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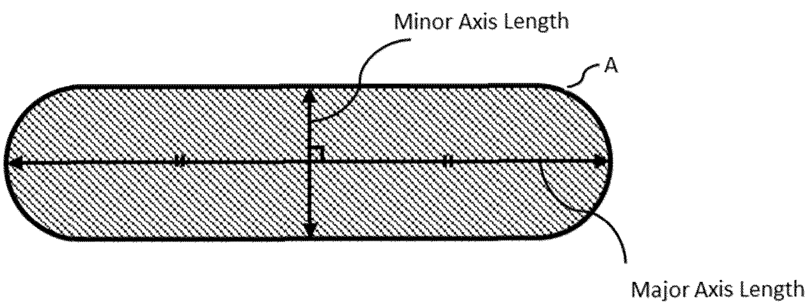
(54) **SHORT FIBERS, FIBER DISPERSED LIQUID AND NONWOVEN FABRIC**

(57) Provided is a shortcut fiber that has a flatness, which is a value obtained by dividing a major axis length of a fiber cross section by a minor axis length of the fiber cross section, of 5 or more, and an average minor axis length of 2,000 nm or less. The present invention relates to a shortcut fiber exhibiting excellent dispersibility in a liquid medium, and provides a shortcut fiber suitable for obtaining a uniform fiber dispersed liquid without entanglement and the like of the shortcut fiber even in a wide range of stirring conditions.

[Fig. 1]



## Description

Technical Field

**[0001]** The present invention relates to a shortcut fiber, a fiber dispersed liquid, and a nonwoven fabric. More particularly, the present invention relates to: a shortcut fiber suitable for a fiber dispersed liquid; a fiber dispersed liquid obtained by dispersing the shortcut fiber in an aqueous medium; and a nonwoven fabric having a special structure in which complex voids are formed by the shortcut fiber.

Background Art

**[0002]** Fibers have various characteristics attributed to their thin and long morphology and are, therefore, widely used not only in clothing applications but also in industrial material applications. Nowadays where people's lives have become richer, there is a growing demand for fiber products having diverse functions.

**[0003]** One of the characteristics of fibers attributed to their morphology is that the specific surface area, which is the surface area per unit weight, is large, and the utilization of this specific surface area enables to obtain, for example, a high adsorption effect for a substance of interest, and a high reinforcing effect when the fibers are added as a filler; therefore, studies have been conducted on a wide variety of high-performance materials that take advantage the specific surface area of fibers.

**[0004]** One of the applications of a fiber product taking advantage of the specific surface area of fibers is a fiber dispersed liquid in which shortcut fibers cut to a desired length are dispersed in a medium, and not only the fiber dispersed liquid itself can be utilized as an adsorbent or for the introduction of a filler into a resin product, but also the fiber dispersed liquid can be made into a paper and molded into the form of a sheet by a wet-laid papermaking process or the like, and thereby developed as a high-performance filter medium or separation membrane; therefore, studies and technological developments have been actively conducted on such fiber dispersed liquids.

**[0005]** One index that determines the performance of a fiber dispersed liquid is that fibers are uniformly dispersed therein and the specific surface area of the fibers can be fully utilized; however, not only the fibers readily agglutinate with each other due to the specific surface area of mixed fibers, but also the dispersion state is likely to be non-uniform due to entanglement of thin and long fibers in the first place. For the purpose of maintaining a high-quality product and its moldability, various technologies aimed at homogenization in a fiber dispersed liquid have been proposed.

**[0006]** Patent Literature 1 proposes a technology for producing ultrafine fibers, which is advantageous for enhancing the effects of specific surface area. In ultrafine fibers, an increase in the specific surface area causes a dramatic increase in the cohesive force attributed to intermolecular force, and this makes it difficult to obtain a uniform dispersion liquid; however, by considerably reducing the fiber length to less than 1 mm, the fibers can be uniformly dispersed without causing the generation of agglutinate-like dispersion defects in which the fibers are entangled in the resulting dispersion liquid.

**[0007]** Patent Literature 2 relates to a technology that improves the dispersibility of fibers by actively allowing electric repulsion to act between ultrafine fibers and, by controlling the electric repulsion acting between the fibers to be stronger than cohesive force, uniform dispersion can be achieved even when the fibers are long.

**[0008]** Patent Literature 3 relates to a technology that is aimed at achieving uniform dispersion in a dispersion liquid based on the morphological characteristics of shortcut fibers by processing the variation in thickness of the shortcut fibers in the longitudinal direction. By partially increasing the thickness along the longitudinal direction and thereby making the shortcut fibers less likely to bend, the generation of agglutinate-like dispersion defects in which the fibers are entangled can be inhibited.

Citation List

Patent Literature

**[0009]**

[Patent Literature 1] JP 2007-107160
[Patent Literature 2] WO 2020-101002
[Patent Literature 3] JP 2018-84008

## Summary of Invention

### Technical Problem

**[0010]** As the diameter of fibers decreases, the fibers become more flexible and easily bendable, and thus more likely to intricately entangle with each other in a dispersion liquid to generate agglutinate-like dispersion defects; therefore, Patent Literature 1 utilizes a property that a reduction in fiber length makes fibers less likely to entangle with each other.

**[0011]** In other words, fibers are made less likely to entangle with each other in a dispersion liquid by reducing the aspect ratio that is a value obtained by dividing the fiber length by the fiber diameter; however, in this method, although a uniform dispersion state is obtained when stirring is performed at a low speed, dispersion defects in which the fibers are entangled are likely to be generated when stirring is performed at a high speed, and the dispersibility may be an issue. Particularly, such dispersion defects tend to be pronounced in ultrafine fibers, and this may limit the processes that can be applied to the preparation of a dispersion liquid of ultrafine fibers.

**[0012]** In Patent Literature 2, by utilizing the electric repulsion between fibers, the fibers are uniformly dispersed by the action of repulsive force between the fibers and are made unlikely to precipitate, and a dispersion state is maintained for an extended period; however, when high-speed stirring causes a force stronger than the electric repulsion to act, the fibers may come into contact with each other to form fiber agglutinates, limiting the processes that can be applied to the preparation of a dispersion liquid.

**[0013]** In Patent Literature 3, ultrafine flat short fibers having a thickness variation in the longitudinal direction are obtained by tearing ultrafine fibers using a roll press, and the short fibers hardly entangle with each other since they are thick in some parts and thus unlikely to bend. However, due to the process of tearing ultrafine fibers into short fibers using a roll press, an upper limit of the difference in thickness of a single short fiber in its longitudinal direction is a factor of about 2 and, after all, the fibers may entangle with each other to form fiber agglutinates during high-speed stirring, and the dispersibility may be an issue in some cases.

**[0014]** As described above, with regard to those shortcut fibers that are expected to be applied to a fiber dispersed liquid, although the technologies for uniformly dispersing shortcut fibers having a large specific surface area in a standing or low-speed stirring condition are available, there is no technology for uniformly dispersing such fibers even in a high-speed stirring condition, and this limits the production process of a fiber dispersed liquid. Therefore, in response to the recent demands, a shortcut fiber which can be applied to a wide range of processes and developed in a variety of fields and is suitable for a fiber dispersed liquid having excellent dispersibility is desired.

### Solution to Problem

**[0015]** **In** order to solve the above-described problems, the present invention has the following constitution.

(1) A shortcut fiber, having a flatness, which is a value obtained by dividing a major axis length of a fiber cross section by a minor axis length of the fiber cross section, of 5 or more, and an average minor axis length of 2,000 nm or less.
(2) The shortcut fiber according to (1), wherein a variation (CV value) in minor axis length of the fiber cross section is 10% or more.
(3) The shortcut fiber according to (1) or (2), wherein a degree of unevenness of the fiber cross section is 20% or more.
(4) The shortcut fiber according to (1), having a crystallinity of 20% or less.
(5) The shortcut fiber according to (4), having a melting point of 180°C or higher.
(6) A fiber dispersed liquid, containing the shortcut fiber according to (1) or (4) dispersed in an aqueous medium.
(7) A nonwoven fabric, at least partially containing the shortcut fiber according to (1) or (4).
(8) A nonwoven fabric, having a density of 0.4 g/cm$^3$ or more, an average pore size of 6 $\mu$m or less, and a pore size distribution with a maximum frequency of 30% or less.
(9) The nonwoven fabric according to (8), having a surface arithmetic mean roughness (Ra) of 5.00 $\mu$m or less.
(10) A fiber product, at least partially including the nonwoven fabric according to (7) or (8).

### Advantageous Effects of Invention

**[0016]** The present invention relates to a shortcut fiber which, because of its morphological characteristic of having a high cross-sectional flatness, exhibits excellent dispersibility in a liquid medium such as water, and this shortcut fiber can provide a uniform fiber dispersed liquid without, for example, entangling with one another, even in a wide range of stirring conditions. Further, utilizing the excellent water dispersibility of the shortcut fiber, a nonwoven fabric having a special structure that is dense but has complex voids formed therein can be obtained by forming a sheet using the shortcut fiber. This nonwoven fabric is expected to be developed into a wide range of industrial materials since it exhibits excellent properties in terms of sound absorption in a low-frequency band that relates to daily life noise, road noise, and the like, as well as filtration and separation of specific components.

Brief Description of the Drawings

**[0017]**

[FIG. 1] FIG. 1 is a schematic drawing that illustrates one example of a cross-sectional structure of the shortcut fiber of the present invention.
[FIG. 2] FIG. 2 is a schematic drawing that illustrates a cross-sectional structure for describing the degree of unevenness of the shortcut fiber of the present invention.
[FIG. 3] FIG. 3 is schematic drawing that illustrates one example of a cross-sectional structure of a multilayer laminated fiber used as a raw material of the shortcut fiber of the present invention.
[FIG. 4] FIG. 4 is a cross-sectional view for describing one example of a method of producing the multilayer laminated fiber.
[FIG. 5] FIG. 5 provides property diagrams each showing a luminance histogram of a fiber dispersed liquid containing the shortcut fiber of the present invention. FIG. 5(a) is a schematic drawing of the luminance histogram of a fiber dispersed liquid in which fibers are uniformly dispersed, and FIG. 5(b) is a schematic drawing of the luminance histogram of a fiber dispersed liquid in which fiber agglutinates are formed.

