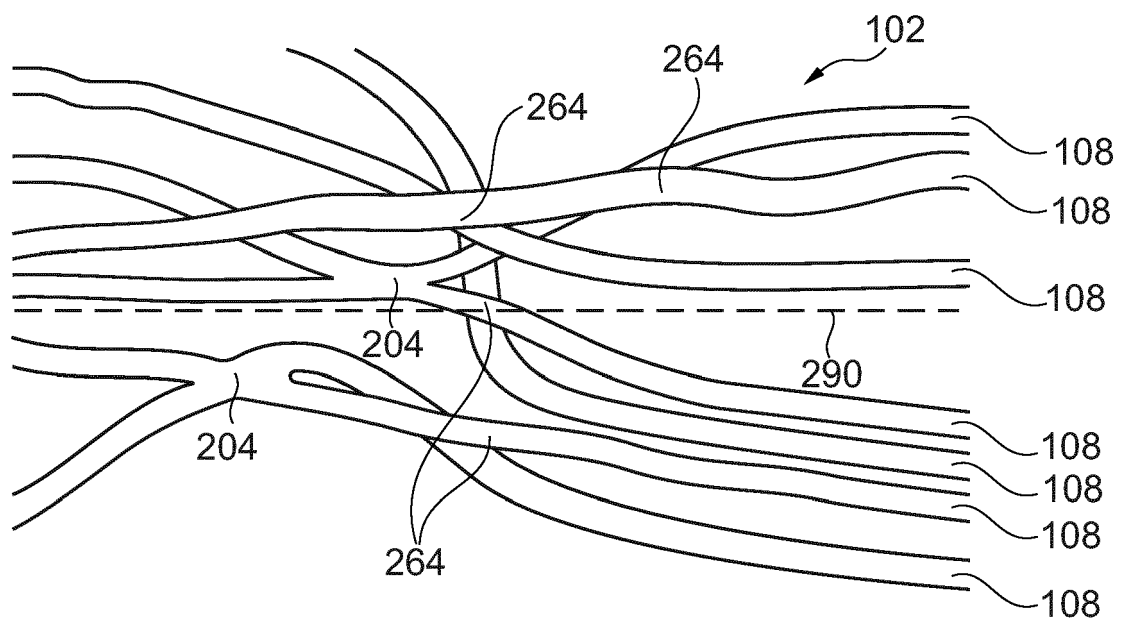


Fig. 16



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