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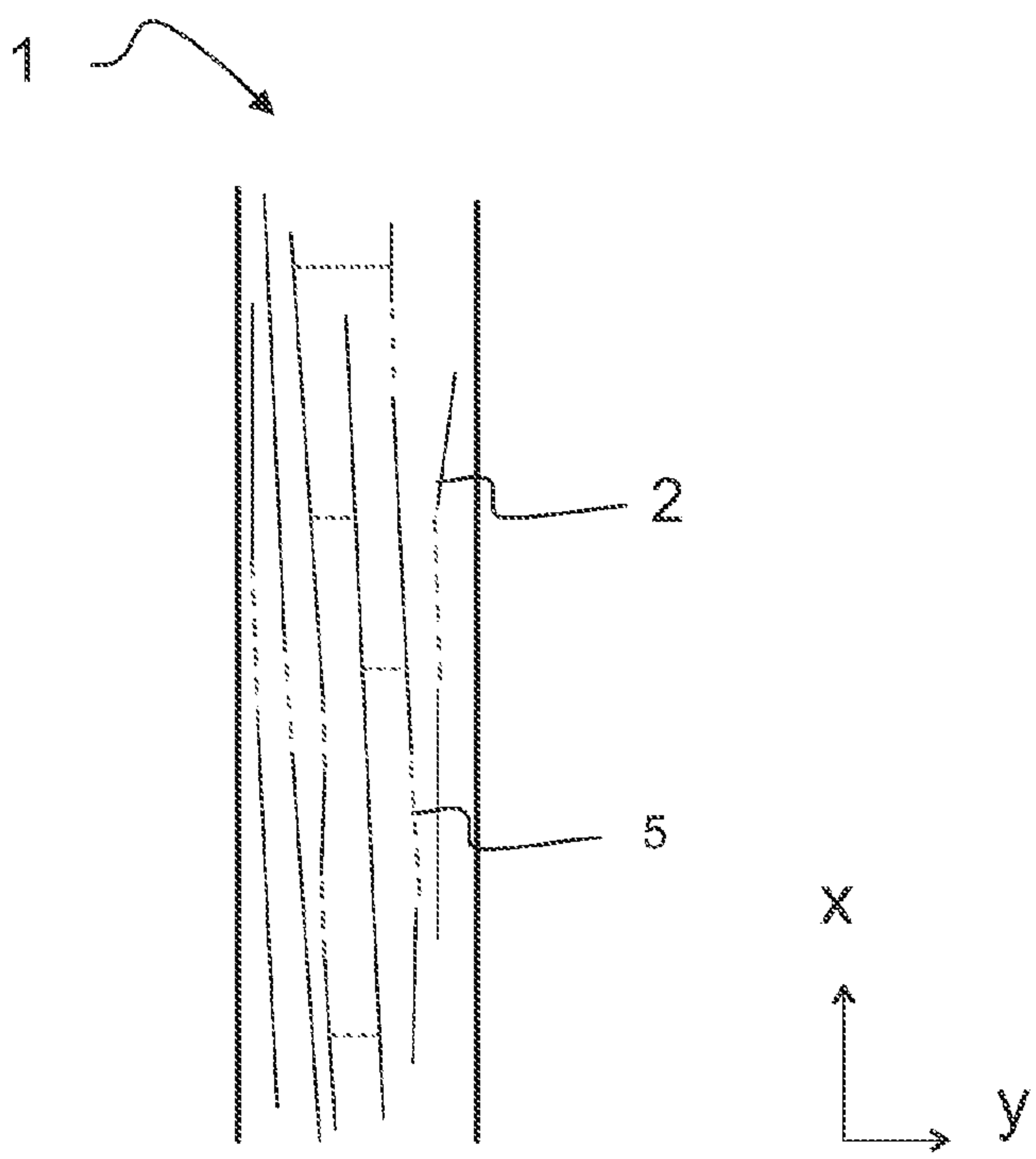

Fig. 7

(57) Abrégé/Abstract:
The application relates to a fibrous monofilament comprising wood pulp fibers. A fibrous monofilament comprises at least 30 wt.% of wood based natural cellulose fibers.

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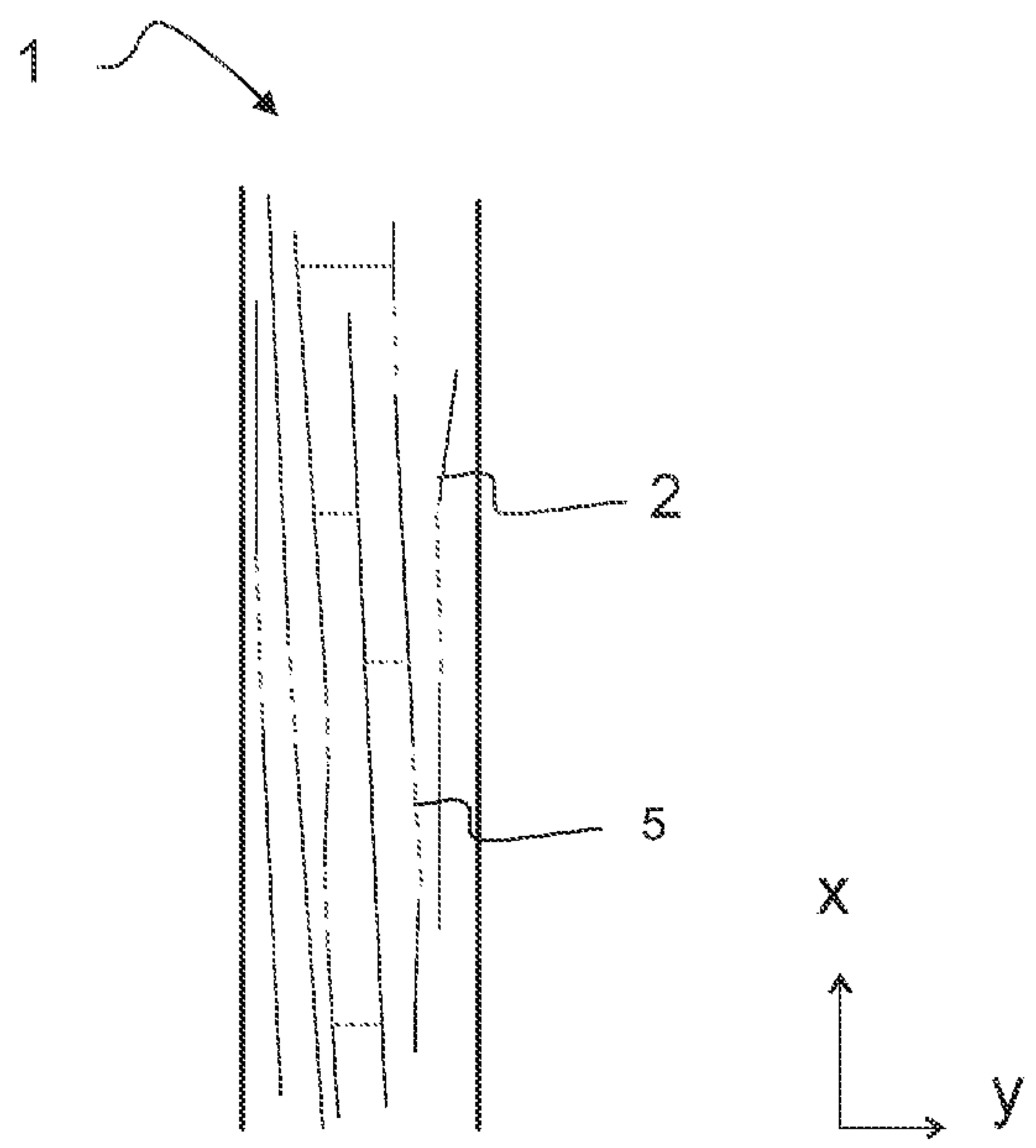

Fig. 7

(57) Abstract: The application relates to a fibrous monofilament comprising wood pulp fibers. A fibrous monofilament comprises at least 30 wt.% of wood based natural cellulose fibers.

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A fibrous monofilament

Technical field

The application concerns a fibrous monofilament comprising wood pulp fibers.

Background

In the textile industry there are several substantially different types of yarns:

Most common are yarns which are fine cords comprising twisted fibers of definite length like cotton, wool or other natural fibers or like synthetic staple fibers made of polyester, nylon or other synthetic polymers.

Also common are filament yarns which consist of bundles of endless filaments. Typical examples are containing natural filaments like silk or manmade filaments like polyester, nylon, viscose or lyocell.

Still another type of yarn is paper yarn which is manufactured from paper sheets. Paper is cut into long, narrow ribbon-like strips which are twisted on a special spinning wheel. Paper yarns are reeled to big reels and post-processed in accordance to desired end properties (hydrophobicity, color, friction etc.) of the yarn. Finally the yarns are wound to smaller customer bobbins. This means that on a microscopic scale paper yarn has the same structure as paper, i.e. it can be untwisted to thin strips of paper. Achieved properties of paper yarn may limit its use and applications. For example the layered or folded structure gives raise to wetting through capillary forces between the layers. The folded structure is porous i.e. the structure comprises interstices between the paper layers, which increases the stiffness and thickness of the paper yarn.

Summary

It is an aim of the application to provide fibrous monofilaments comprising properties suitable for multiple uses. Properties, like strength and thickness, may effect utilization possibilities of the fibrous monofilament.

Aspects of the invention comprises a fibrous monofilament comprising wood pulp fibers. In addition or alternatively other natural cellulose fibers and blends thereof with synthetic or man-made cellulosic fibers may be used.

According to an aspect of the invention a fibrous monofilament comprises at least 30 wt.% of wood based natural cellulose fibers. The wood based natural cellulose fibers are non-regenerated. The fibrous monofilament may comprise between 30 and 99 wt.%, or between 50 and 99 wt.%, or between 70 and 99 wt.% of the wood based natural cellulose fibers.

Wood based natural cellulose fibers may be mechanically and chemically interlinked to each other. The chemical interlinking may be provided by hydrogen bonds between the wood based natural cellulose fibers.

A fibrous monofilament may further comprise man-made cellulosic fibers. The man-made cellulosic fibers may have a length between 1 and 10 mm, preferably between 2 and 10 mm, more preferably between 4 and 6 mm; and/or yarn count between 0.7 and 7 dtex, preferably between 0.9 and 1.7 dtex.

The fibrous monofilament may further comprise recycled textile waste fibers. The fibrous monofilament may further comprise additives. The fibrous monofilament may comprise density between 800 and 1700 kg/m^3. The fibrous monofilament may comprise diameter of 20-400 µm. The fibrous monofilament may comprise linear mass density of 5-100 grams per 1000 meters, being 5-100 tex; or preferably linear mass density of 5-50 tex. The fibrous monofilament may comprise tenacity of 5 - 25 cN/tex, when measured according to ASTM D5035.