Description of Embodiments

**[0018]** The present invention will now be described in detail along with desired embodiments.
**[0019]** The present invention relates to a shortcut fiber characterized by having excellent dispersibility in a liquid medium such as water. The term "shortcut fiber" used herein refers to a fiber of less than 100 mm in length, which is cut to a desired length in the longitudinal direction of the fiber.
**[0020]** The shortcut fiber of the present invention utilizes its large specific surface area to exert, for example, a high adsorption effect for a substance of interest, and a high reinforcing effect when added as a filler. Among the applications of the shortcut fiber of the present invention, when the shortcut fiber is used as a filter medium or a separation membrane, from the standpoint of improving the performance thereof, the shortcut fiber preferably has a specific surface area of 0.0010 $nm^{-1}$ or larger.
**[0021]** The "specific surface area" is determined as follows.
**[0022]** A fiber bundle formed of the shortcut fiber of the present invention is embedded in an embedding agent such as an epoxy resin, and a fiber cross section is cut out using a microtome equipped with a diamond knife, after which this cross section is photographed under a scanning electron microscope (SEM) or the like at a magnification that allows identification of the cross section.
**[0023]** For a cross section of a single fiber included in the photographed image, using an image analysis software (WINROOF), a measurement start point is set at an arbitrary position on the outer periphery of the cross section, and the length following the outer periphery on a series of images from the measurement start point back to the measurement start point is measured. The thus measured value is defined as the circumferential length of the single fiber and expressed as an integer (rounded off to the nearest whole number) in nm. The area of a part enclosed by this circumferential length is measured using the image analysis software (WINROOF), and the thus obtained value is defined as the cross-sectional area of the single fiber and expressed as an integer (rounded off to the nearest whole number) in $nm^2$. From the circumferential length and the cross-sectional area, the specific surface area of the single fiber is calculated using the following equation and rounded off to four decimal places.

$$\text{Specific surface area } (nm^{-1}) = \text{Circumferential length (nm)/Cross-sectional area } (nm^2)$$

**[0024]** The above-described measurement is performed for 100 fibers to calculate the specific surface area of each fiber, and an arithmetic mean of the thus obtained values is defined as the specific surface area.
**[0025]** When the specific surface area is 0.0010 $nm^{-1}$ or larger, the effects of specific surface area equivalent to those of an ultrafine fiber having a fiber diameter of several micrometers can be exerted, allowing the shortcut fiber to exhibit excellent adsorption performance and the like.
**[0026]** From this standpoint, the effects of the present invention can be more pronounced as the specific surface area increases and, as a more preferred range, for example, when the specific surface area is 0.0040 $nm^{-1}$ or larger, excellent effects equivalent to those of a nanofiber having a fiber diameter of several hundred nanometers are exerted. Further, in the present invention, the specific surface area is particularly preferably 0.0080 $nm^{-1}$ or larger and, in this range, excellent effects are exerted by mixing the shortcut fiber of the present invention into a fiber product. The utilization of such an

increased specific surface area allows the shortcut fiber to have excellent filtration/separation performance, adsorption performance, and the like, and to exhibit unique performance even when, for example, the shortcut fiber is molded as a mixed material with other skeleton material. For example, the shortcut fiber is capable of capturing ions and the like in a liquid without a surface treatment or the like being performed thereon; therefore, the shortcut fiber can be utilized for the recovery of valuable resources from seawater, or the adsorption of malodorous components in the air.

**[0027]** The shortcut fiber of the present invention, because of its morphological characteristics, is characterized by having excellent dispersibility in a liquid medium such as water, in addition to having the above-described improved performance as a fiber product. As an important requirement for achieving both the specific surface area and the excellent dispersibility of the shortcut fiber that are not attained in prior art, the shortcut fiber is required to have a flatness, which is a value obtained by dividing a major axis length of a fiber cross section by a minor axis length of the fiber cross section, of 5 or more, and this is a first requirement of the present invention.

**[0028]** The flatness of a fiber cross section is determined as follows (also see FIG. 1).

**[0029]** For a cross section of a single fiber included in the image photographed at the time of determining the specific surface area, the maximum length of the cross section is measured using an image analysis software (WINROOF), and the thus measured value is defined as the major axis length of the single fiber and expressed as an integer in nm by rounding off the measured value to the nearest whole number. Subsequently, the length of a line segment that is perpendicular to a line segment having the maximum length and intersects the fiber cross section at a midpoint of the maximum length is measured, and the thus measured value is defined as the minor axis length of the single fiber and expressed as an integer in nm by rounding off the measured value to the nearest whole number. From the major axis length and the minor axis length, the flatness of the single fiber is calculated using the following equation.

$$\text{Flatness} = \text{Major axis length (nm)}/\text{Minor axis length (nm)}$$

**[0030]** The above-described measurement is performed for 100 fibers to calculate the flatness of each fiber, and an arithmetic mean of the thus obtained values is defined as the flatness.

**[0031]** In the shortcut fiber of the present invention, the above-described flatness is required to be 5 or more. **In** this range, the flexural rigidity in the minor axis direction and that in the major axis direction are greatly different due to the cross-sectional morphological characteristics, i.e. the cross-sectional shape anisotropy, and the bending direction of the shortcut fiber is limited to the minor axis direction when the shortcut fiber is made into a fiber dispersed liquid. Because of this limitation on the direction of deformation, even if the shortcut fiber comes into contact with one another in the fiber dispersed liquid, agglutinate-like dispersion defects in which the shortcut fiber is bent and intricately entangled with one another are not generated, so that excellent dispersibility is exerted.

**[0032]** In this manner, by utilizing the cross-sectional shape anisotropy to limit the bending direction, the shortcut fiber of the present invention is made unlikely to be entangled with one another in a dispersion liquid and, based on this technical idea, a higher cross-sectional flatness leads to a larger difference in flexural rigidity between the minor axis direction and the major axis direction, as a result of which the bending direction is firmly limited to the minor axis direction when the shortcut fiber is made into a fiber dispersed liquid. In other words, when the flatness is 15 or more, the flexural rigidity differs by a factor of 200 or more between the minor axis direction and the major axis direction of a cross section, and the bending direction of the shortcut fiber in a dispersion liquid is thus substantially limited only to the minor axis direction. By firmly limiting the bending direction to the minor axis direction in this manner, entanglement of the shortcut fiber with one another in a dispersion liquid is made unlikely to occur even when the dispersion liquid is stirred at a high speed, and this allows the shortcut fiber to exhibit excellent dispersibility; therefore, the flatness is preferably 15 or more.

**[0033]** Further, when the flatness is 30 or more, even in high-speed stirring conditions where a high shear force that causes opening of shortcut fiber bundles agglutinated due to a cohesive force such as intermolecular force is applied, entanglement of the shortcut fiber with one another after the fibrillation is unlikely to occur because of the limitation on the bending direction that is attributed to the cross-sectional shape anisotropy. From the standpoint of obtaining excellent dispersibility in a wide range of stirring conditions that encompass fibrillation and the like, the flatness is more preferably 30 or more.

**[0034]** Moreover, if the flatness is 50 or more, the exceptional shape anisotropy makes a fiber dispersed liquid likely to assume a fluid state, in which the cross-sectional short-axis directions of shortcut fibers are aligned by a difference in flow rate in the fiber dispersed liquid, when the fiber dispersed liquid is stirred. In such a fluid state, the shortcut fibers are unlikely to come into contact with one another due to the alignment of their minor axis directions, and this makes it easier to obtain a uniform dispersion state; therefore, the flatness is particularly preferably 50 or more.

**[0035]** On the other hand, as the cross-sectional flatness increases, fibrillation tends to be more likely to occur in the major axis direction of the cross section when an external force is applied in the stirring step or the like; however, as long as the flatness is less than 800, there is no problem in practical use, and the object of the present invention can be achieved.

**[0036]** As described above, because of the high cross-sectional shape anisotropy, the bending direction of the shortcut fiber of the present invention in a dispersion liquid is limited from all 360° directions to only the minor axis direction as compared to conventional fibers having a round cross section; therefore, agglutinate-like dispersion defects in which the shortcut fiber is intricately entangled with one another are unlikely to be formed and, even when the shortcut fiber has a large specific surface area, it can exhibit excellent dispersibility in a wide range of stirring conditions.

**[0037]** The dispersibility of the shortcut fiber is affected not only by the cross-sectional flatness but also by the fiber diameter, and the fiber diameter is thus also an important requirement for sufficiently improving the dispersibility attributed to the cross-sectional shape in a wide range of stirring conditions that encompass low-speed to high-speed stirring. As an index of the fiber diameter, it is a second requirement that the shortcut fiber of the present invention has a short minor axis at a cross section, and the average minor axis length is required to be 2,000 nm or less.

**[0038]** The term "average minor axis length" used herein refers to a value determined as an integer in nm by rounding off an arithmetic mean of the minor axis length measured above for 100 fibers to the nearest whole number.

**[0039]** In the shortcut fiber of the present invention, when the average minor axis length is 2,000 nm or less, the precipitation rate of the fiber in a dispersed liquid is sufficiently slow, so that a uniform fiber dispersion state is maintained.

**[0040]** Based on this technical idea, a shorter minor axis length leads to a slower precipitation rate of the fiber, and this makes the fiber unlikely to precipitate over time; therefore, in the shortcut fiber of the present invention, the average minor axis length is preferably 1,000 nm or less. In this range, the fiber does not precipitate even when stirred with a weak force, so that a uniform dispersion state can be maintained.

**[0041]** Further, even when a stirring force does not act for a short period during the transport process or the like of the fiber dispersed liquid, the fiber does not precipitate as long as the average minor axis length is 500 nm or less, and this is one example of a more preferred range in the present invention.

**[0042]** Moreover, the average minor axis length is particularly preferably 250 nm or less and, in this range, even when a stirring force does not act over an extended period during storage of the fiber dispersed liquid, the fiber hardly precipitates and a uniform dispersion state is maintained.

**[0043]** On the other hand, as a range in which the shortcut fiber of the present invention is unlikely to be broken when an external force is applied thereto in the stirring step or the like, the average minor axis length of the shortcut fiber is, for example, 20 nm or more, and this is a practical lower limit value in the present invention.

**[0044]** The shortcut fiber of the present invention has an ultra-flat cross section in which the major axis is extremely long relative to the minor axis, and this puts limitation on the bending direction of the shortcut fiber itself and makes it possible to, for example, employ a wide range of stirring conditions encompassing low-shear to high-shear conditions when the shortcut fiber is dispersed in a liquid medium such as water, so that the range of conditions in which a uniform dispersion state can be maintained is dramatically broadened as compared to prior art. With regard to this characteristic fiber cross section, from the standpoint of inhibiting entanglement and adhesion of adjacent fibers and thereby ensuring dispersibility over time, the fiber cross-sectional shape is preferably in a state of having a distribution within a certain range, and the shortcut fiber of the present invention desirably has a variation in the minor axis length.

**[0045]** In the present invention, the "variation (CV value) in the minor axis length" refers to an integer (unit: %) determined by calculating an arithmetic mean and a standard deviation of the minor axis length measured above for 100 fibers, and rounding off the coefficient of variation, which is obtained by dividing the standard deviation by the arithmetic mean, to the nearest whole number.

**[0046]** With the presence of a moderate distribution in the minor axis length, not only shortcut fibers are unlikely to be joined with one another due to the inconsistency in their fiber cross-sectional shapes, but also the shortcut fibers each move differently when an external force such as shear force is applied thereto, as a result of which, for example, a difference in the buckling behavior is generated at the time when the shortcut fibers come into contact with one another and are bent in a liquid medium; therefore, a uniform state can be maintained over time without entanglement and the like of the shortcut fibers with one another. From this standpoint, in the shortcut fiber of the present invention, the variation in the minor axis length is preferably 10% or more and, in this range, even in a dispersion liquid in which the shortcut fiber likely to come into contact with one another is added at a high concentration, entanglement and the like does not occur because of the difference in the bending behavior and the like between fibers, so that a uniform dispersion state can be ensured.

**[0047]** Further, when the variation in the minor axis length is 20% or more, even in a fiber dispersed liquid that is in the state of clay containing the shortcut fiber at an extremely high concentration with respect to a medium, entanglement of the shortcut fiber is unlikely to occur, and excellent dispersibility is obtained again by dilution or the like of the fiber dispersed liquid with another liquid; therefore, this range is mentioned as one example of a more preferred range in the present invention.