Drawings

In the following aspects of the invention are described in more detail with the accompanying figures, in which

Figure 1 illustrates yarn breaking force vs. yarn stretch for 20 tex fiber yarn according to an embodiment,

Figure 2a illustrates force vs. position change during dynamic tensile testing experiment according to an embodiment,

Figure 2b illustrates force vs. yarn stretch during dynamic tensile testing experiment according to an embodiment,

Figure 3 shows a transmission microscopic view of a fibrous monofilament (scale bar 500 μm),

Figure 4 shows a microscopic view of a failure location of 20 tex fibrous monofilament after yarn failure during tensile test (scale bar 500 μm),

Figure 5 shows examples of partially untwisted paper yarns (scale bar 5000 μm),

Figure 6 shows a transmission microscopic view of untwisted paper yarn (scale bar 100 μm),

Figure 7 illustrates a longitudinal cross section of fibrous monofilament,

Figure 8 shows a cross section of 20 tex fibrous monofilament according to an embodiment,

Figure 9 shows an example of stress-strain curves of wood fibers collected from different locations (year ring) of a loblolly Pine.

Description of embodiments

In this description and claims, the percentage values relating to an amount of raw materials are percentages by weight (wt.%) unless otherwise indicated. Word “comprising” may be used as an open term, but it also comprises the closed term “consisting of”. The following reference numbers and denotations are used:

1 fibrous monofilament,

2 cellulosic fiber,
3 surface of the fibrous monofilament,
4 end of the cellulosic fiber,
5 hydrogen bond,
x longitudinal axis.

Yarn count, tex refers to linear mass density i.e. an amount of mass per unit length (1 tex = 1 g/1000 m; and 1 decitex =1 dtex = 1 g/ 10000 m).

The term “fibrous monofilament” (for the purposes of the present invention also simply referred to as “filament”) refers to a continuous length of individual fibers grouped. The fibers may be interlocked together in order to form a permanent monofilament structure. The monofilament cannot be opened or disassembled. Fibers grouped together cannot be separated into substructures, such as fiber ribbons or strips via e.g. mechanical cutting, grinding or chemical separating means. Disintegration of fibrous monofilament yields only individual fibers. The fibrous monofilament comprises continuous length of several meters or kilometers.

Natural fibers refer to fibers originating from a plant based raw material source, such as wood. Natural wood based fibers are composed of fibrils of cellulose in a matrix of hemicellulose and lignin. Cellulose is a linear polysaccharide polymer with several glucose monosaccharide units. Natural cellulose fibers may be separated from the wood raw material in chemical or mechanical pulping process and the pulp comprises cellulosic fibrous material.

Cellulosic fibers refer to organic fibers originating from cellulose, preferably from wood based cellulose, such as wood pulp. Cellulose is an organic compound comprising linear chains of D-glucose units linked through *β*-(1,4)glycosidic bonds. Cellulosic fibers comprise plant based fibers, such as wood based fibers. A paper pulp is an example of a mix of cellulosic fibers. Cellulosic fibers in native form refer to natural cellulose fibers. Natural cellulose fibers have not undergone chemical or physical modification of the cellulose polymer structure.

According to an aspect of the invention and with reference to Figures 3 and 4 a fibrous monofilament 1 comprises fibers 2, also referred to as fibrous elements, which are interlocked together such that the fibers are part of permanent fibrous monofilament. At least part of the fibers are cellulosic fibers originating from plant based pulp. In addition at least part of the fibers may be man-made cellulosic fibers (for example lyocell, viscose or modal). Referring to Fig. 7, the cellulosic fibers 2 of the monofilament structure 1 are interlocked to each other via hydrogen bonds 5. These hydrogen bonds can be broken, for example, by using water or another aqueous solution so as to return the fibrous monofilament structure into separate primary cellulosic fibers.

According to an aspect of the invention, a fibrous monofilament is made of an aqueous suspension. Aqueous suspension comprises water, cellulosic fibers and at least one rheology modifier. Aqueous suspension may comprise wood based pulp fibers or other short natural cellulose fibers like cotton or flax or other short man made cellulose fibers i.e. regenerated cellulose fibers like viscose, cupro or lyocell. During manufacturing the aqueous suspension is directed through a small nozzle where fibers align (orient) well with the flow (see later description about orientation). The nozzle feeds the aqueous suspension to a twisting and dewatering section which is followed by drying in order to obtain fibrous monofilament. The fibrous monofilament is produced via a single step process. This avoids any need of additional steps, like manufacturing or processing of paper. Thus manufactured fibrous monofilament is continuous but it may be post processed into shorter lengths. Thickness of the fibrous monofilament may be effected at least in part by adapting manufacturing speed, aqueous suspension concentration and nozzle geometry.

<u>Fibers</u>

Cellulosic fibers are natural fibers, which originate from a plant based raw material source. Plant based raw materials may originate from cellulose pulp, refined pulp, chemical pulp, thermomechanical pulp, mechanical pulp or waste paper pulp. Cellulosic fibers may be isolated from any cellulose containing material using bio-, chemical-, mechanical-, thermo-mechanical- or chemi-thermo-mechanical pulping process.

Cellulosic fibers may originate from nanocellulose comprising nano-structured cellulose and nanosized fibers. There are several widely used synonyms for nanocellulose. For example: nanofibrillated cellulose, microfibrillar cellulose, nanofibrillar cellulose, cellulose nanofiber, nano-scale fibrillated cellulose, microfibrillated cellulose (MFC), or cellulose microfibrils. Nanocellulose fibers comprise a high aspect ratio, being the length to width ratio. Nanocellulose fibers may comprise width or lateral dimensions of less than 200 nanometers, preferably between 2-20 nanometers, especially preferred between 5-12 nanometers. Nanocellulosic fibers may comprise length or longitudinal dimension from one to several micrometers, for example. Nanocellulosic fibers may be isolated from any cellulose-containing material, for example wood pulp. The dimensions of fibers or fiber bundles are dependent on raw material and isolation method. The nanocellulosic fibers may be isolated from wood based fibers through high pressure, high temperature and high velocity impact homogenization. The homogenization process is used to delaminate or disintegrate the cell walls of the fibers and to liberate their sub-structural fibrils and micro fibrils. Enzymatic and/or mechanical pre-treatments of wood fibers may also be used. Nanocellulosic fibers may be in native form, which have not undergone any chemical modification. Alternatively nanocellulosic fibers may be chemically pre-modified, for example N-oxyl mediated oxidation.

Cellulosic fibers may comprise natural fibers originated from a plant. Plant based fibers may comprise virgin or recycled plant material or combinations of such. Plant based fibers may originate from wood or non-wood material. Plants may comprise wood, like softwood, hardwood or any combination of such. Softwood may comprise spruce, pine, fir, larch, douglas-fir, hemlock. Hardwood may comprise birch, aspen, poplar, alder, eucalyptus, acacia. Alternatively or in addition cellulosic fibers may originate from other plants (non-wood), such as cotton, hemp, flax, sisal, jute, kenaf, bamboo, peat or coconut. Non-wood cellulosic fibers can also be from agricultural residues, grasses or other plant substances such as straw, leaves, bark, seeds, hulls, flowers, vegetables or fruits.

The fibrous monofilament comprises at least 30 wt.%, preferably at least 50 wt.% of natural cellulose fibers. In an example, between 30 and 99 wt.% for preferably between 50 and 99 wt.%, and most preferably between 70 and 99 wt.% of natural cellulose fibers. As presented above, natural cellulose fibers are non-regenerated. Thus, natural cellulose fibers have not undergone chemical regeneration or physical modification of the cellulose polymer structure. Natural cellulose fibers are non-regenerated and consists mainly of crystalline structure of cellulose I. Cellulose I may have structures I_α and I_β. Man-made cellulosic fibers are regenerated and crystalline structure is mainly other than cellulose I. Conversion of cellulose I to cellulose II (or other forms, like cellulose III or cellulose IV) is irreversible. Thus, these forms are stable and cannot be converted back to cellulose I.

Natural cellulosic fiber chemical composition, fiber size and aspect ratio and orientation in the filament effect the mechanical and physical properties of the fibrous monofilament. For example, mechanical and physical properties of cellulosic fibers are influenced by their chemical composition, mainly cellulose, hemicellulose and lignin. As an example, higher tensile strength and higher ductility can be obtained with fibers containing crystalline cellulose. The rigidity of cellulose fibers increases and their flexibility decreases with increasing the ratio of crystalline to amorphous regions. Fiber tensile strength increases and stretch decreases with decreasing primary fibril angle.

In the monofilament structure the aspect ratio of the cellulosic fibers (ratio of the length of the fiber to diameter of the fiber) may be from 10 to 300, preferably from 30 to 100. High aspect ratio of the fibers has effect on the flexibility of the monofilament.

According to an aspect of the invention, the fibrous monofilament comprises cellulosic fibers in native form i.e. natural cellulose fibers. Natural cellulose I may have effect on the degree of structural order of cellulose, or of fibers of cellulose. Additionally, natural cellulose I may have effect on the stiffness and density of fibrous filament.

In addition, fibrous monofilament may comprise other fibers, such as natural plant based fibers, modified or regenerated natural fibers or synthetic fibers. Fibers of the fibrous filament may comprise man-made fibers, like viscose, modal, acetate, rayon, or synthetic fibers, like polyester or polyamide and recycled textile waste fibers.

Man-made cellulosic fibers may be added to the natural cellulosic fiber mixture. Man-made cellulosic fibers may comprise a narrow distribution in fiber length and diameter, since they are gained out of industrial processes instead of isolated from nature. Natural fibers being isolated from nature may have rather broad distribution in fiber length and diameter compared to that of man-made cellulosic fibers. Thin and long man-made cellulosic fibers may improve tensile strength and stretch of the fibrous monofilament. As an example the fibrous monofilament may be wholly made of man-made cellulosic fibers further improving its properties.

Monofilament may comprise man-made cellulose fibers originating from man-made cellulose process. Man-made cellulose fibers are regenerated cellulose fibers. Monofilament may comprise between 1 and 50 wt.% of man-made cellulosic fibers, preferably between 1 and 30 wt.% of man-made cellulosic fibers, more preferably between 1 and 20 wt.% of man-made cellulosic fibers. One such process is so-called Lyocell process, wherein fibers and other molded articles may be obtained from a solution of cellulose in an aqueous, organic solvent. More specifically, an aqueous solution of NMMO (N-methyl-morpholine-N-oxide) has been the solvent used on a commercial scale for more than twenty years. Typically, spinning dopes containing approximately 13% by weight of cellulose are used in the related production facilities. Pulp is a preferred cellulosic raw material, but, depending on the circumstances, other cellulosic raw materials such as cotton linters can also be employed. Monofilament may comprise man-made Lyocell fibers.