**[0048]** Moreover, in the present invention, the variation in the minor axis length is particularly preferably 30% or more and, in this range, even when shortcut fibers are dispersed into a medium from agglutinated shortcut fiber bundles or fiber assemblies, the shortcut fibers each exhibit different behaviors and are broken apart by an external force, as a result of which the agglutinated state is dissolved, and the shortcut fibers can be easily dispersed with stirring in a short time.

**[0049]** Based on this standpoint, a larger variation in the minor axis length leads to a further improvement in the dispersibility in a liquid medium; however, when an external force is applied in the stirring step or the like, unevenness may be generated in the dispersibility, and breakage and the like of the shortcut fiber may occur due to an excessively short minor axis; therefore, the variation in the minor axis length is preferably 50% or less, and this is a practical upper limit value in the present invention.

**[0050]** In the shortcut fiber of the present invention, not only entanglement is inhibited by the difference between the cross sections of individual shortcut fibers, but also adhesion and entanglement of shortcut fibers can be suppressed by steric hindrance because of the presence of irregularities on the outer periphery, and the degree of unevenness of the fiber cross section is preferably 20% or more.

**[0051]** With regard to the "degree of unevenness" according to the present invention, the degree of unevenness of a single fiber is defined as a value that is obtained by, in a photographed image of a fiber cross section, measuring the length of a line segment that is perpendicular to a line segment having a maximum length and intersects the fiber cross section at each of 10 points equally dividing the maximum length of the cross section, calculating an arithmetic mean and a standard deviation of the length measured at these 10 points, dividing the standard deviation by the arithmetic mean, and then rounding off the thus obtained value to nearest whole number in % (also see FIG. 2). The same measurement is performed for cross sections of 10 fibers, and an arithmetic mean of the degree of unevenness that is calculated for the 10 fibers is defined as the "degree of unevenness". When the degree of unevenness is 20% or more, the shortcut fiber can be easily and uniformly dispersed in a short time, starting from fine voids between fibers.

**[0052]** Entanglement and the like of shortcut fibers can be inhibited by a high degree of unevenness; however, as a range in which fibrillation caused by concentration of a load in some parts of the cross section does not occur, the degree of unevenness is 50% or less, and this is one example of a practical upper limit value in the present invention.

**[0053]** The shortcut fiber of the present invention has a high specific surface area effect attributed to its fiber cross section as well as excellent dispersibility that allows the specific surface area effect to work effectively, and is thus advantageous when added as a filler into a resin. By forming a sheet using the shortcut fiber, the sheet can be utilized as, for example, a highly functional nonwoven fabric having performance in separation, filtration, adsorption, and the like.

**[0054]** When the shortcut fiber is made into a nonwoven fabric, because of cross-linked structures formed by frictional force and the like between adjacent shortcut fibers, the nonwoven fabric exhibits mechanical properties of a sheet. The cross-linked structures are such structures in which shortcut fibers existing in a medium interact with each other to transmit a force; therefore, when the shortcut fibers in the medium exist at the same concentration, a smaller fiber diameter and a longer fiber length lead to the formation of more cross-linked structures, as a result of which the transmission of a force is facilitated. In other words, the higher the ratio of the fiber length to the fiber diameter, the more accelerated is the formation of cross-linked structures and, as an index of this, it is said preferred that the aspect ratio of the shortcut fiber of the present invention, which is a value obtained by dividing the fiber length by the minor axis length, be high.

**[0055]** The term "aspect ratio" used herein refers to a value determined as follows.

**[0056]** An image of a fiber bundle formed of the shortcut fiber of the present invention is photographed under a microscope at a magnification at which at least 10 shortcut fibers can be observed to measure their full length. The fiber length is measured for 10 shortcut fibers randomly extracted from the photographed image. The term "fiber length" used herein refers to the length of a single fiber in the longitudinal direction, which is measured in a two-dimensionally photographed image using an image analysis software (WINROOF) and rounded off to one decimal place in mm. The above operation is performed for 10 images that are photographed in the same manner, and an arithmetic mean of the fiber length of 100 fibers is defined as the fiber length in the present invention. From a value obtained by converting this fiber length into nanometers and the above-determined average minor axis length, the aspect ratio is calculated using the following equation and rounded off to the nearest whole number.

**[0057]**

$$\text{Aspect ratio} = \text{Fiber length (nm)}/\text{Average minor axis length (nm)}$$

**[0058]** When the shortcut fiber of the present invention is made into a sheet, the aspect ratio is preferably 3,000 or higher and, in this range, cross-linked structures are sufficiently formed between shortcut fibers; therefore, even without reinforcement with a binder or the like, the resulting nonwoven fabric exhibits mechanical properties at a level that presents no problem in practical use.

**[0059]** Further, in the present invention, the aspect ratio of the shortcut fiber is more preferably 6,000 or higher and, in this range, when the shortcut fiber is made into a sheet, not only the resulting sheet exhibits sufficient mechanical properties, but also excellent processability is obtained in that, for example, detachment of the shortcut fiber is minimized during the sheet-forming step and the like.

**[0060]** On the other hand, as a range in which there is no limitation on the stirring conditions and the like and good ease of handling can be ensured without entanglement of the shortcut fiber in a dispersion liquid, the aspect ratio of the shortcut fiber is preferably 50,000 or lower, and this is a practical upper limit value in the present invention.

**[0061]** Taking into consideration the intended effects of the present invention and the practical use of the shortcut fiber of the present invention as a fiber product, polymers constituting the shortcut fiber of the present invention are preferably excellent in heat resistance and chemical resistance. In other words, the polymers constituting the shortcut fiber preferably contain at least one polymer selected from the group consisting of polyesters, polyamides, polyphenylene sulfides, and polyolefins. In addition to the above-described advantage, these polymers are thermoplastic and thus preferred, not only from the standpoint of enabling to produce the shortcut fiber of the present invention by a melt-spinning method having a high productivity, but also from the standpoint of adjusting the mechanical properties and the like through, for example, high-degree oriented crystallization in a drawing process.

**[0062]** Particularly, from the standpoint of ensuring dispersibility, the shortcut fiber of the present invention is more preferably composed of polymers having a high elastic modulus, such as a polyester and a polyphenylene sulfide, and this enables to prevent the shortcut fiber from being bent when an external force is applied thereto, and to effectively inhibit the generation of dispersion defects in which the shortcut fiber is entangled with one another in the step of dispersing the shortcut fiber.

**[0063]** Further, by selecting a polymer such as a polyester that has a functional group exerting electric repulsion such as a carboxyl terminal group, agglutination is inhibited by the action of repulsive force between fibers, so that a uniform dispersion state is likely to be achieved.

**[0064]** The shortcut fiber of the present invention is preferably dispersed in a medium and thereby made into a fiber dispersed liquid. In this process, the medium is more preferably an aqueous medium from the standpoint of dispersing the shortcut fiber by the use of electric repulsion of a dispersant or the like. Such a fiber dispersed liquid serves as a material that exhibits unique performance in adsorption, reinforcement, and the like.

**[0065]** As described above, when the shortcut fiber of the present invention is dispersed in a liquid medium such as water, because of its cross-sectional shape anisotropy, a uniform dispersion state can be maintained in a wide range of stirring conditions encompassing low-shear to high-shear conditions. The utilization of this excellent water dispersibility allows the shortcut fiber to be spread in a uniformly dispersed state and evenly distributed even in the sheet-forming step of a wet-laid papermaking process or the like in which shear forces of various strengths act on the shortcut fiber, and this enables to obtain a nonwoven fabric having a special structure that is dense but has complex voids formed therein. Further, in a process in which fibers are spread into the form of a nonwoven fabric, because of the high-flatness cross-sectional shape of the shortcut fiber, the shortcut fiber is densely stacked on one another with the minor axis direction of the cross section being naturally aligned with the thickness direction of the nonwoven fabric, and this, in conjunction with the effect of the uniform dispersion state, leads to the formation of a special structure that is not achieved in prior art. Therefore, the nonwoven fabric preferably contains the shortcut fiber of the present invention.

**[0066]** The nonwoven fabric of the present invention is characterized by having a special structure that is dense but has complex voids formed therein, and a first requirement thereof is that the density of the nonwoven fabric is 0.4 g/cm$^3$ or more.

**[0067]** The term "density of the nonwoven fabric" used herein refers to a value determined as follows.

**[0068]** That is, the basis weight of the nonwoven fabric is determined by measuring the weight of a square piece of 250 mm × 250 mm cut out from the nonwoven fabric, converting the measured value into the weight (g) per unit area (1 m$^2$), and then rounding off the thus obtained value to the nearest whole number, and the thickness is measured in mm using a dial thickness gauge SM-114 (manufactured by TECLOCK Corporation, probe shape: 10 mmφ, scale interval: 0.01 mm, measuring force: 2.5 N or less). The measurement is performed at five arbitrary spots per sample, and a value obtained by rounding off an average of the measured values to two decimal places is defined as the thickness of the nonwoven fabric.

**[0069]** The density of the nonwoven fabric is calculated by the below-described equation from the above-determined basis weight and thickness of the nonwoven fabric. The density of the nonwoven fabric is determined for 10 samples, and a simple average value thereof is rounded off to two decimal places and defined as the density of the nonwoven fabric.

**[0070]**

$$\text{Density of nonwoven fabric (g/cm}^3\text{)} = \text{Basis weight/Thickness}$$

**[0071]** The nonwoven fabric of the present invention is required to have a density of 0.4 g/cm$^3$ or more. In this range, the nonwoven fabric has a dense structure containing only a small amount of voids even when the nonwoven fabric is sufficiently thin; therefore, the use of the nonwoven fabric as a sound-absorbing material can be expected to improve the sound absorption coefficient in a low-frequency band. Assuming that the nonwoven fabric will be further reduced in thickness and arranged in a limited space for a vehicle exterior member or the like, the density of the nonwoven fabric is preferably 0.6 g/cm$^3$ or more. From this standpoint, the higher the density of the nonwoven fabric, the more preferred it is, and the density of the nonwoven fabric is more preferably 1.0 g/cm$^3$ or more. In this range, the nonwoven fabric of the present invention can, while being an extremely thin sheet that does not affect the architecture and design of a structure, favorably exert the effects of the present invention without reflecting the sound to be absorbed because of the presence of voids penetrating the sheet suitable for a sound absorption mechanism.

**[0072]** The above-described density of the nonwoven fabric can be achieved by appropriately adjusting the sheet thickness and basis weight, based on the premise that fibers constituting the sheet are in a dispersed state. In this case, by setting the basis weight of the sheet at a certain level, fine spaces of an intended size can be formed, so that a nonwoven fabric maintaining a practical sheet strength is obtained. From the above-described standpoint, the nonwoven fabric of the present invention preferably has a basis weight of 3 to 500 g/m$^2$ and, in this range, the nonwoven fabric provides a sheet in which fibers exist stably and uniformly, without impairing the intended effects of the present invention.

**[0073]** A second requirement of the special structure of the nonwoven fabric of the present invention is that the average pore size is 6 $\mu$m or less and a maximum frequency of the pore size distribution is 30% or less.

**[0074]** The term "pore size" used herein refers to a value determined by a bubble point method. For the bubble point method, for example, a porous material automatic pore measurement system PERM-POROMETER (manufactured by Porous Materials, Inc.) can be used. In the measurement using PERM-POROMETER, the nonwoven fabric is immersed in a liquid having a known surface tension value, and a gas is applied from the upper side of the sheet while increasing the pressure of the gas, and the pore size is determined based on the relationship between the pressure and the liquid surface tension on the surface of the nonwoven fabric.

**[0075]** Specifically, the pore size is calculated using the porous material automatic pore measurement system PERM-POROMETER (manufactured by Porous Materials, Inc.).

**[0076]** Three pieces of the nonwoven fabric are cut out as measurement samples, and the pore size distribution is measured for each of the measurement samples using GALWICK (surface tension: 16 mN/m) as a measurement liquid having a known surface tension. An average flow rate diameter obtained by automatic calculation is defined as the average pore size, and an average value of the samples that is rounded off to one decimal place is used.

**[0077]** Further, the pore size frequency is expressed in % by converting values obtained by automatic calculation into percentage, and a value at which the frequency of the pore size distribution is maximum is defined as the maximum frequency. An average of the maximum frequency of the samples is determined, and a value obtained by rounding off the thus determined average to one decimal place is used.

**[0078]** The nonwoven fabric of the present invention is required to have an average pore size of 6 $\mu$m or less, and a pore size distribution with a maximum frequency of 30% or less. In these ranges, the voids contained in the nonwoven fabric have a small size and exist in various sizes. Therefore, when the nonwoven fabric is used as a sound-absorbing material, its complex void structure can absorb the sound in a wide low-frequency band.

**[0079]** In order to attain a high sound absorption coefficient in a lower and wider frequency band, it is more preferred that the average pore size be 2 $\mu$m or less and the maximum frequency of the pore size distribution be 20% or less. As lower limits at which the object of the present invention can be substantially and sufficiently achieved, for example, the average pore size is 0.1 $\mu$m or more, and the maximum frequency of the pore size distribution is 10% or more. In these ranges, the nonwoven fabric can exhibit effective sound absorption performance without interfering with a fluid.

**[0080]** The nonwoven fabric of the present invention exhibits excellent properties even when it is used by itself as a sound-absorbing material; however, assuming a case where the nonwoven fabric is utilized in a sound-absorbing material or the like for electric vehicles that have been rapidly developed in recent years, it is envisioned to use the nonwoven fabric as a laminated material with other materials. In this case, the nonwoven fabric is bonded with the other materials using a binder in the production of a molded body; therefore, from the standpoint of improving the bonding strength with the other materials, the nonwoven fabric of the present invention preferably has a surface arithmetic mean roughness (Ra) of 5.0 $\mu$m or less.

**[0081]** The term "arithmetic mean roughness (Ra)" used herein refers to a value determined as follows. That is, the surface of the nonwoven fabric is observed under a laser microscope (VK-X200 manufactured by KEYENCE Corporation, or one having equivalent performance) and measured in accordance with JIS B0601 using an image analysis software (VK-H1XA manufactured by KEYENCE Corporation, or one having equivalent performance). The measurement is performed at five arbitrary spots per sample, and a value obtained by rounding off an average of the measured values to two decimal places is defined as Ra.

**[0082]** In the present invention, an arithmetic mean roughness (Ra) value of 5.0 $\mu$m or less means that the surface of the nonwoven fabric has sufficient smoothness for exhibiting practical properties and, because of the absence of coarse irregularities on the surface, the nonwoven fabric can be integrally molded with other materials by lamination or the like in a favorable manner, and excellent peeling resistance over time can be obtained. Further, in this range, the nonwoven fabric of the present invention also exhibits preferred effects in terms of sound absorption performance and, for example, when the nonwoven fabric of the present invention is used as a sound-absorbing material, the diffused reflection of sound wave from the surface is inhibited, so that sound can be effectively absorbed. From this standpoint, in order to further inhibit the diffused reflection of sound wave from the surface, the arithmetic mean roughness (Ra) of the surface of the nonwoven fabric is more preferably 2.0 $\mu$m or less.

**[0083]** By utilizing a special structure that is dense but has complex voids formed therein, which is a characteristic feature of the nonwoven fabric of the present invention as described above, the nonwoven fabric of the present invention as a sound-absorbing material not only exhibits excellent sound absorption performance mainly in a low-frequency band, but also can realize a wide range of sound absorption performance based on the design of sheet structure and the combination with other materials. Moreover, a special sheet structure formed in the nonwoven fabric of the present invention is excellent not only in general filtration but also in adsorption and filtration of valuable substances and hazardous substances; therefore, the nonwoven fabric of the present invention can also be effectively utilized as a substrate for filtration media.

**[0084]** Among various nonwoven fabric production methods, a wet method that is good at producing a highly dense nonwoven fabric, i.e. a wet-laid papermaking process, is preferably used for the formation of a dense structure that is a characteristic feature of the nonwoven fabric of the present invention, and this enables to stably produce a sheet structure that is a characteristic feature of the present invention.

**[0085]** The special structure that is dense but has complex voids formed therein, which is a characteristic feature of the nonwoven fabric of the present invention, can be adjusted as appropriate by adjusting the mixing ratio of various fibers constituting the nonwoven fabric, and changing the cross-sectional morphology of the shortcut fiber of the present invention. In terms of the cross-sectional morphology of the shortcut fiber, a higher flatness of the fiber cross section leads to a more pronounced effect that fibers are spread with their cross sections being uniformly oriented, and a shorter minor axis of the fiber cross section leads to more flexible bending in the minor axis direction and an improved compatibility with other mixed materials, as a result of which a nonwoven fabric having a denser and more complex void structure can be obtained. Further, since the fiber cross section has a large variation in minor axis length and a high degree of unevenness to some extent, the shortcut fiber also acts as steric hindrance in the nonwoven fabric, and fine voids are generated between shortcut fibers, as a result of which the special structure that is a characteristic feature of the nonwoven fabric of the present invention can be more pronounced.

**[0086]** As described above, in the nonwoven fabric of the present invention, because of the high-flatness cross-sectional shapes of shortcut fibers, the shortcut fibers having a large specific surface area exist uniformly without any uneven distribution, and the fibers are densely spread with their flat cross sections being oriented, as a result of which the contact area between fibers is dramatically increased in the nonwoven fabric. By utilizing this feature to bond the fibers constituting the nonwoven fabric, a thin nonwoven fabric having excellent mechanical properties can be obtained.

**[0087]** That is, by using the shortcut fiber of the present invention constituting the nonwoven fabric as a binder fiber responsible for bonding of fibers in the nonwoven fabric, excellent bondability can be exerted in a thin nonwoven fabric having a low basis weight, so that a thin nonwoven fabric having excellent mechanical properties can be obtained.

**[0088]** From the standpoint of allowing the shortcut fiber of the present invention to exhibit excellent thermal bondability, the shortcut fiber preferably has a crystallinity of 20% or less. The term "thermal bondability" used herein refers to a function of a material to be softened/fluidized by heating to adhere to adherends, and then solidified by cooling to allow adhesion/bonding of the adherends.

**[0089]** When the shortcut fiber of the present invention is made into a nonwoven fabric, not only a large contact area is obtained between fibers because of the morphological characteristics of the fibers, but also the shortcut fiber exhibits thermal bondability, so that the fibers can be strongly bonded, and the strength of the nonwoven fabric can thus be improved. The thermal bondability is also affected by the impregnation state of the shortcut fiber at each bonding point and, in order to allow the shortcut fiber to exhibit sufficient thermal bondability, the fluidity thereof is also an important requirement. As an index of the fluidity, the shortcut fiber of the present invention preferably has a crystallinity of 20% or less.

**[0090]** The term "crystallinity" used herein refers to a value determined as follows.

**[0091]** The shortcut fiber is weighed in an amount of about 5 mg using an electronic balance and then set in a differential scanning calorimeter (DSC), and differential scanning calorimetry is performed in a nitrogen atmosphere at a heating rate of 16°C/min in a measurement temperature range of 50°C to 320°C.

**[0092]** In the thus obtained measurement results (DSC curve), the heat of crystallization $\Delta$Hc (J/g) and the heat of crystal fusion $\Delta$Hm (J/g) are calculated from the area of an exothermic peak and the area of an endothermic peak, respectively. When plural exothermic peaks and endothermic peaks are observed, the $\Delta$Hc and the $\Delta$Hm are each calculated from a total area of all peaks of the respective kinds. The measurement is performed three times per level at different positions, and arithmetic mean values are calculated to determine the $\Delta$Hc and the $\Delta$Hm, after which the crystallinity is calculated using the following equation and rounded off to the nearest whole number.

$$\text{Crystallinity (\%)} = (\Delta\text{Hm} - \Delta\text{Hc})/\Delta\text{Hm}^0 \times 100$$

(wherein, $\Delta\text{Hm}^0$ represents the heat of complete crystal fusion (J/g))

**[0093]** With the crystallinity of the shortcut fiber of the present invention being 20% or less, when the shortcut fiber is heated to a temperature equal to or higher than a glass transition temperature, the resulting amorphous region is unlikely to be interfered with a crystalline region, and the shortcut fiber can thus be sufficiently softened/fluidized; therefore, the softened/fluidized shortcut fiber can penetrate between adherends to exhibit high thermal bondability when hot-pressed in a calendering process or the like.

**[0094]** Based on this technical idea, a thermoplastic fiber having a lower crystallinity is more favorably softened/fluidized in the thermal bonding step, and the crystallinity of the shortcut fiber of the present invention is thus more preferably 15% or less. In this range, the shortcut fiber is likely to penetrate also into complex irregularities of the adherends, and can thereby exhibit excellent thermal bondability regardless of the shape of the adherends.

**[0095]** The crystallinity is still more preferably 10% or less and, in this range, even when the hot-pressing pressure is low in the calendering process, the softened/fluidized shortcut fiber is likely to penetrate between the adherends; therefore, adhesion of the adherends to a roller caused by hot-pressing can be reduced and the process tension can thereby be reduced, so that breakage can be inhibited during the production process of a thin sheet-like material having a low basis weight.

**[0096]** Further, the crystallinity is particularly preferably 8% or less and, in this range, even when non-contact heating by means of an oven or the like without a calendering process is employed, a thermoplastic fiber is softened/fluidized and penetrates between the adherends, and can thereby exhibit excellent thermal bondability.

**[0097]** As described above, in addition to the bonding area-increasing effect attributed to the fiber morphological characteristics, the shortcut fiber of the present invention exhibits excellent thermal bondability by penetrating between adherends without leaving any gaps by way of having good fluidity when heated, which is attributed to the fiber structure; therefore, the shortcut fiber of the present invention can achieve excellent mechanical properties in a thin sheet-like material having a low basis weight, which was difficult in prior art.

**[0098]** In terms of exhibiting superior thermal bondability by way of having good fluidity when heated, it is preferred that the shortcut fiber of the present invention penetrate not only into macro irregularities between adherends but also into fine irregularities of bonding points, without leaving any gaps at the molecular level. As an index of this feature, the tanδ peak value of the shortcut fiber of the present invention is preferably 0.10 or more.