The fibrous monofilament may comprise recycled textile waste fibers. The fibrous monofilament may contain from 1 to 50 wt.% of recycled textile waste fibers, preferably between 30 to 50 wt.% of recycled textile waste fibers, more preferably between 40 and 50 wt.% of recycled textile waste fibers. Recycled textile waste fibers may comprise thermoplastic or thermobonding fibers, like polypropylene, polyamide, polyester, polypropylene/polyester and bi-component short cut fibers. Bi-component refers to different material and/or properties between internal structure and external surface of short cut fibers. For example, external surface layer(s) of a bi-component may comprise thermobonding material. The recycled textile waste fibers may be distributed evenly in the monofilament structure and thermobonded in an after-treatment step. Thermobonding may lead to desired properties of the fibrous monofilament, for example increased tenacity and better washability.

The recycled textile waste fibers may be isolated from either pre- or post-consumer waste textiles comprising either one fiber type or a mixture of different fiber types. Pre-consumer (or post-industrial) waste is accumulated during a textile manufacturing process, where significant amounts of waste material are generated, for example spinning waste or cuttings from confectioning. Post-consumer waste is generated once the fabric is discarded by the user. Existing pathways for textile recycling, covering only minor amounts of textile waste, include for example donation of post-consumer textiles to charity organizations or the production of wipes or shoddy fibers for insulation materials from post-consumer waste cuttings. WO2015/077807 and US2016/237619 – the whole content of both documents is incorporated herein by reference - describe a way to recycle pre-consumer textile waste fibers in the production of molded bodies from regenerated cellulose. Such recycled pre-consumer textile waste fibers being prepared according to a process for pretreating reclaimed cotton fibres, wherein the pretreatment of the reclaimed cotton fibres includes a metal removing stage and an oxidative bleaching stage.

Therefore in a particular embodiment of the present invention the fibrous monofilament contains from 1 to 50 wt.% of recycled pre-consumer textile waste fibers, preferably between 30 to 50 wt.% of recycled pre-consumer textile waste fibers, more preferably between 40 and 50 wt.% of recycled pre-consumer textile waste fibers, such recycled pre-consumer textile waste fibers being prepared according to a process for pretreating reclaimed cotton fibers, wherein the pretreatment of the reclaimed cotton fibers includes a metal removing stage and an oxidative bleaching stage.

According to WO2015/077807 the cotton fibers may be reclaimed from pre-consumer cotton waste or post-consumer cotton waste. They may include pulp prepared from cotton rags. Moreover the reclaimed cotton fibers may be mechanically shredded, milled, or opened prior to their use.

In particular according to WO2015/077807 the metal removing stage can be an acidic washing treatment and/or a treatment with a complexing agent and the reclaimed cotton fibers may be treated by an aqueous solution of a complexing agent. In particular both treatments may be combined in one step by adding a complexing agent to the acidic washing treatment. Moreover, according to WO2015/077807 the oxidative bleaching stage may comprise an oxygen bleaching treatment and/or a peroxide bleaching treatment. The oxidative bleaching stage also may comprise an ozone bleaching treatment. The oxidative bleaching stage may comprise a sequence of oxidative bleaching treatments according to the above.

Clothing textile waste material may compose 43% cotton, 36% oil-based fibers, like polyester, acrylic, or alike, and 21% natural-based fibers, like viscose, silk, or alike, covering 51% of the market share published by Wrap in 2011, “Textiles flow and market development opportunities in the UK”. Household textiles show a similar composition of 30% cotton and 70% other fibers, for example oil-based and natural fibers. This fiber composition is suitable as raw material for the fibrous monofilament production. A fibrous monofilament may comprise at least 30 wt.% of recycled textile cellulose-based waste fibers, more preferably 40-50 wt.% of recycled textile cellulose-based waste fibers. In addition the fibrous monofilament may comprise polyester, acrylic or polypropylene fibers or mixtures thererof, which may enable thermobonding and effecting on desired properties of the fibrous monofilament, like increased tenacity or better washability.

In addition, the fibrous monofilament comprises between 0.01 and 30 wt.%, preferably from 0.05 to 20 wt.% or from 0.1 to 15 wt.% of non-fiber additives like binder(s), rheology modifier, etc.

Orientation

Fig. 4 illustrates a microscopic view of a failure location of 20 tex fibrous monofilament after yarn failure during tensile test (scale bar 500 µm). In Fig. 4, fibrous monofilament 1 comprises cellulosic fibers 2. Individual cellulosic fibers of the fibrous monofilament are mainly oriented along length (i.e. longitudinal axis x) of the fibrous filament. The fibers are oriented (aligned) in such way that the longitudinal dimension of a single fiber essentially corresponds to the longitudinal dimension of the fibrous monofilament. Referring to Fig. 6, the fibrous elements of the paper yarn manufactured from thin paper strips have random orientation along the machine direction MD and corresponding to the longitudinal direction x of the yarn.

Initial fiber orientation of the fibrous monofilament may be achieved during the manufacturing phase in a nozzle. A nozzle having the outlet diameter of a nozzle smaller than or equal to the maximum length weighed fiber length of the fibers, the fibers orientate substantially in the longitudinal direction x of the suspension exiting the nozzle. Fiber orientation may be further controlled in the twisting and dewatering unit. Fiber orientation along the longitudinal direction of the fibrous filament provides strength to the filament.

Additives

In addition to fibrous elements the fibrous monofilament may comprise additive(s). For example, polysaccharide additive(s) such as binders, cation active reagent(s), crosslinking agent(s), dispersion agent(s), pigment(s), and/or other modifier(s). Total amount of additive(s) in the fibrous monofilament may be between 0.01 and 30 wt.%, between 0.05 and 20 wt.%, preferably between 0.1 and 15 wt.%.

An additive may comprise polysaccharide additives, such as alginate, alginic acid, pectin, carrageenan or nanocellulose, or a combination of such. During manufacturing of the fibrous monofilament, the polysaccharide additive, such as an alginate, may have effect on forming hydrogel. In the fibrous monofilament the polysaccharide additive may be arranged to react with at least one reagent, for example a cation active agent. The reagent may comprise salt, like calcium chloride or magnesium sulfite. The chemical reaction between the polysaccharide additive and the reagent provides rapid increase on viscosity and yield stress of the aqueous suspension. Increase of viscosity of the aqueous suspension has effect of increasing strength of the fibrous monofilament. In addition, the polysaccharide additives, such as alginate, may act as a binder(s) in the fibrous monofilament structure. Alginate may cause crosslinking, which may have effect on binding of fibers of the fibrous monofilament. Alginate matrix may crosslink around the fibers and enclose the fibers.

An additive may comprise a crosslinking agent and reagent pair. A crosslinking agent may be arranged to react with the reagent at the nozzle exit. Crosslinking reaction between the crosslinking agent and – reagent pair creates an aqueous hydrogel and thereby influences the initial strength of the fibrous suspension. A fibrous monofilament may comprise 0-25 wt.% crosslinking agent. The crosslinking agent together with crosslinking reagent creates a hydrogel, which enables the fibrous suspension to maintain its properties during following manufacturing phases. For example twisting and fast dewatering may pose high stresses to the fibrous suspension. Hydrogel additionally effects the tensile strength of fibrous filament.

An additive may comprise a dispersion agent. A dispersion agent may comprise anionic long chained polymer, nanocellulose, carboxymethyl cellulose (CMC), starch, anionic polyacrylamides (APAM) or a combination of such. A fibrous monofilament may comprise 0-20 wt.% of dispersion agent. The dispersion agent may have effect on shear strength of the fibrous monofilament.

According to an embodiment, the fibrous monofilament includes between 30 and 99 wt.% of natural cellulose fibers, and further between 0.1 and 15 wt.% of binder, such as alginate.

According to an embodiment, the fibrous monofilament includes between 50 and 99 wt.%, or between 70 and 99 wt.% of natural cellulose fibers, and further between 0.1 and 15 wt.% of binder, such as alginate.

According to another embodiment, the fibrous monofilament includes between 50 and 99 wt.%, or between 70 and 99 wt.%, or preferably between

90 and 99 wt.% of natural cellulose fibers, and further between 0.1 and 10 wt.% of binder, such as CMC (carboxymethyl cellulose) or starch.

Binder has effect on chemically bonding the natural cellulosic fibers via hydrogen bonds, and accordingly increasing the mechanical properties of the fibrous monofilament.

Structure and properties

Individual fibers i.e. fibrous elements of the fibrous monofilament are assembled (interlocked/grouped) together and most of the fibers are oriented along the longitudinal dimension x of the fibrous monofilament.

With reference to Fig. 3, a fibrous monofilament comprises a permanent, monofilament type structure 1. The fibrous monofilament comprises an irrevocable or irreversible structure. Structure of the fibrous monofilament cannot be converted or disassembled into monolithic substructures, such as strips or ribbons, using mechanical or chemical means. Since the fibrous monofilament is made by a single-step process, there are no such substructures, intermediates or intermediate phases between the original suspension and the fibrous monofilament, which would be revocable or reversible. Disintegration of fibrous monofilament 1 only yields to individual cellulosic fibers 2. With reference to Fig. 4, a fibrous monofilament cut by drawing and individual cellulosic fibers 2 at the cut end of the filament are shown. Fig. 4 illustrates a microscopic view of a failure location of 20 tex fibrous monofilament after yarn failure during tensile test (scale bar 500 μm).

Shape of the fibrous monofilament can be controlled by manufacturing process. The fibrous monofilament may have circular cross-section. Alternatively the cross-section may be flat, such as an ellipse. Shape of the filament can be controlled during manufacturing process, such as during feeding of the aqueous suspension or during drying process of the fibrous monofilament. A cross sectional shape of the fibrous monofilament according to an example concerning 20 tex fibrous monofilament, is shown in Fig. 8.

The fibrous monofilament structure, despite the shape of the filament, is characterized by having uniform and closed surface texture 3, as shown in

Fig. 3. The fibrous monofilament cannot be untwisted or otherwise mechanically opened into any substructures, such as fiber ribbons or strips. The fibrous elements of the fibrous monofilament are both mechanically and chemically (e.g. via hydrogen bonds) interlinked with each other. Fig. 5 shows examples of untwisted, or partially untwisted, paper yarns (scale bar 5000 μm). In Fig. 5, the paper yarn manufactured from thin strips of paper has a folded structure, which can be untwisted. The folded like structure results into a highly porous surface of the paper yarn.

Further, the longitudinal dimension of the fibrous elements 2 of the monofilament are aligned essentially parallel to the longitudinal axis x of the filament also at the outer surface thus forming a tight and closed surface structure 3. In other words, the surface of the intact monofilament does not include cut ends of the cellulosic fibers 4 protruding from the outer peripheral surface of the monofilament. Tight surface structure has effect on increasing surface density and reducing the capillary attraction of the fibrous monofilament. Tight surface structure may also have effect on preventing access of small particles to the interior of the monofilament. With reference to Fig. 6 showing microscopic view of un-twisted paper yarn random fiber orientation in longitudinal axis MD is observed. Also cut ends of the cellulosic fibers 4 protruding from the outer peripheral surface can be observed forming a loose and an open surface structure. Such surface structure may result in enhanced capillary forces and further increase accumulation of small particles of foreign matter.

The fibrous monofilament according to at least some/all embodiments may have a density between 800 and 1700 kg/m^3. Fibrous monofilament according to at least some/all embodiments may have a density between 1000 and 1500 kg/m^3. As an example, the fibrous monofilament comprising between 70 and 90 wt.% of natural cellulosic fibers may exhibit a density of 1300 kg/m^3.

The fibers of the fibrous monofilament may be essentially arranged in longitudinal direction of the fibrous monofilament. In addition or alternatively the fibers may have irregular arrangement. For example, the fibers may be twisting around the longitudinal axis. In all cases, the structure of the fibrous monofilament is irrevocable (/irreversible). Thus it is not possible to open/disassemble the monofilament structure or untwist the fibers of the fibrous monofilament. The fibrous monofilament may comprise diameters of 20-400 µm. The fibrous monofilament may comprise linear mass density of preferably 5-100 tex, i.e. 5-100 grams per 1000 meters and especially preferably the fibrous monofilament may comprise linear mass density of 5-50 tex.

Figure 1 shows yarn breaking force in function of yarn stretch for 20 tex fiber yarn according to an embodiment. Fibrous monofilament breaking force varies from 0.06 to 0.23 kgF (0.6 - 2.3 N) in the embodiment of Figure 1. Fibrous monofilament comprising linear mass densities of 5 - 20 tex, comprises tenacities from 11 to 15 cN/tex. Fibrous monofilament comprising linear mass density of 20 - 50 tex, comprises tenacities from 11 to 5 cN/tex. Breaking force is determined according to standard ASTM D5035.

Elongation at break of the fibrous monofilament may be between 2 and 6%. Fibers of the monofilament have effect on the elongation at break. For example, thermobonding fibers have effect of increasing the elongation at break values of the fibrous monofilament. Fibrous monofilament structure and its mechanical and haptic properties may be altered gradually by altering pulp concentration and processing parameters of the aqueous suspension during manufacturing of the fibrous monofilament.

Fiber based raw materials may have effect on fibrous monofilament properties. The fibrous monofilament may comprise 0-99 wt.% of cellulosic fibers originating from plant based raw material source. The fibrous monofilament may comprise at least 30% or at least 50% of cellulosic fibers originating from wood pulp. The fibrous monofilament may optionally comprise virgin or recycled fibers originating from synthetic materials, such as glass fibers, polymeric fibers, metal fibers, and/or from natural fibers, such as wool fibers or silk fibers. The fibrous filament may optionally include cotton, flax, hemp, man-made cellulosic fibers and/or pulp made from textile waste.

Combination of fibers having average fiber length between “2 and 3 mm” (describing short fibers) and fibers having average fiber length between “5 and 10 mm” (describing long fibers) may be used to effect positively to strength and stretch of the fibrous filament.

Combination of fibers having average fiber length between “1 and 2 mm” (describing short fibers) and fibers having average fiber length between “2 and 4 mm” (describing long fibers) may be used to effect positively to filament evenness.

Fig. 9 shows an example of stress-strain curves of wood fibers collected from different locations (year ring) of a loblolly Pine. Origin and different fiber sources may alter the fiber properties and also properties of the fibrous monofilament. Fibers may comprise, for example, different: aspect ratios, diameter, bending stiffnesses, breaking strengths. For example fibers that grow in spring time (describing earlywood) and fibres that grow in late summer (describing latewood) have different density, strength and stretch. Also young wood fibers and old wood fibers have different mechanical properties. Young pine wood fibers may comprise average stretch up to 8%, or some up to 25%, and average maximum tensile stress of 400 MPa, while an old pine wood fibers can have average stretch of 4% and maximum tensile stress of 1200 MPa, as shown in Fig. 9 (*Mechanical properties of individual southern pine fibers. Part III: Global relationships between fiber properties and fiber location within an individual tree. Groom et. Al. Wood and fiber science. 2002, 34(2), pp. 238-250)*.

Length of cellulosic fibers of the fibrous monofilament may have effect on strength properties of the fibrous monofilament. Long cellulosic fibers (e.g. of northern soft wood) enable providing thin fibrous monofilaments with good strength properties. The fibrous monofilament may comprise thickness of less than 0.1 mm. For example, pine may be utilized as a source material for long fibers and eucalyptus as a source for short fibers. Virgin fibers originating from pine may have average length weighed fiber length of 2-3 mm. Average length weighed fiber length (measured using L&W Fiber Tester) of the fibers refers to length weighed fiber length where at least 90 percent of fibers are in the range of the average length.

In an example, crosslinking agent, -reagent pair may have effects on the properties of fibrous monofilament. For example, different reagents can have differences in strength and stretch but also in other properties, thus further affecting the mechanical and physical properties of the fibrous monofilament.

In an example, refining level (fibrillation of the fiber) may have effects on the properties of fibrous monofilament. Mechanical fibrillation of the fibers increases the fiber surface area and thus creates more bonds with other fibers. This changes the mechanical properties of the fibrous monofilament.

Figure 2a illustrates measured force in function of position change during dynamic tensile test experiment. Figure 2b illustrates measured force in function of yarn stretch during dynamic tensile test experiment. In the test one fibrous monofilament has been stretched between jaws to different lengths cyclically and returned to the original length. Distance between the jaws and force are measured during the experiment. Results shows that fibrous monofilament can withstand repeated stretching. Figures 2a and 2b also show that fibrous yarn is elastic. When the stretching force decreases the filament length also decreases.

Color of the fibrous monofilament may be changed by either dyeing individual fibers of the fibrous monofilament or dyeing the fibrous monofilament itself. This can be done using dyeing methods well known to the skilled artisan e.g. from papermaking processes. With these dyeing methods the resulting filament has even color through the whole cross section. In this case yarn doesn't change the color even when mechanical stress is applied (e.g. washing, rubbing). Fibrous monofilament may be subjected to dyeing also using textile dyes. For example common cotton and cellulosic dyes may be utilized. Individual fibers in aqueous suspensions may be subjected to dyeing before manufacturing of fibrous monofilament. This may have positive effect on required amount of dye, dye penetration, wear of dyes, tones, quality and stability of tones.

Fibrous monofilament according to at least some or all aspects of the invention enable use of the fibrous monofilament in multiple applications due to variable properties of the fibrous monofilament. Properties of the fibrous monofilament may be selected according to use. The use as well as the desired properties of the fibrous monofilament may be selected according to end use of the fibrous monofilament, material made of the fibrous monofilament, material comprising the fibrous monofilament and/or use of material comprising the fibrous monofilament. Several fibrous monofilament type yarns may be twisted so as to form multifilament type fibrous structures.

Properties of fibrous monofilament may comprise desired thickness and strength depending on the utilization and use. For example, properties like softness, flexibility, sustainability, wear-sustainability, shape stability, elasticity/inelasticity and/or combinability with other materials or yarns may have effect on utilization possibilities of the fibrous monofilament.

Fibrous monofilament according to at least some aspects of the invention has an effect of a small water footprint. Use of pulp based fibers enable utilization and recycling of wood, pulp and waste pulp material.

Fibrous monofilament according to at least some embodiments provides sustainable and ecological means for clothing industry. In some applications fibrous monofilament enables to replace e.g. cotton. Large-scale cotton cultivation requires significant resources of water. Cotton cultivation is widely carried out in regions already experiencing shortage of both water and food. Cotton cultivation reduces the available farming area for food production, increases consumption of water, and worsens the food and water supply problem. The use of cotton is unsustainable and replacing fiber sources are needed. Previously presented properties and production methods of paper yarn have not enabled replacing cotton.

Fibrous monofilament according to at least some or all aspects of the invention has effect of biodegradability. Use of natural based fibers enables recycling, re-utilization and re-use of the fibrous monofilament and materials and products made of such.

The previously presented description is presented as illustrative of aspects of the invention. Parts or details may be replaced, changed, combined or omitted without departing from the scope of the present invention as defined in the claims.

Claims:

1. A fibrous monofilament of a diameter of 20-400 μm, comprising at least 30 wt.% of wood based natural cellulose fibers, wherein the wood based natural cellulose fibers are non-regenerated.

2. A fibrous monofilament according to claim 1, further comprising man-made cellulosic fibers, containing between 1 and 50 wt.% of man-made cellulosic fibers, preferably between 1 and 30 wt.% of man-made cellulosic fibers, more preferably between 1 and 20 wt.% of man-made cellulosic fibers.

3. A fibrous monofilament according to the previous claims, further comprising man-made cellulosic Lyocell fibers, containing between 1 and 50 wt.% of man-made cellulosic Lyocell fibers, preferably between 1 and 30 wt.% of man-made cellulosic Lyocell fibers, more preferably between 1 and 20 wt.% of man-made cellulosic Lyocell fibers.

4. A fibrous monofilament according to any of the previous claims, further comprising recycled textile waste fibers, containing from 1 to 50 wt.% of recycled textile waste fibers, preferably between 30 to 50 wt.% of recycled textile waste fibers, more preferably between 40 and 50 wt.% of recycled textile waste fibers.

5. A fibrous monofilament according to claim 4, wherein the recycled textile waste fibers comprise thermobonding fibers, optionally comprising at least one of polypropylene, polyamide, polyester, polypropylene/polyester and bi-component short cut fibers.

6. A fibrous monofilament according to any of the previous claims, further comprising recycled textile waste fibers from pre-consumer textile waste, containing from 1 to 50 wt.% of recycled pre-consumer textile waste fibers, preferably between 30 to 50 wt.% of recycled pre-consumer textile waste fibers, more preferably between 40 and 50 wt.% of recycled pre-consumer textile waste fibers, such recycled pre-consumer textile waste fibers being prepared according to a process

for pretreating reclaimed cotton fibers, wherein the pretreatment of the reclaimed cotton fibers includes a metal removing stage and an oxidative bleaching stage.

7. A fibrous monofilament according to any of the previous claims, wherein the man-made cellulosic fibers have a length between 1 and 10 mm, preferably between 2 and 10 mm, more preferably between 4 and 6 mm; and/or yarn count between 0.7 and 7 dtex, preferably between 0.9 and 1.7 dtex.

8. A fibrous monofilament according to any of the previous claims, wherein the fibrous monofilament comprises between 30 and 99 wt.%, or between 50 and 99 wt.%, or between 70 and 99 wt.% of the wood based natural cellulose fibers.

9. A fibrous monofilament according to any of the previous claims, wherein the wood based natural cellulose fibers are mechanically and chemically interlinked to each other, and optionally wherein the chemical interlinking is provided by hydrogen bonds between the wood based natural cellulose fibers.