**[0099]** The "tanδ" is measured using a dynamic viscoelasticity automatic analyzer (RHEOVIBRON). A sample is held at a chuck distance of 30 mm, a tension of 0.07 g/dtex is applied thereto, and the measurement is performed at a heating rate of 3°C/min and a frequency of 110 Hz.

**[0100]** The tanδ peak value corresponds to the amount of molecular chains that can move without being restrained at a given temperature, and a larger value means a higher fluidity of a material at the temperature. When the tanδ peak value is 0.10 or more, the softened/fluidized shortcut fiber is likely to penetrate between adherends and can thereby firmly bond the adherends together; therefore, this range is mentioned as one example of a preferred range in the present invention.

**[0101]** Further, as a more preferred range, for example, when the tanδ peak value is 0.15 or more, the softened/fluidized shortcut fiber is likely to penetrate into irregularities on the surfaces of adherends as well, so that the detachment of the shortcut fiber adhered to the adherends can be inhibited. As a still more preferred range, for example, when the tanδ peak value is 0.20 or more, the shortcut fiber penetrates even into fine irregularities on the surfaces of adherends at the molecular level, so that the detachment of the shortcut fiber adhered to the adherends can be markedly inhibited.

**[0102]** Taking into consideration the practical use of the shortcut fiber of the present invention as a sheet-like material or a fiber product, a polymer constituting the shortcut fiber of the present invention is preferably excellent in heat resistance, and the polymer preferably has a melting point of 180°C or higher.

**[0103]** The "melting point" of the polymer is determined as follows.

**[0104]** The polymer is dried to a moisture content of 200 ppm or less using a vacuum dryer, and about 5 mg of the thus dried polymer is weighed and subjected to DSC measurement using a differential scanning calorimeter (DSC) in which the polymer is heated from 0°C to 320°C at a heating rate of 16°C/min and then maintained at 320°C for 5 minutes. The melting point is calculated from a melting peak observed during the heating process. The measurement is performed three times per sample, and an arithmetic mean of the thus measured values is defined as the melting point of the polymer in the present invention. When plural melting peaks are observed, a melting peak top on the highest temperature side is defined as the melting point.

**[0105]** When the melting point of the polymer constituting the shortcut fiber of the present invention is 180°C or higher, even in a case where a sheet-like material formed of the shortcut fiber is processed in various ways before use, the bonding strength of the shortcut fiber is unlikely to be deteriorated due to softening caused by heat applied during the processing step, and the sheet-like material thus exhibits excellent processability; therefore, this range is mentioned as one example of a preferred range.

**[0106]** Further, as a more preferred range, for example, when the melting point of the polymer constituting the shortcut fiber is 200°C or higher, even in a case where other thermoplastic resin having a low melting point is applied, the mechanical properties of the sheet-like material are unlikely to be deteriorated by softening of bonding points, so that the sheet-like material can be processed in a favorable manner.

**[0107]** As a still more preferred range, for example, when the melting point of the polymer constituting the shortcut fiber is 220°C or higher, even in a case where the tension is high in the above-described processing step in which heat is applied, the bonding points can maintain a sufficiently solidified state, so that various processes can be applied without deteriorating the mechanical properties.

**[0108]** The shortcut fiber of the present invention maintains an amorphous state before the thermal bonding step and is thermally crystallized after the thermal bonding step, whereby the shortcut fiber of the present invention can exhibit a heat resistance sufficient for practical use while realizing strong thermal bonding in a low-temperature heat treatment. Examples of polymers based on the above include polyethylene terephthalate and copolymers thereof, as well as polyethylene naphthalate and polyphenylene sulfide, and as-spun fibers obtained by spinning any of these polymers are likely to maintain an amorphous state in a room-temperature environment, and are allowed to strongly bond adherends together through softening/fluidization based on glass transition and to subsequently crystallize, whereby excellent heat resistance and chemical resistance can be exerted.

**[0109]** As described above, by using the shortcut fiber of the present invention as a binder fiber responsible for bonding of fibers in a nonwoven fabric, a structure in which skeleton fibers are strongly and uniformly bonded together is formed in the nonwoven fabric. As an index of this structure, at a cross section of the nonwoven fabric, a variation in bonding ratio $P_b/P_m$, which is a ratio between the circumferential length $P_m$ of a fiber cross section and the bonding length $P_b$ that is the length of a portion of $P_m$ in contact with a bonded part, is preferably 80% or less.

**[0110]** The term "bonded part" used herein refers to a part where the binder fiber constituting the nonwoven fabric is softened/fluidized by heating and thereby bond adjacent skeleton fibers and, in this bonded part, the binder fiber may have completely lost its pre-softening/fluidization fiber form, or may partially maintain the fiber form. The variation in bonding ratio $P_b/P_m$ is determined as follows.

**[0111]** A cross section of the nonwoven fabric of the present invention is cut out using a razor or the like, and this cross section is photographed under a scanning electron microscope (SEM) at a magnification that allows observation of the nonwoven fabric over its entire thickness direction.

**[0112]** For a cross section of a single fiber (skeleton fiber) in the thus obtained image, the length of the outer periphery of the cross section is measured using an image analysis software (WINROOF). This value is defined as the circumferential length $P_{m1}$ of the single fiber, and rounded off to two decimal places to be expressed in μm. Of this circumferential length $P_{m1}$, the length of an outer peripheral portion bonded with a binder fiber is measured using an image analysis software (WINROOF). This value is defined as the bonding length $P_{b1}$ of the single fiber, and rounded off to two decimal places to be expressed in μm. At a cross section of the nonwoven fabric, the binder fiber may be in the form of being softened/fluidized by the thermal bonding step and impregnated between skeleton fibers (although this binder fiber may already have lost its form as a fiber, it may be still described as "binder fiber" below for convenience); however, since a contrast is generated by a difference in unevenness between the skeleton fibers and the binder fiber impregnated therebetween, the interface between the skeleton fibers and the binder fiber can be identified. From the circumferential length $P_{mn}$ and the bonding length $P_{bn}$, the bonding ratio $P_{bn}/P_{mn}$ of the single fiber is calculated as an integer (rounded off to the nearest whole number) using the following equation.

$$P_{bn}/P_{mn}\ (\%) = P_{bn}\ (\mu m)/P_{mn}\ (\mu m) \times 100$$

**[0113]** The above-described measurement is performed for 100 fibers to calculate the bonding ratio $P_{bn}/P_{mn}$ (n = 1 to 100) of each skeleton fiber, and an arithmetic mean and a standard deviation of the thus obtained values are calculated. An integer (unit: %) determined by rounding off the coefficient of variation, which is obtained by dividing the standard deviation by the arithmetic mean, to the nearest whole number is defined as the variation in bonding ratio $P_b/P_m$ according to the present invention.

**[0114]** In order to allow the nonwoven fabric of the present invention to exhibit excellent mechanical properties, it is preferred that the skeleton fibers be uniformly bonded together in the whole nonwoven fabric and, as an index of this feature, the variation in bonding ratio $P_b/P_m$ is preferably 80% or less. In this range, the ratio of the skeleton fibers that are not bonded by a binder fiber is low, and the skeleton fibers hardly slip out; therefore, excellent mechanical properties can be exerted.

**[0115]** Based on this technical idea, a smaller variation in bonding ratio $P_b/P_m$ leads to more uniform bonding of the skeleton fibers in the whole nonwoven fabric and thus superior mechanical properties; therefore, the variation in bonding ratio $P_b/P_m$ is more preferably 70% or less. In this range, the skeleton fibers are ensured to have a certain bonding length in the whole nonwoven fabric, so that the breakage of the nonwoven fabric that originates from a bonding point having an extremely short bonding length is unlikely to occur.

**[0116]** The variation in bonding ratio $P_b/P_m$ is still more preferably 60% or less and, in this range, since the skeleton fibers in the whole nonwoven fabric can uniformly bear a stress, the nonwoven fabric can exhibit excellent mechanical properties even when it is thin and has a low basis weight.

**[0117]** From the standpoint of the bonding strength between the skeleton fibers and the binder fibers at each bonding point, the higher the bonding ratio $P_b/P_m$, the more preferred it is and, when the bonding ratio $P_b/P_m$ is 25% or higher, the skeleton fibers are strongly bonded by the binder fibers and are thus not easily detached at their interface; therefore, this range is mentioned as one example of a preferred range.

**[0118]** Further, as a more preferred range, for example, when the bonding ratio $P_b/P_m$ is 30% or higher, strong bonding is obtained at the bonding points to such an extent that breakage of the skeleton fibers themselves causes breakage of a sheet-like material, so that the mechanical properties of the skeleton fibers can be sufficiently exerted as the mechanical properties of the sheet-like material.

**[0119]** One example of a method of producing the shortcut fiber and the nonwoven fabric of the present invention will now be described.

**[0120]** The shortcut fiber of the present invention can be produced by cutting a long fiber having the characteristic cross-sectional morphology of the present invention to a desired length. Specifically, the shortcut fiber of the present invention is produced by preparing a tow in which several tens to several ten thousands of such long fibers are bundled, and subsequently cutting the tow to a desired fiber length using a cutting machine such as a guillotine cutter, a slicing machine, or a cryostat. As the long fiber, a fiber composed of a single polymer may be produced; however, for the production of a fiber having a minor axis length of 2,000 nm or less, which is a characteristic feature of the present invention, by means of a conventional technology without any problem in operability, there may be a limitation in terms of spinning conditions. Therefore, it is preferred to employ a method of generating the shortcut fiber from a fiber having a flat cross section that can be produced by removing an easily soluble polymer from a multilayer laminated fiber composed of a hardly soluble polymer and the easily soluble polymer (FIG. 3).

**[0121]** The term "multilayer laminated fiber" used herein refers to a fiber having a cross section of a multilayer laminated structure in which two or more kinds of polymers are laminated alternately, in the same order, or in random order. As for the form of this laminated structure, the laminated structure may take not only a form in which a hardly soluble polymer and an easily soluble polymer are alternately laminated in one direction, but also a form in which the polymers are laminated radially from the center of the fiber toward the outer layer, a form in which the polymers are irregularly laminated at a fiber cross section, or a combination of these forms.

**[0122]** A method of producing the multilayer laminated fiber of the present invention is selected as appropriate in accordance with the production process in possession and the polymers to be used; however, it is preferred to employ a melt-spinning method from the standpoint of obtaining excellent productivity.

**[0123]** The multilayer laminated fiber produced by a melt-spinning method may be composed of melt-moldable polymers, such as polyethylene terephthalate or a copolymer thereof, polyethylene naphthalate, polybutylene terephthalate, polytrimethylene terephthalate, polypropylene, polyolefin, polycarbonate, polyacrylate, polyamide, polyphenylene sulfide, polylactic acid, and thermoplastic polyurethane. These polymers may contain various additives, examples of which include: inorganic substances, such as titanium oxide, silica, and barium oxide; coloring agents, such as carbon blacks, dyes, and pigments; flame retardants; fluorescent brighteners; antioxidants; and ultraviolet absorbers. When polymers containing these additives are selected, irregularities corresponding to the size of the fine particles of the respective additives are generated in each layer of the multilayer laminated fiber, so that any irregularities can be imparted to the fiber generated from these polymers.