10. A fibrous monofilament according to any of the previous claims, wherein the wood based natural cellulose fibers originate from chemical pulp, thermomechanical pulp, mechanical pulp or waste paper pulp.

11. A fibrous monofilament according to any of the previous claims, wherein the monofilament further comprises from 0.01 to 30 wt.% of additives, or preferably from 0.05 to 20 wt.% of additives, or more preferably from 0.1 to 15 wt.% of additives.

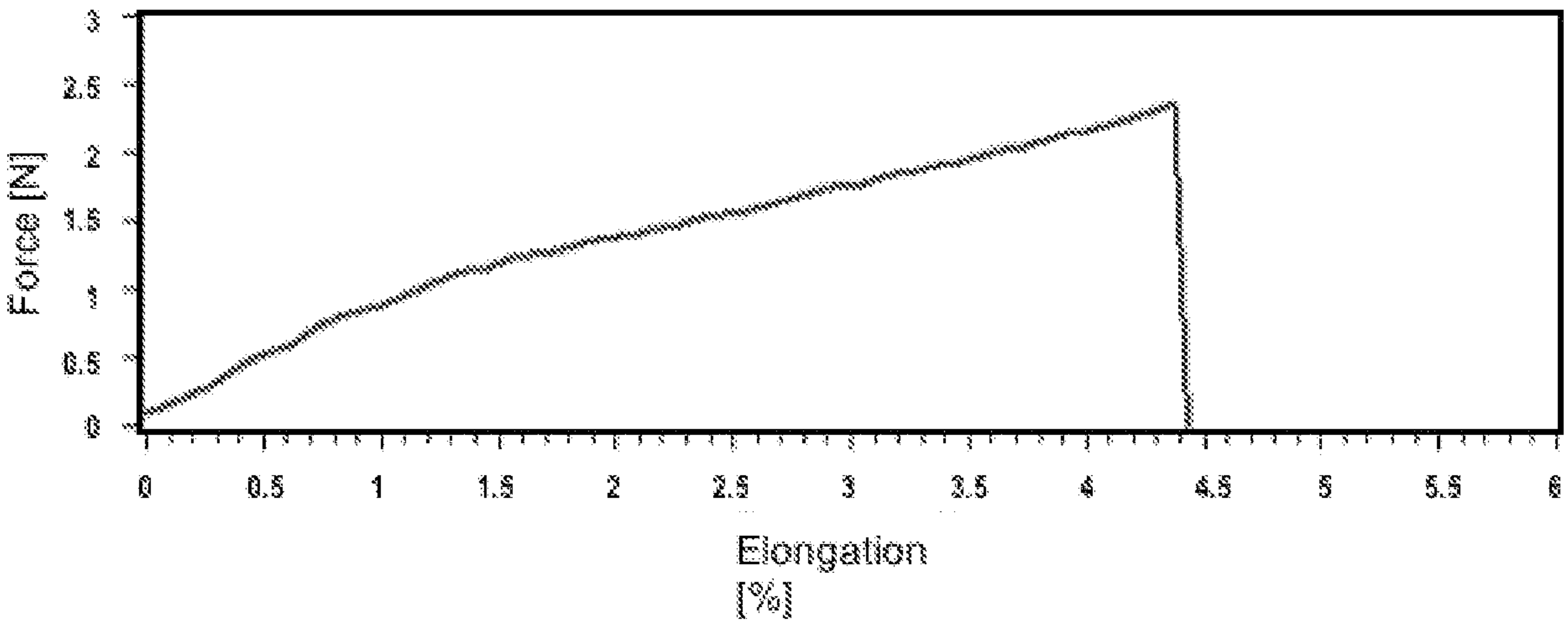
12. A fibrous monofilament according to claim 11, wherein the additives include at least one of the following: alginate, alginic acid, pectin, carrageenan, carboxymethyl cellulose, starch, polyacrylamides, nanocellulose and resins like vinyl acetate.

13. A fibrous monofilament according to claim 11 or 12, wherein the fibrous monofilament comprises additives including thermoplastic fibers, optionally at least one of the following thermoplastic fibers: polypropylene, polyamide, polyester, polypropylene/polyester and bi-component short cut fibers.

14. A fibrous monofilament according to any of the previous claims, wherein the fibrous monofilament comprises density between 800 and 1700 kg/m^3.

15. A fibrous monofilament according to any of the previous claims, comprising linear mass density of 5-100 grams per 1000 meters, being 5-100 tex; or preferably comprising linear mass density of 5-50 tex.

16. A fibrous monofilament according to any of the previous claims, comprising tenacity of 5 - 25 cN/tex, when measured according to ASTM D5035.


Force [N]
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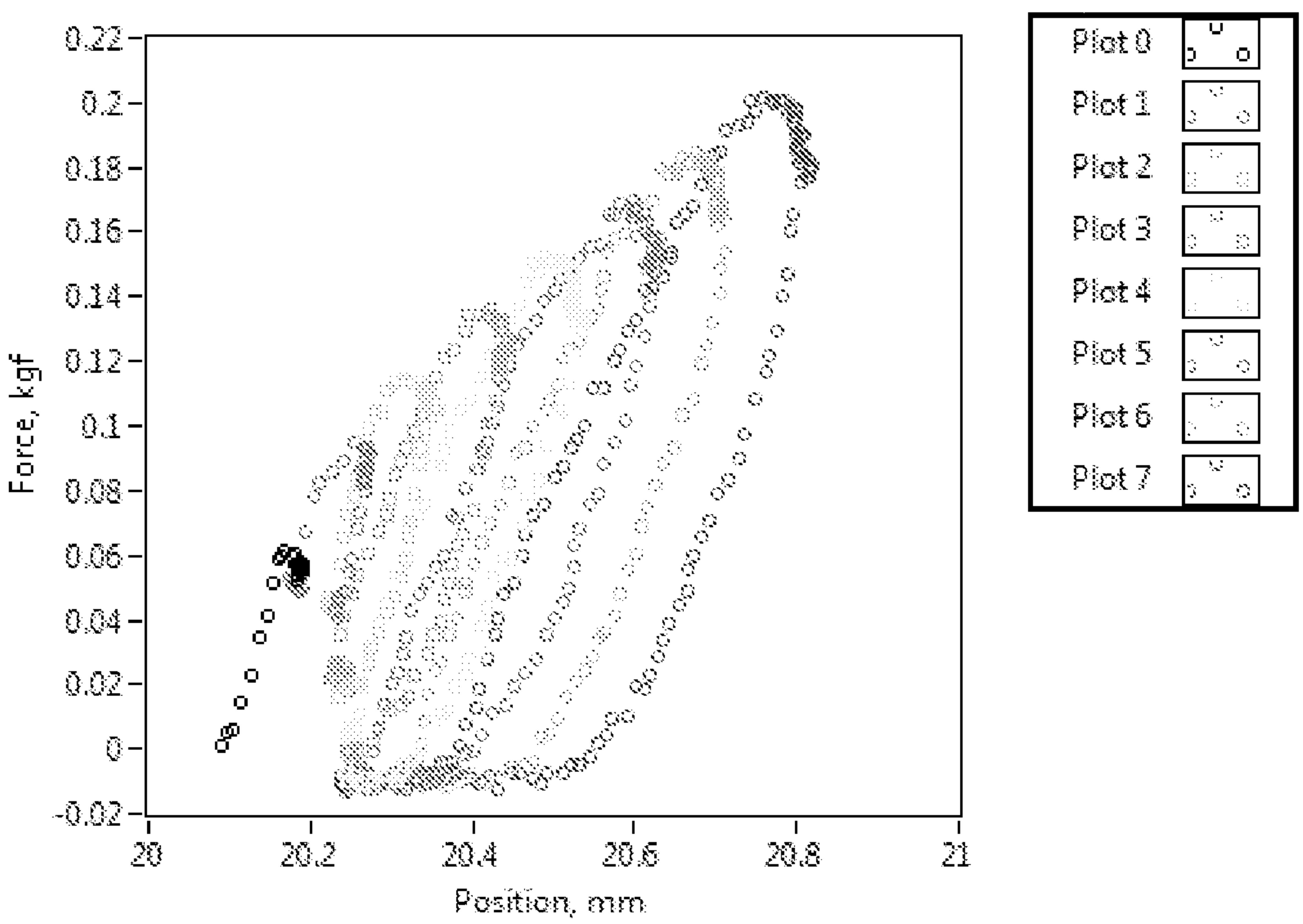
2.5
2
1.5
1
0.5
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
Elongation
[%]

Fig. 1


Force, kgf
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0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
20
20.2
20.4
20.6
20.8
21
Position, mm
Plot 0
Plot 1
Plot 2
Plot 3
Plot 4
Plot 5
Plot 6
Plot 7

Fig. 2a

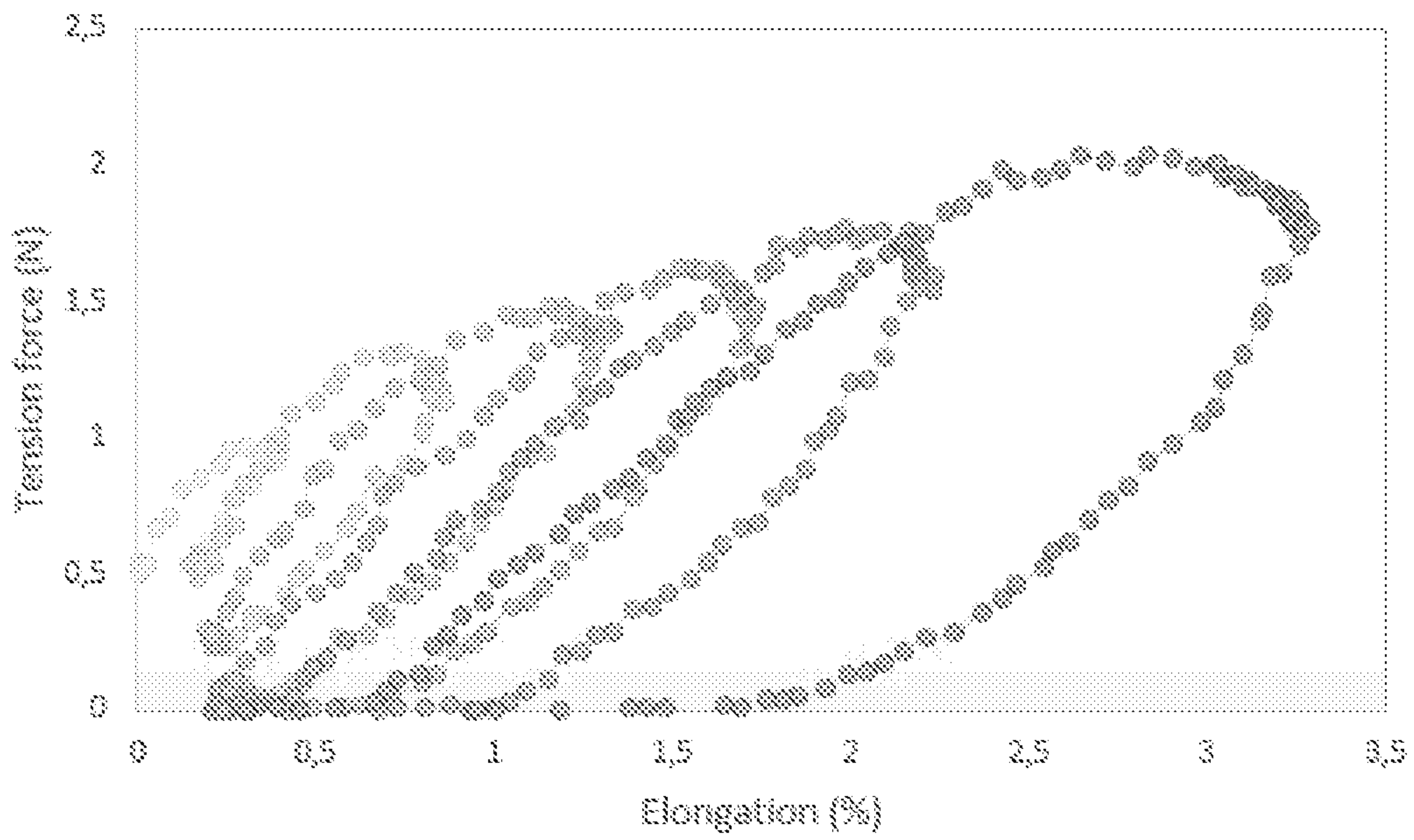
Tension force (N)
Elongation (%)
0
0,5
1
1,5
2
2,5
3
3,5