**[0124]** The multilayer laminated fiber is produced by spinning two or more kinds of polymers selected from the above-exemplified polymers and, from the standpoint of forming a stable laminated structure, a combination of the polymers is also important. In other words, a smaller difference in solubility parameter (SP value) between the polymers to be combined leads to the formation of a more favorable laminated structure without interlayer merging and the like, and it is thus preferred to select the polymers such that the difference in solubility parameter between two kinds of polymers forming an interface is 3.0 or less.

**[0125]** The term "solubility parameter (SP value)" used herein refers to a parameter that reflects the cohesive force of a substance defined by (evaporation energy/molar volume)$^{1/2}$, and can be calculated from the values listed in, for example, "Plastics Data Book" (coedited by Asahi Kasei Amidas Corporation/Plastic Editorial Department, p.189). An absolute value obtained by subtracting the solubility parameter of one component from the solubility parameter of the other component means the difference in solubility parameter in the present invention.

**[0126]** Further, by using polymers that are different in solubility, an easily soluble polymer of the multilayer laminated fiber can be removed to efficiently generate a shortcut fiber composed of a hardly soluble polymer. For example, when the polymers constituting the multilayer laminated fiber are a combination of an easily-alkali-soluble polyester and a hardly-alkali-soluble polyester, an easily-alkali-soluble polyester and a polyphenylene sulfide (hardly soluble in alkali), or an easily-alkali-soluble polyester and a polyamide (hardly soluble in alkali), a shortcut fiber composed of a hardly-alkali-soluble polymer is generated in a favorable manner by an alkali reduction treatment. Particularly, as the easily soluble polyester, from the standpoint of spinnability and ease of dissolving the polyester in a low-concentration aqueous solvent, it is preferred to use a polyester copolymerized with a polyethylene glycol or sodium sulfoisophthalate alone, or a combination thereof. As a combination of polymers suitable for the generation of a shortcut fiber from the multilayer laminated fiber, for example, considering the relationship of melting points, a polyethylene terephthalate copolymerized with 5% by mole to 15% by mole of sodium 5-sulfoisophthalate, and a polyethylene terephthalate copolymerized with 5% by mole to 15% by mole of a polyethylene glycol having a weight-average molecular weight of 500 to 3,000 in addition to the above-mentioned sodium 5-sulfoisophthalate may be used as easily soluble components, and a polyethylene terephthalate, a polyphenylene sulfide, or polyamide-6 may be used as a hardly soluble component.

**[0127]** At the time of spinning the multilayer laminated fiber, the spinning temperature is a temperature at which, among the two or more kinds of polymers, mainly a polymer having a high melting point or viscosity exhibits fluidity. The temperature at which a polymer exhibits fluidity may vary depending on the molecular weight; however, the spinning temperature may be set in a range from the melting point of this polymer to a temperature of (melting point + 60°C). At this temperature or lower, thermal decomposition and the like of the polymer do not occur in a spinning head or a spinning pack, and a reduction in the molecular weight is thus inhibited, which is preferred. The multilayer laminated fiber can be stably produced by controlling the discharge amount in the spinning to be 0.1 g/min·hole to 20.0 g/min·hole. Further, a ratio of components A and B can be selected in a range of 5/95 to 95/5 in terms of weight ratio (component A/component B) based on the discharge amount. When a shortcut fiber is generated from the multilayer laminated fiber using a hardly soluble polymer as the component A and an easily soluble polymer as the component B, from the standpoint of the productivity of flat ultrafine fiber, the higher the ratio of the hardly soluble polymer, the more preferred it is. When the component A/component B ratio is 50/50 to 90/10, the multilayer laminated fiber can be stably obtained without any partial disruption in its laminated structure, so that a shortcut fiber can be obtained with high production efficiency.

**[0128]** By inserting the polymers that are melted and fluidized at the above-described spinning temperature into a spinneret, a composite flow is formed, and this enables to produce a fiber having a multilayer laminated cross section. As the spinneret to be used, any conventionally known composite spinneret that combines two or more kinds of polymers can be applied to carry out the fiber production; however, in order to stably form a special multilayer laminated cross section, it is preferred to use the below-described composite spinneret.

**[0129]** The composite spinneret preferably used in the present invention is, for example, a composite spinneret in which three kinds of members, namely a measuring plate D, a composite plate E, and a discharge plate F, are laminated as illustrated in FIG. 4. Incidentally, FIG. 4 illustrates an example where two kinds of polymers, namely components A and B, are used and, if necessary, three or more kinds of polymers may be used for the fiber production.

**[0130]** This composite spinneret plays a role in: by means of the measuring plate D, measuring the amount of the respective polymers per hole of the composite plate E; by means of the composite plate E, merging the thus measured different kinds of polymer flows to form a composite flow, and dividing and re-merging this composite flow to double the number of layers constituting the composite flow; and, by means of the discharge plate F, compressing and discharging the composite flow formed by the composite plate E. The term "composite flow" used herein means a fluid in which a cross section perpendicular to a flow direction is composed of two or more kinds of polymers.

**[0131]** A fine flow path of the composite plate E is configured such that it minimizes the disturbance of the flow therein, and thereby enables the production of a multilayer laminated fiber. Incidentally, the above-described fine flow path may be said to have the same feature as a conventional static mixer in terms of merging or dividing fluids in the flow path, however, an ordinary static mixer has a flow path design aimed at mixing two kinds of polymers, and the interface of a layered composite flow is likely to be disturbed; therefore, in order to inhibit this, a method using the above-described composite spinneret is preferably employed.

**[0132]** Although not illustrated in the drawing to avoid confusion in the description of the composite spinneret, as a member to be arranged above the measuring plate D, a member that forms a flow path may be used in accordance with a spinning machine and a spinning pack. By designing the measuring plate D to fit with an existing flow path member, any existing spinning pack and its members can be utilized as-is. Therefore, it is not necessary to use a spinning machine exclusively made for the above-described spinneret.

**[0133]** Practically, plural flow path plates may be stacked between the flow path and the measuring plate D, or between the measuring plate D and the composite plate E. The purpose of this is to obtain a configuration in which flow paths for efficiently transferring the polymers in the cross-sectional direction of the spinneret and the cross-sectional direction of a monofilament are provided, and the polymers are introduced to the composite plate E therethrough.

**[0134]** The composite flow discharged from the discharge plate F is cooled and solidified, and an oil agent is subsequently applied thereto, after which the resultant is taken up by a roller having a prescribed peripheral speed, whereby a composite fiber is obtained. The take-up speed may be determined based on the discharge amount and the intended fiber diameter and, in order to stably produce a composite fiber used in the present invention, the take-up speed is preferably in a range of 100 to 7,000 m/min. When the composite fiber is expected to be used as a binder fiber that exhibits thermal bondability, the composite fiber is more preferably taken up as an as-spun fiber in a range of 100 to 3,000 m/min. From the standpoint of improving the orientation of this multilayer laminated fiber and thereby improving the mechanical properties, the multilayer laminated fiber may be subjected to drawing. This drawing may be performed after the multilayer laminated fiber is once wound in the spinning step, or may be continuously performed without the multilayer laminated fiber being once wound. As for the drawing conditions, for example, in the case of a fiber composed of a thermoplastic polymer that is generally melt-spinnable, the fiber is easily drawn in the fiber axis direction, heat-set, and then wound in a drawing machine including one or more pairs of rollers, by means of a peripheral speed ratio between a first roller set at a temperature of not lower than the glass transition temperature but not higher than the melting point and a second roller set at a temperature equivalent to the crystallization temperature, as a result of which a composite fiber having such a composite cross section as illustrated in FIG. 3 can be obtained. An upper limit of the temperature of the first roller is preferably a temperature at which the path of the fiber is not disturbed in a preheating process and, for example, in the case of using a polyethylene terephthalate having a glass transition temperature of about 70°C, the preheating temperature is usually set to about 80°C to 95°C. When the composite fiber is expected to be used as a binder fiber, the crystallinity thereof can be maintained to be low by directly using the composite fiber as an as-spun fiber without drawing.

**[0135]** An example of employing a melt-spinning method has been described thus far; however, it is needless to say that, by using the above-described composite spinneret, the multilayer laminated fiber used in the present invention can also be produced by a spinning method that uses a solvent, such as solution spinning. Several tens to several ten thousands of the thus obtained multilayer laminated fibers are bundled into a tow, and this tow is cut to a desired fiber length and subsequently removed of the easily soluble polymer, whereby the shortcut fiber of the present invention can be obtained.

**[0136]** In order to obtain a fiber dispersed liquid containing the shortcut fiber of the present invention, the above-described multilayer laminated fiber cut to a desired fiber length may be immersed in a solvent or the like capable of dissolving the easily soluble polymer to remove the easily soluble polymer. When the easily soluble polymer is a copolymerized polyethylene terephthalate copolymerized with sodium 5-sulfoisophthalate, polyethylene glycol, or the like, an alkaline aqueous solution such as an aqueous sodium hydroxide solution can be used. In this case, a bath ratio of the multilayer laminated fiber and the alkaline aqueous solution (weight of multilayer laminated fiber (g)/weight of alkaline aqueous solution (g)) is preferably 1/10,000 to 1/5, more preferably 1/5,000 to 1/10. By controlling the bath ratio to be in this range, the generation of agglutinate-like dispersion defects caused by entanglement of the shortcut fiber with one another at the time of dissolving the easily soluble polymer can be inhibited.

**[0137]** In this case, the alkali concentration of the alkaline aqueous solution is preferably 0.1 to 10% by weight, more preferably 0.5 to 5% by weight. By controlling the alkali concentration to be in this range, the dissolution of the easily soluble polymer can be completed in a short time, so that a fiber dispersed liquid in which the shortcut fiber of the present invention is uniformly dispersed can be obtained without unnecessarily deteriorating the hardly soluble polymer. Further, although the temperature of the alkaline aqueous solution is not particularly limited, by controlling this temperature to be 50°C or higher, the progress of the dissolution of the easily soluble polymer can be accelerated. When the shortcut fiber is expected to be used as a binder fiber, the temperature of the alkaline aqueous solution is preferably 40°C to 70°C since this can accelerate the progress of hydrolysis while maintaining the crystallinity of the fiber to be low.

**[0138]** In this fiber dispersed liquid, additives may be used as required for the purposes of inhibiting the agglutination and precipitation of the shortcut fiber over time and increasing the viscosity of the medium. Examples of the types of the additives include natural polymers, synthetic polymers, organic compounds, and inorganic compounds. Examples of an additive for inhibiting the agglutination of fibers include cationic compounds, nonionic compounds, and anionic compounds. The amount of these additives is preferably 0.001 to 10 equivalents with respect to the weight of the shortcut fiber. In this range, the additives can sufficiently provide their functions.

**[0139]** The fiber dispersed liquid obtained by the above-described production method can be used as-is. Alternatively, the fiber dispersed liquid may be used after neutralization of its medium with an acid such as hydrochloric acid or acetic acid, or dilution with water after the dehydration step. It is preferred to neutralize the medium in this manner from the standpoint of ease of handling.

**[0140]** As described above, the fiber dispersed liquid in which the shortcut fiber of the present invention is uniformly dispersed in a medium not only can be used as-is and developed as a high-performance adsorbent or reinforcing material, but also can be developed into a wide range of materials, such as high-performance filter media, separation membranes, and sound-absorbing materials when the fiber dispersed liquid is made into a fiber assembly by removing the medium by a wet-laid papermaking process, a spray process, or the like.