Fig. 2b

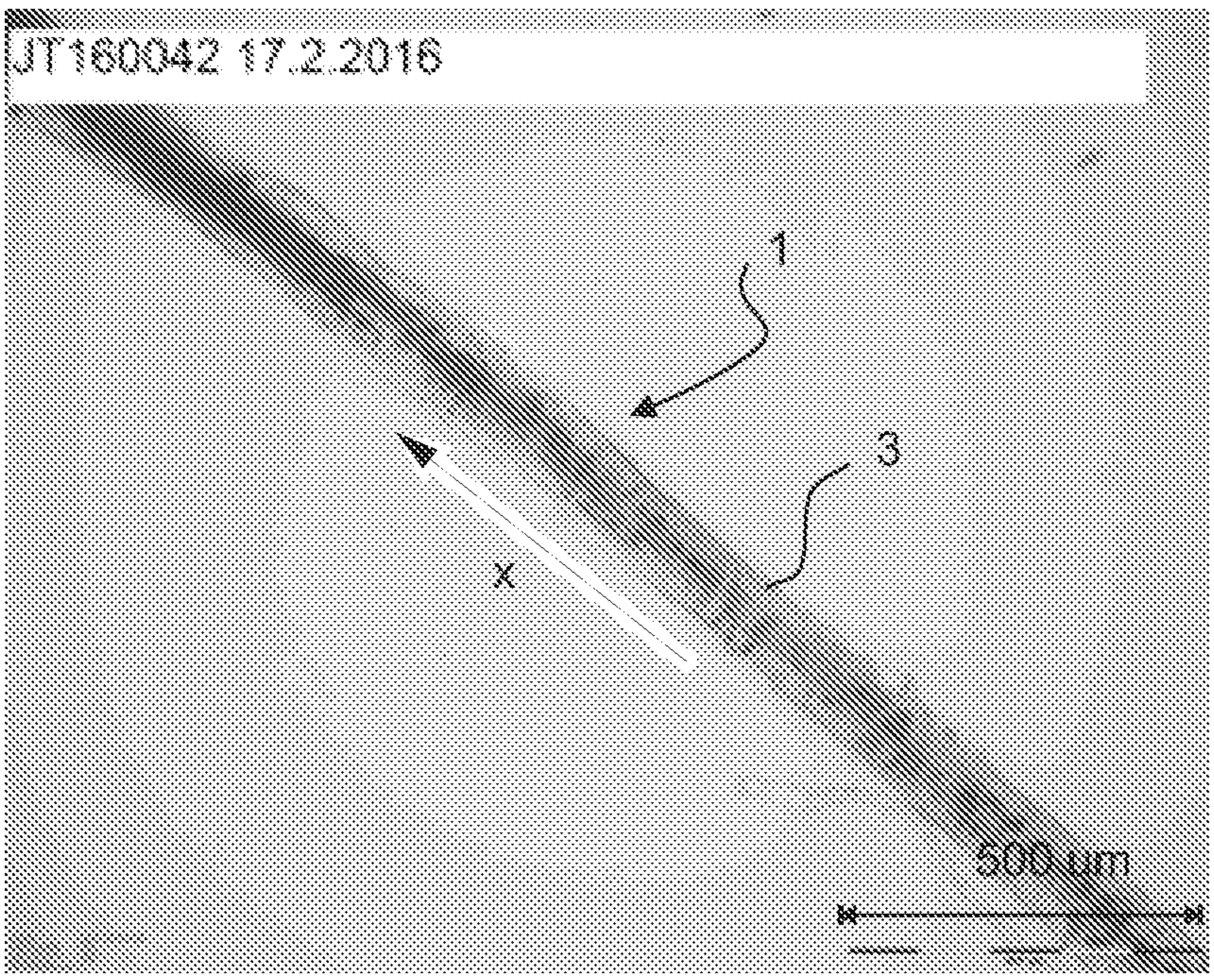
JT160042 17.2.2016
1
3
x
500 um

Fig. 3

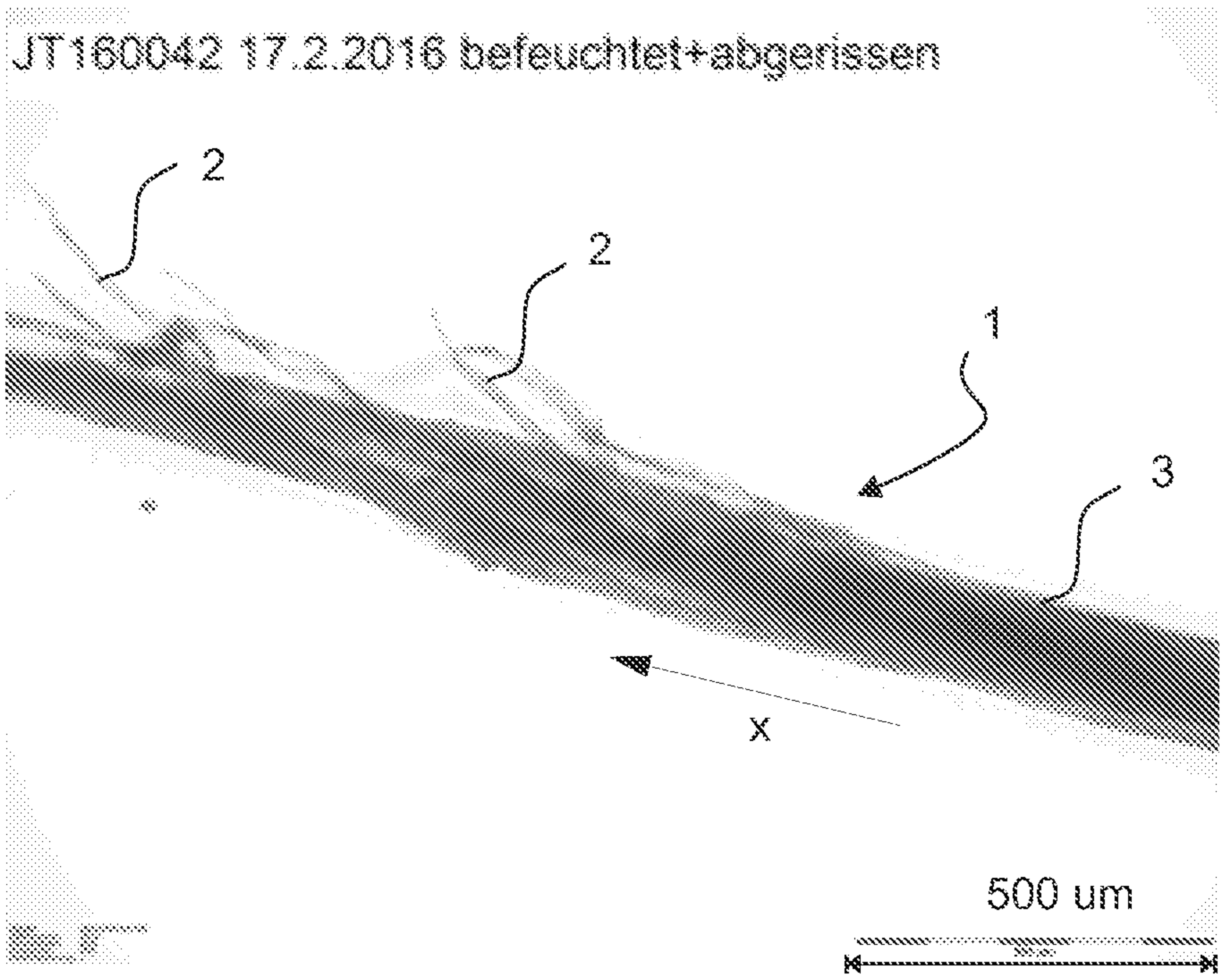

Fig. 4

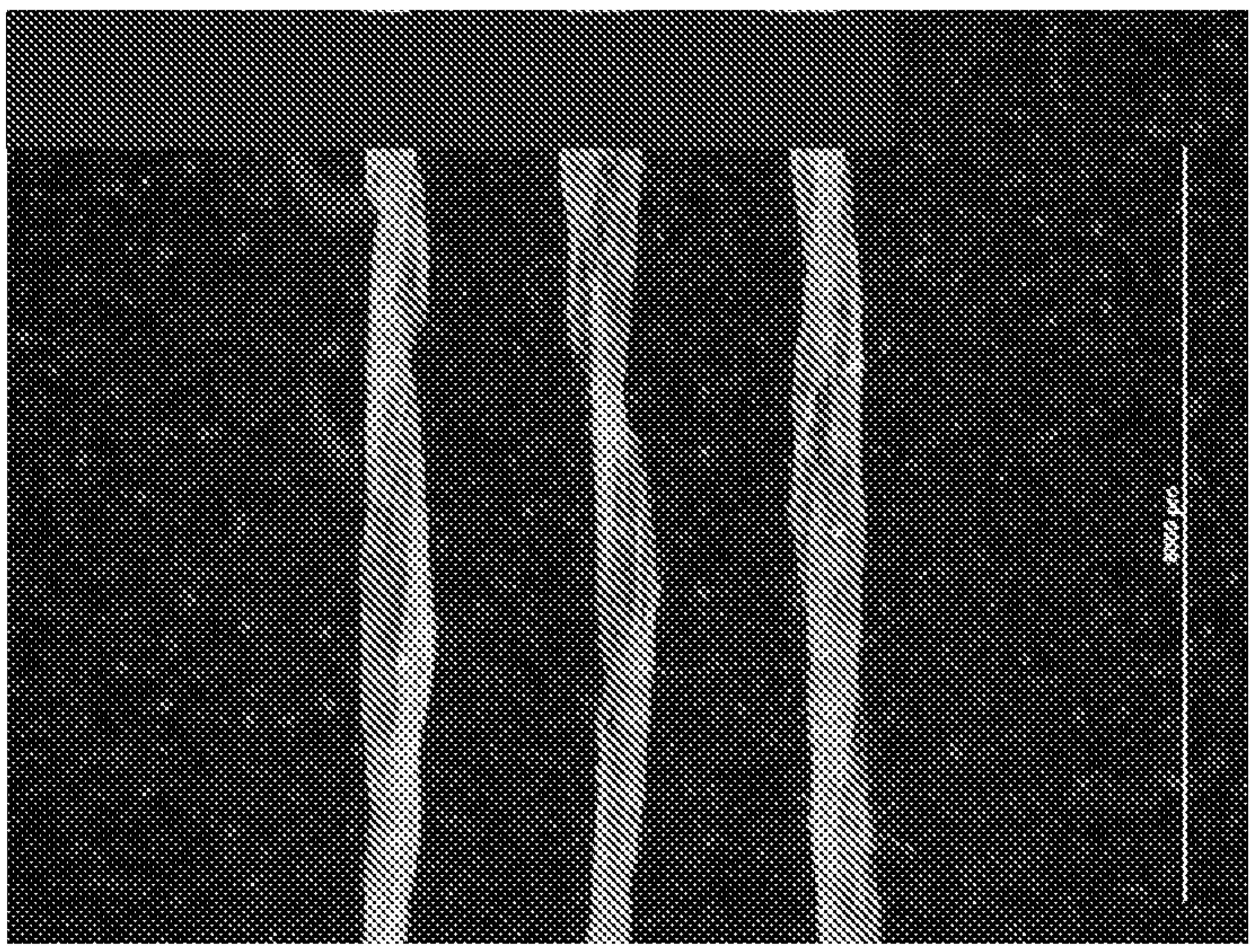

Fig. 5