**[0141]** In the case of forming a nonwoven fabric by a wet-laid papermaking process, for example, skeleton fibers that constitute the skeleton of the nonwoven fabric, binder fibers that adhere shortcut fibers together when heat-treated, and functional shortcut fibers that form a special structure are added to water and stirred after the pulping step or the refining step if necessary, and papermaking is preformed using the resulting fiber dispersed liquid for papermaking in which the various shortcut fibers are uniformly dispersed. In these steps of preparing the fiber dispersed liquid for papermaking, the dispersibility can be adjusted by changing the amount of the shortcut fibers to be added, the amount of the water medium, the stirring time, and the like, and the fiber dispersed liquid for papermaking is preferably adjusted based on the dispersion state of the various shortcut fibers.

**[0142]** For the purpose of producing a nonwoven fabric having a dense structure in a stable manner while inhibiting the agglutination of the shortcut fibers added to water, a dispersant may be incorporated if necessary.

**[0143]** Examples of the type of the dispersant include natural polymers, synthetic polymers, organic compounds, and inorganic compounds. Examples of an additive for inhibiting the agglutination of fibers include cationic compounds, nonionic compounds, and anionic compounds. Thereamong, for the purpose of improving the dispersibility, it is preferred to use an anionic compound from the standpoint of electric repulsion in the water medium. In the production according to the present invention, the amount of the dispersant to be added is preferably 0.001 to 10 equivalents with respect to the weight of the fibers constituting the nonwoven fabric and, in this range, the dispersibility of the fibers can be improved, and the nonwoven fabric of the present invention can be produced, without deteriorating the workability in wet-laid papermaking.

**[0144]** When wet-laid papermaking is employed as a production method of the nonwoven fabric, the various shortcut fibers used in the fiber dispersed liquid for papermaking preferably have a fiber length of 0.3 to 30.0 mm and, in this range, the dispersibility of the shortcut fibers in the fiber dispersed liquid for papermaking is maintained, so that the wet-laid papermaking can be carried out in a favorable manner.

**[0145]** The fiber length of the shortcut fibers can be adjusted as appropriate in accordance with the intended use. Generally, as the fiber length is increased, entanglement of the shortcut fibers tends to increase, and this tends to improve the mechanical properties and the form stability of the nonwoven fabric; however, since entanglement and agglutination of the shortcut fibers tend to occur during stirring of the fiber dispersed liquid for papermaking, it is preferred to adjust the fiber length in accordance with the specification and the expected design of the shortcut fibers mixed in the fiber dispersed liquid for papermaking.

**[0146]** From the standpoint of stabilizing the form of the nonwoven fabric in practical use and the like and improving the mechanical properties, the binder fibers are preferably mixed in an amount of 5 to 70% by weight and, in this range, not only the dense structure of the nonwoven fabric can be fixed and the sheet strength can be improved, but also the smoothness of the surface of the nonwoven fabric can be improved. Further, skeleton fibers are preferably mixed as other fibers so as to serve as the skeleton of the nonwoven fabric, and the amount thereof can be adjusted as appropriate to be 10 to 95% by weight with respect to a total weight of the nonwoven fabric. When skeleton fibers are mixed as other fibers, the shortcut fiber of the present invention forms a cross-linked structure having the skeleton fibers on both ends, and the space between the skeleton fibers is filled with the shortcut fiber, as a result of which a nonwoven fabric having complex fine voids can be produced.

**[0147]** With regard to the skeleton fibers and the binder fibers that are mentioned above, the fiber diameter and the fiber cross-sectional shape can be selected as appropriate in accordance with the intended purpose; however, in consideration of producing a nonwoven fabric having a special structure that is dense but has complex voids formed therein, fibers having a flat cross section in which the major axis length is greater than the minor axis length are preferably used also as the skeleton fibers and the binder fibers and, in this case, such fibers smoothly form a laminated structure with the shortcut fiber of the present invention, so that a nonwoven fabric having excellent denseness can be produced.

**[0148]** The fiber dispersed liquid for papermaking prepared from the above-described various shortcut fibers is diluted to a certain concentration and then dehydrated on an inclined wire, a circular net, or the like to form a nonwoven fabric. Examples of a device used for papermaking include a cylinder machine, a Fourdrinier machine, an inclined TANMO machine, and a paper machine in which the above-described machines are combined. In the papermaking step, the papermaking speed, the amount of the fibers, and the amount of the water medium are adjusted in accordance with the dispersibility of the fibers in the fiber dispersed liquid for papermaking as well as the desired basis weight, and the accumulation of the fibers during filtration is thereby controlled. The thus formed sheet-like material is put through the drying step and the heat-treatment step to remove water and adhere the binder fibers, whereby the nonwoven fabric of the present invention is produced. As a drying method, from the standpoint of drying the sheet and thermally boning the binder fibers at the same time, a method utilizing hot air ventilation (air-through) or a method of bringing the sheet into contact with a heated rotating roll (e.g., a heated calender roll) is preferably employed.

## Examples

**[0149]** The shortcut fiber of the present invention will now be described concretely by way of Examples thereof.

**[0150]** The following evaluations were performance for Examples and Comparative Examples.

### A. Melt Viscosity of Polymer

**[0151]** A polymer in the form of chips was dried to a moisture content of 200 ppm or less using a vacuum dryer, and the melt viscosity was measured at a strain rate of 1,216 $s^{-1}$ using CAPIROGRAPH 1B manufactured by Toyo Seiki Seisaku-sho, Ltd. The measurement temperature was set to be equal to a spinning temperature, and the melt viscosity measured at 1,216 $s^{-1}$ is indicated below for each of Examples and Comparative Examples. The period from the addition of a sample to a heating furnace to the start of the measurement was 5 minutes, and the measurement was performed in a nitrogen atmosphere.

### B. Melting Point of Polymer

**[0152]** A polymer in the form of chips was dried to a moisture content of 200 ppm or less using a vacuum dryer, and about 5 mg of the chips was weighed and subjected to DSC measurement using a differential scanning calorimeter (DSC) Q2000 manufactured by TA Instruments Inc. in which the chips were heated from 0°C to 300°C at a heating rate of 16°C/min and then maintained at 300°C for 5 minutes. The melting point was calculated from a melting peak observed during the heating process. The measurement was performed three times per sample, and an average value thereof was defined as the melting point. When plural melting peaks were observed, a melting peak top on the highest temperature side was defined as the melting point.

C. Difference in Solubility Parameter

**[0153]** The solubility parameter (SP value), which reflects the cohesive force of a substance defined by a square root of (evaporation energy/molar volume), can be determined by immersing a polymer in various solvents and taking the (evaporation energy/molar volume) value of each solvent giving a maximum swelling pressure as the (evaporation energy/molar volume) value of the polymer. The SP value determined in this manner is listed in, for example, "Plastics Data Book" (coedited by Asahi Kasei Amidas Corporation/Plastic Editorial Department, p.189), and this value was used. The difference in solubility parameter between polymers to be combined was calculated as an absolute value of (SP value of component A - SP value of component B).

D. Fineness

**[0154]** The weight of 100 m of a composite fiber was measured, and a 100-fold value of the thus measured value was calculated. This measurement was repeated 10 times, and an average value thereof was defined as the fineness (dtex). Further, a value obtained by dividing the fineness by the number of filaments was defined as the single-fiber fineness (dtex).

E. Specific Surface Area

**[0155]** A fiber bundle formed of shortcut fibers was embedded in an embedding agent such as an epoxy resin, frozen using an FC-4E cryosectioning system manufactured by Reichert Inc., and then cut using a Reichert-Nissei ULTRACUT N (ultramicrotome) equipped with a diamond knife, after which an image of the resulting cut surface was photographed under a H-7100FA transmission electron microscope (TEM) manufactured by Hitachi, Ltd. at a magnification that allowed observation of a cross section. Using an image analysis software (WINROOF), a measurement start point was set at an arbitrary position on the outer periphery of the cross section, and the length following the outer periphery on a series of images from the measurement start point back to the measurement start point was measured. The thus measured value was defined as the circumferential length of a single fiber and expressed as an integer (rounded off to the nearest whole number) in nm. Further, the area of a part enclosed by this circumferential length was measured using the image analysis software (WINROOF), and the thus obtained value was defined as the cross-sectional area of the single fiber and expressed as an integer (rounded off to the nearest whole number) in $nm^2$. From the circumferential length and the cross-sectional area, the specific surface area of the single fiber was calculated using the following equation and rounded off to four decimal places.

Specific surface area ($nm^{-1}$) = Circumferential length (nm)/Cross-sectional area ($nm^2$)

**[0156]** The above-described measurement was performed for 100 fibers to calculate the specific surface area of each fiber, and an arithmetic mean of the thus obtained values was defined as the specific surface area of the present invention.

F. Flatness

**[0157]** For the above-photographed fiber cross section, the maximum length of the cross section of a single fiber was measured using the image analysis software (WINROOF), and the thus measured value was defined as the major axis length of the single fiber and expressed as an integer (rounded off to the nearest whole number) in nm. Subsequently, the length of a line segment that is perpendicular to a line segment having the maximum length and intersects the fiber cross section at a midpoint of the maximum length was measured, and the thus measured value was defined as the minor axis length of the single fiber and expressed as an integer (rounded off to the nearest whole number) in nm. From the major axis length and the minor axis length, the flatness of the single fiber was calculated using the following equation.

Flatness = Length (nm) in major axis direction/Length (nm) in minor axis --> direction

**[0158]** The above-described measurement was performed for 100 fibers to calculate the flatness of each fiber, and an arithmetic mean of the thus obtained values was rounded off to the nearest whole number and defined as the flatness.

G. Average Minor Axis Length

**[0159]** The average minor axis length was calculated as an integer (rounded off to the nearest whole number) in nm of an arithmetic mean of the minor axis length measured above for 100 fibers.

H. Variation (CV Value ) in Minor Axis Length

**[0160]** An arithmetic mean and a standard deviation of the minor axis length measured above for 100 fibers were calculated, and the variation in minor axis length was calculated as an integer in % by rounding off the coefficient of variation, which was obtained by dividing the standard deviation by the arithmetic mean, to the nearest whole number.

I. Degree of Unevenness

**[0161]** Using the above-photographed image of the fiber cross section, the length of a line segment that is perpendicular to a line segment having the maximum length and intersects the fiber cross section was measured at each of 10 points equally dividing the maximum length of the cross section, and an arithmetic mean and a standard deviation of the length measured at these 10 points were calculated. The standard deviation was divided by the arithmetic mean, and the resulting value in % was rounded off to the nearest whole number to determine the degree of unevenness of a single fiber (also see FIG. 2). The same measurement was performed for cross sections of 10 fibers, and an arithmetic mean of the degree of unevenness that was calculated for the 10 fibers was defined as the degree of unevenness.