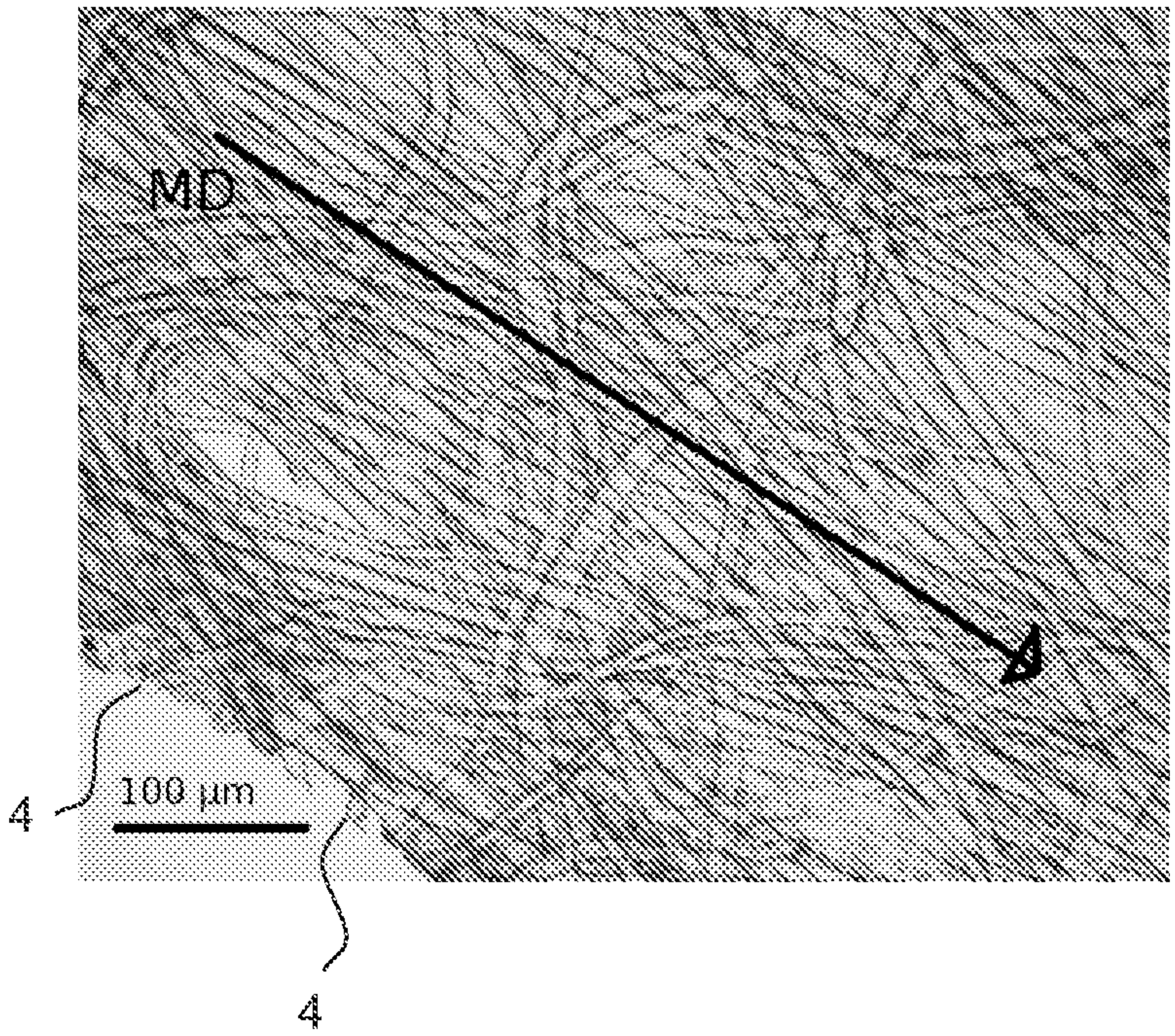

Fig. 6

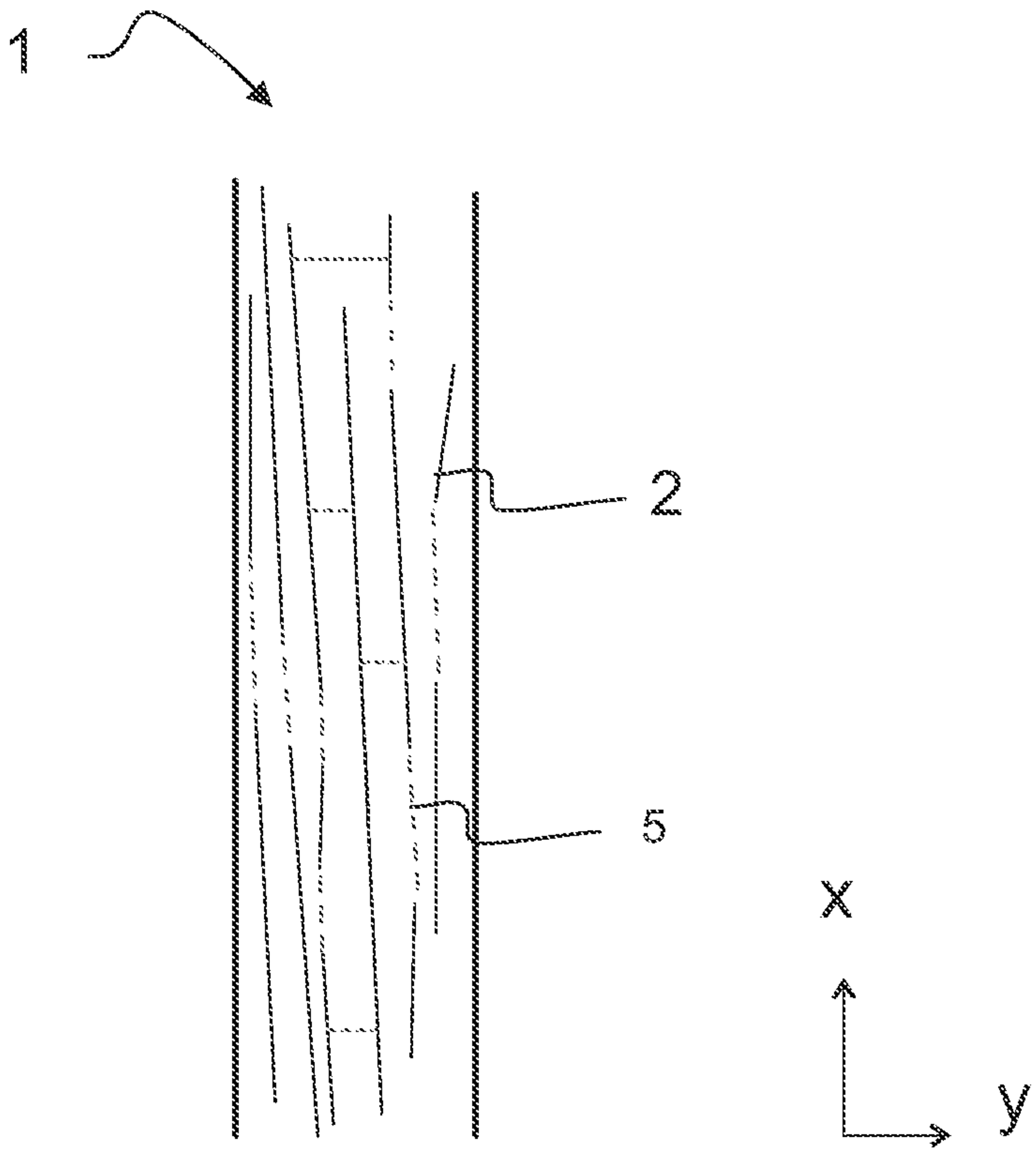

Fig. 7

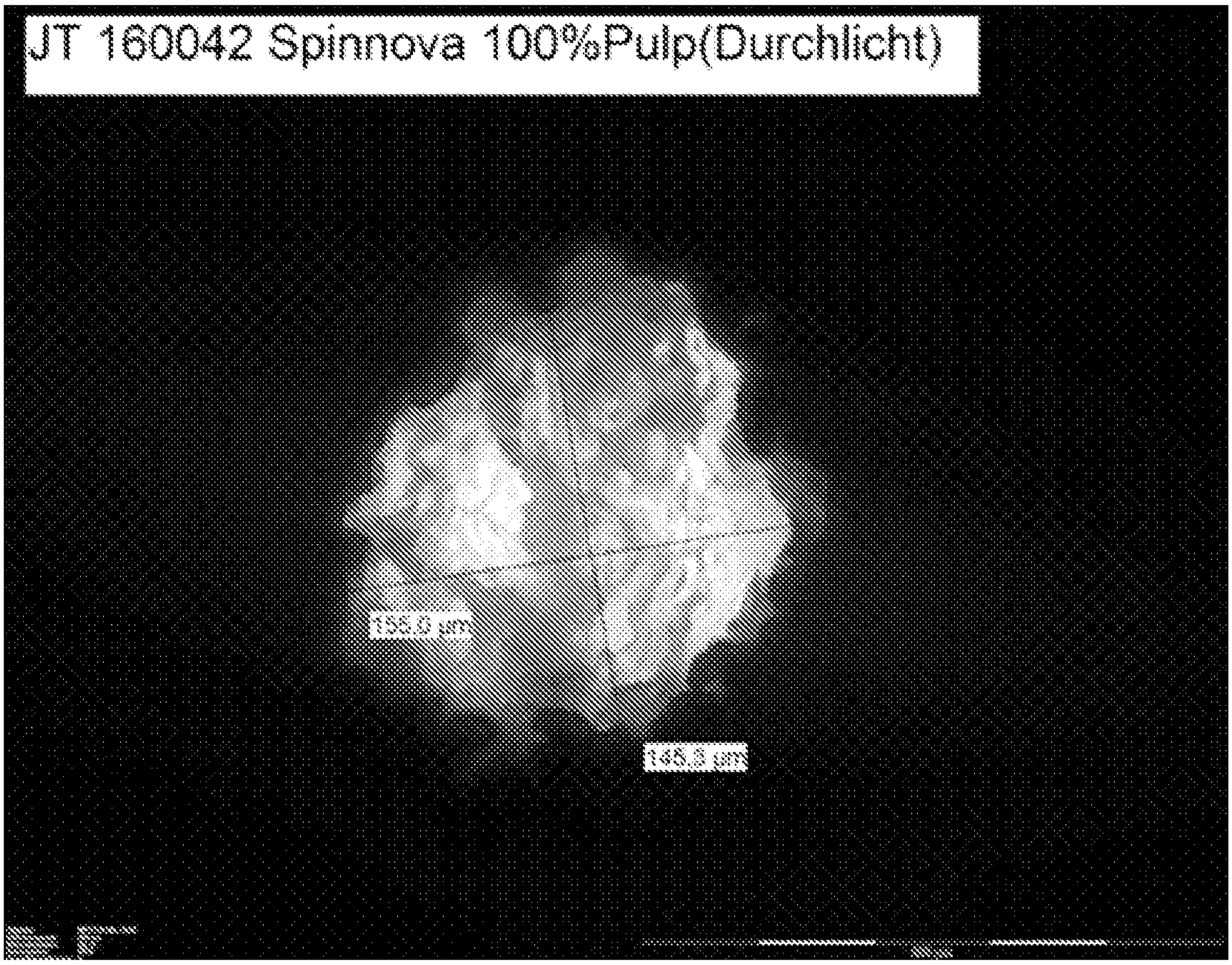
JT 160042 Spinnova 100%Pulp(Durchlicht)

Fig. 8

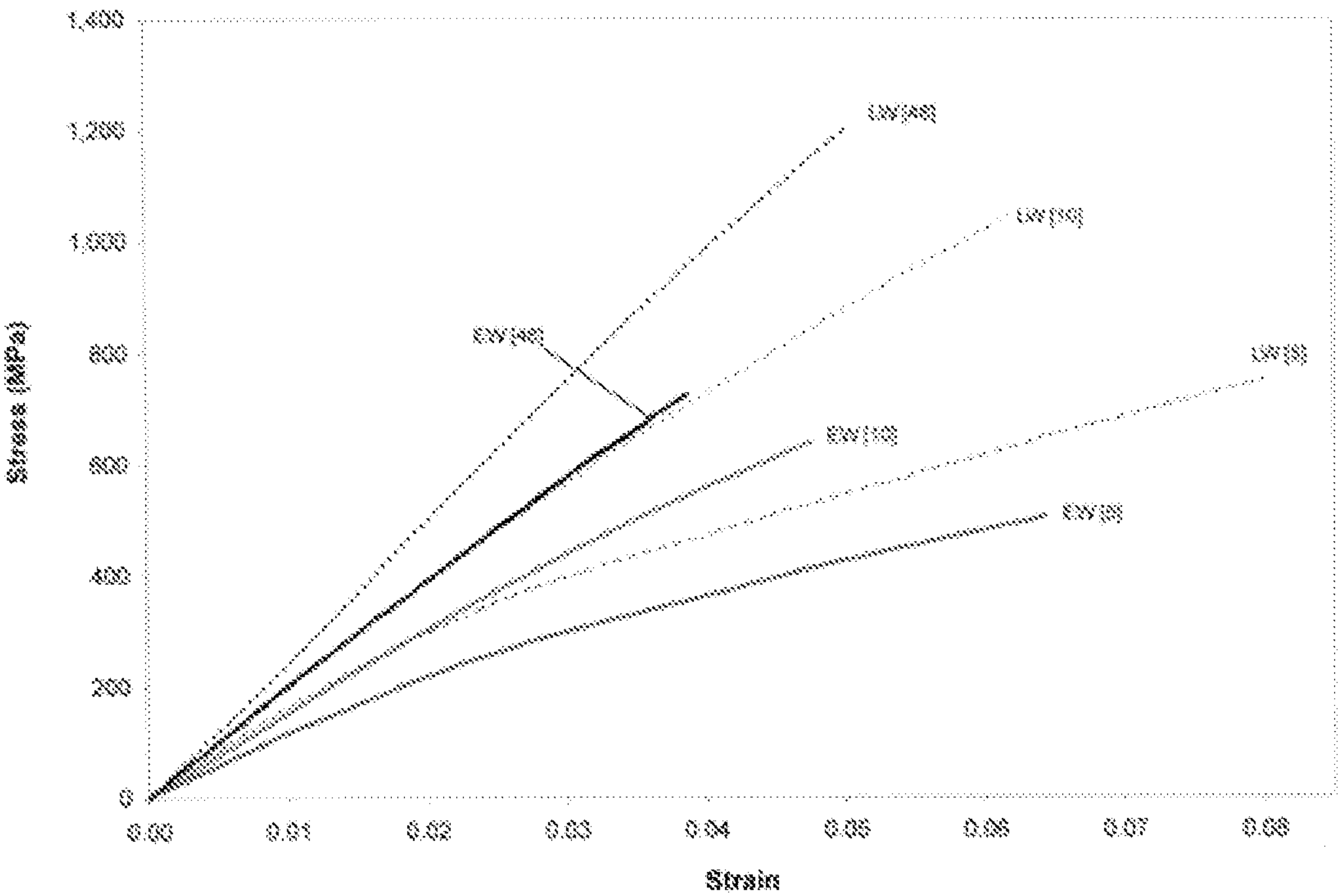
Stress (MPa)
0
200
400
600
800
1,000
1,200
1,400
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
Strain

Fig. 9

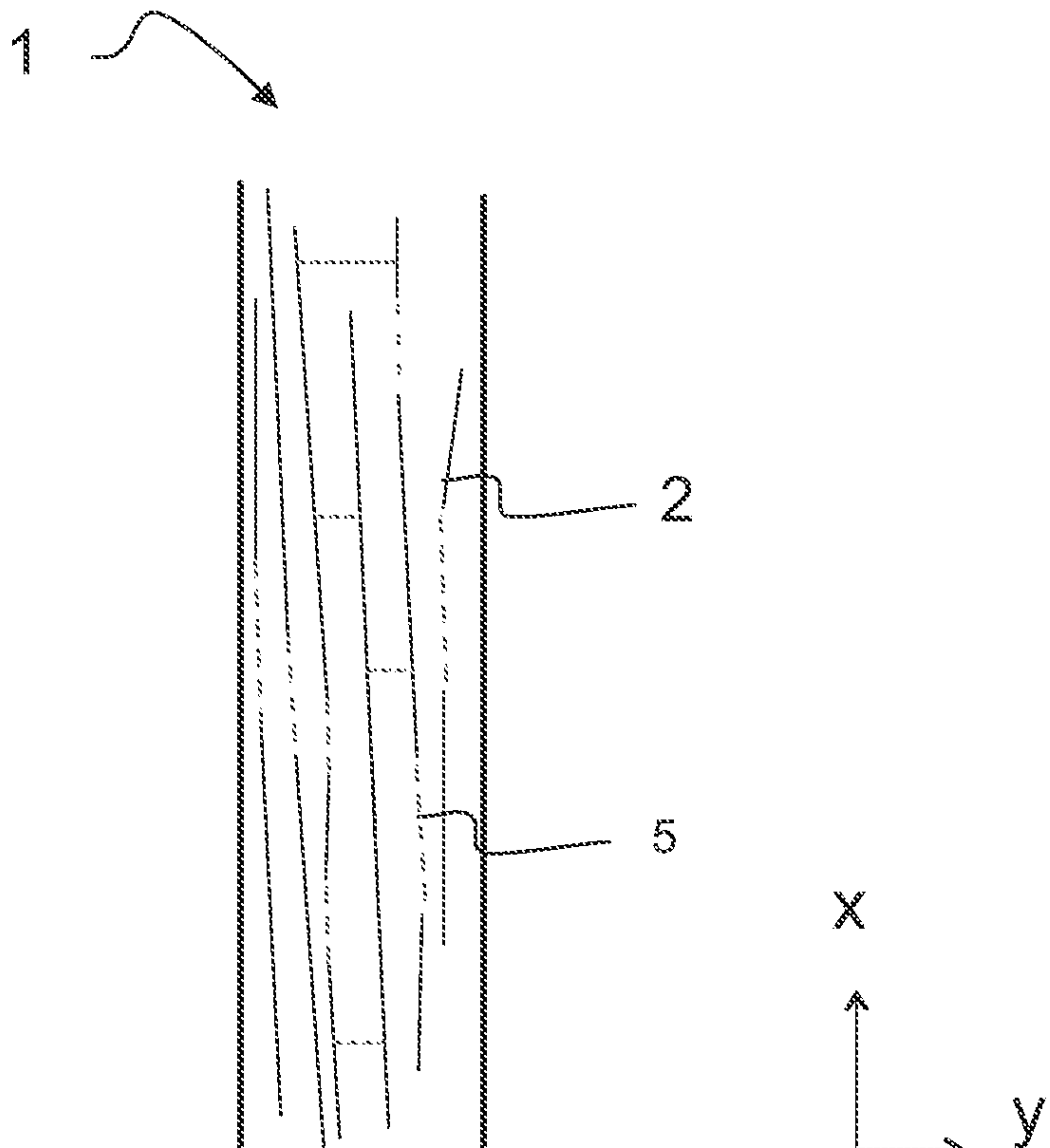

Fig. 7