J. Aspect Ratio

**[0162]** An image of a fiber bundle formed of shortcut fibers is photographed under a microscope at a magnification at which at least 10 shortcut fibers can be observed to measure their full length. The fiber length is measured for 10 shortcut fibers randomly extracted from the photographed image. The term "fiber length" used herein refers to the length of a single fiber in the longitudinal direction, which is measured in a two-dimensionally photographed image using an image analysis software and rounded off to one decimal place in mm. The above operation is performed for 10 images that are photographed in the same manner, and an arithmetic mean of the fiber length of 100 fibers is defined as the fiber length in the present invention. From a value obtained by converting this fiber length into nanometers and the above-determined average minor axis length, the aspect ratio is calculated using the following equation and rounded off to the nearest whole number.

$$\text{Aspect ratio} = \text{Fiber length (nm)}/\text{Average minor axis length (nm)}$$

K. Dispersion Index in Low-Speed Stirring

**[0163]** A fiber dispersed liquid, in which a shortcut fiber was dispersed in an aqueous medium such that the shortcut fiber concentration was 0.01% by weight with respect to a total amount of the fiber dispersed liquid, was stirred at 100 rpm for 30 minutes using a stirrer, and then put into a 20-mL screw tube bottle manufactured by AS ONE Corporation. This screw tube bottle was photographed from a side using a digital camera under transillumination, and the thus obtained image was converted to a monochrome image using an image processing software (WINROOF), after which a 256-gradation luminance histogram (ordinate: frequency (number of pixels), abscissa: luminance; also see FIG. 5) was obtained, and a standard deviation of the luminance value in one image was calculated. The same operation was performed for 10 images, and an arithmetic mean of the standard deviation of the luminance values of these images was determined and rounded off to one decimal place. The thus obtained value was defined as a dispersion index in low-speed stirring.

L. Dispersion Index in High-Speed Stirring

**[0164]** A fiber dispersed liquid, in which shortcut fibers were dispersed in an aqueous medium such that the shortcut fiber concentration was 0.01% by weight with respect to a total amount of the fiber dispersed liquid, was stirred at 19,000 rpm for 30 minutes using a stirrer, and then put into a 20-mL screw tube bottle manufactured by AS ONE Corporation. This screw tube bottle was photographed from a side using a digital camera under transillumination, and the thus obtained image was converted to a monochrome image using an image processing software (WINROOF), after which a 256-gradation luminance histogram (ordinate: frequency (number of pixels), abscissa: luminance; also see FIG. 5) was obtained, and a standard deviation of the luminance value in one image was calculated. The same operation was performed for 10 images, and an arithmetic mean of the standard deviation of the luminance values of these images was determined and rounded off to one decimal place. The thus obtained value was defined as a dispersion index in high-speed stirring.

M. Evaluation of Dispersibility

**[0165]** Using the dispersion index in low-speed stirring and the dispersion index in high-speed stirring that were measured in the above-described manner, the dispersibility was evaluated based on the following criteria.

**[0166]** Good: The dispersion index in low-speed stirring and the dispersion index in high-speed stirring were both less than 30.

**[0167]** Poor: Either the dispersion index in low-speed stirring or the dispersion index in high-speed stirring was 30 or more.

N. Average Pore Size and Maximum Frequency of Pore Size Distribution

**[0168]** Using a porous material automatic pore measurement system PERM-POROMETER (manufactured by Porous Materials, Inc.), the pore size was determined in accordance with a bubble point method (based on ASTM F-316-86). Three pieces of a nonwoven fabric were cut out as measurement samples, and the pore size distribution was measured for each of the measurement samples using GALWICK (surface tension: 16 mN/m) as a measurement liquid having a known surface tension. An average flow rate diameter obtained by automatic calculation was defined as the average pore size, and an average value of the samples that was rounded off to one decimal place was used.

**[0169]** As for the frequency of the pore size distribution, the distribution of values obtained by automatic calculation was determined with a class interval of 0.1 μm, and a value at which the frequency of the pore size distribution was maximum was defined as the maximum frequency. This value was converted into a percentage to determine an average of the maximum frequency of the samples in %, and a value obtained by rounding off the thus determined average to one decimal place was used.

O. Basis Weight

**[0170]** The weight of a nonwoven fabric cut out into a square piece of 250 mm × 250 mm was measured, converted into the weight (g) per unit area (1 $m^2$), and then rounded off to the nearest whole number, and thus obtained integer value was defined as the basis weight of the nonwoven fabric.

P. Thickness

**[0171]** The thickness of a nonwoven fabric was measured in mm using a dial thickness gauge SM-114 (manufactured by TECLOCK Corporation, probe shape: 10 mmφ, scale interval: 0.01 mm, measuring force: 2.5 N or less). The measurement was performed at five random spots per sample, and a value obtained by rounding off an average of the measured values to two decimal places was defined as the thickness of the nonwoven fabric.

Q. Density of Nonwoven Fabric

**[0172]** The density of a nonwoven fabric is calculated by the equation (1) from the above-determined basis weight and thickness. The density was determined for 10 samples, and a simple average value thereof was rounded off to two decimal places and defined as the density of the nonwoven fabric.

R. Arithmetic Mean Roughness (Ra) of Nonwoven Fabric Surface

**[0173]** The surface of a nonwoven fabric was observed under a laser microscope VK-X200 (manufactured by KEYENCE Corporation) and measured in accordance with JIS B0601 using an image analysis software VK-H1XA (manufactured by KEYENCE Corporation). The measurement was performed at five arbitrary spots per sample, and a value obtained by rounding off an average of the measured values to two decimal places was defined as Ra.

S. Sound Absorption Coefficient

**[0174]** The sound absorption coefficient was measured in accordance with JIS A1405-1 (2007) "Determination of normal incidence sound absorption coefficient of building materials by tube method" using "Automatic Normal Incident Sound Absorption Coefficient Measurement System" manufactured by Japan Electronic Instruments Co., Ltd. A 20-mm thick hard cotton formed of PET fibers having a fiber diameter of 15 μm was prepared as a support, and each nonwoven fabric sample was pasted to this support. The above-described measurement was evaluated for 10 samples, and the sound absorption coefficient at 1,000 Hz was determined to one decimal place in %, and a simple average value thereof was rounded off to the nearest whole number and defined as the sound absorption coefficient.

T. Crystallinity

**[0175]** Thermoplastic fibers were weighed in an amount of about 5 mg using an electronic balance and then set in a differential scanning calorimeter (DSC) Q2000 manufactured by TA Instruments Inc., and differential scanning calorimetry was performed in a nitrogen atmosphere at a heating rate of 16°C/min in a measurement temperature range of 50°C to 320°C.

**[0176]** In the thus obtained measurement results (DSC curve), the heat of crystallization ΔHc (J/g) and the heat of crystal fusion ΔHm (J/g) were calculated from the area of an exothermic peak and the area of an endothermic peak, respectively. When plural exothermic peaks and endothermic peaks were observed, the ΔHc and the ΔHm were each calculated from a total area of all peaks of the respective kinds. The measurement was performed three times per level at different positions, and arithmetic mean values were calculated to determine the ΔHc and the ΔHm, after which the crystallinity was calculated using the following equation and rounded off to the nearest whole number.

$$\text{Crystallinity (\%)} = (\Delta Hm - \Delta Hc)/\Delta Hm^0 \times 100$$

**[0177]** In this equation, $\Delta Hm^0$ represents the heat of complete crystal fusion (J/g), and is 140.1 (J/g) for PET, or 146.2 (J/g) for PPS.

U. Tanδ

**[0178]** The fiber dynamic viscoelasticity was measured using RHEOVIBRON DOV-II-EP manufactured by Orientec Co., Ltd. The peak top temperature and the peak value of tanδ were evaluated when a sample was held at a chuck distance of 30 mm, a tension of 0.07 g/dtex was applied thereto, and the measurement was performed at a heating rate of 3°C/min and a frequency of 110 Hz.

V. Bonding Ratio and Variation in Bonding Ratio

**[0179]** A cross section of a nonwoven fabric was cut out using a razor or the like, and this cross section was photographed under a scanning electron microscope S-5500 (SEM) manufactured by Hitachi High-Tech Corporation at a magnification that allowed observation of a sheet-like material over its entire thickness direction. For a cross section of a single skeleton fiber in the thus obtained image, the length of the outer periphery of the cross section was measured using an image analysis software (WINROOF). This value was defined as the circumferential length $P_{m1}$ of the single fiber, and rounded off to two decimal places to be expressed in μm. Of this circumferential length $P_{m1}$, the length of an outer peripheral portion bonded with a binder fiber was measured using an image analysis software (WINROOF). This value was defined as the bonding length $P_{b1}$ of the single fiber, and rounded off to two decimal places to be expressed in μm. At a cross section of the nonwoven fabric, the binder fiber was in the form of being softened/fluidized by the thermal bonding step and impregnated between skeleton fibers; however, since a contrast was generated by a difference in unevenness between the skeleton fibers and the binder fiber impregnated therebetween, the interface between the skeleton fibers and the binder fiber was identified. From the circumferential length $P_{mn}$ and the bonding length $P_{bn}$, the bonding ratio $P_{bn}/P_{mn}$ of the single fiber was calculated as an integer (rounded off to the nearest whole number) using the following equation.

$$P_{bn}/P_{mn}\ (\%) = P_{bn}\ (\mu m)/P_{mn}\ (\mu m) \times 100$$

**[0180]** The above-described measurement was performed for 100 fibers to calculate the bonding ratio $P_{bn}/P_{mn}$ (n = 1 to 100) of each skeleton fiber, and an arithmetic mean of the thus obtained values was defined as the bonding ratio $P_b/P_m$ according to the present invention. A standard deviation was calculated in the same manner, and an integer in % determined by rounding off the coefficient of variation, which was obtained by dividing the standard deviation by the arithmetic mean, to the nearest whole number was defined as the variation in bonding ratio $P_b/P_m$ according to the present invention.

W. Uniformity

**[0181]** The uniformity of a sheet-like material cut out into a square piece of 250 mm × 250 mm was visually observed and evaluated by the following three grades.

A: The sheet-like material had good uniformity with no fiber agglutinate therein.
B: Fiber agglutinates were observable in the sheet-like material.
C: Not only fiber agglutinates were observable in the sheet-like material, but also the sheet-like material was torn and pinholes were generated therein.

X. Strength

**[0182]** The value of a maximum point load was measured using TENSILON UTM-III-100 manufactured by Orientec Co., Ltd. under the following conditions: sample width = 15 mm, initial length = 20 mm, and tensile speed = 20 mm/min. A simple number average of five measured values was determined, and the strength (N/15 mm) of a sheet-like material was calculated and expressed as a value rounded off to the nearest whole number.

[Example 1]

**[0183]** A polyethylene terephthalate (PET, melt viscosity: 120 Pa·s, melting point: 254°C, SP value: 21.4 $MPa^{1/2}$), and a polyethylene terephthalate (SSIA-PEG-copolymerized PET, melt viscosity: 95 Pa·s, melting point: 233°C, SP value: 22.9 $MPa^{1/2}$) copolymerized with 8.0% by mole of sodium 5-sulfoisophthalate and 9% by weight of polyethylene glycol were prepared as components A and B, respectively. It is noted here that the difference in solubility parameter between these polymers was 1.5 $MPa^{1/2}$.
**[0184]** The components A and B were separately melted at 290°C and then introduced to a spinning pack integrated with the composite spinneret illustrated in FIG. 4 at a component A/component B composite ratio of 80/20, and the resulting composite polymer flow was discharged from the discharge holes. The composite plate was provided with a fine flow path G in which the components were alternately laminated in 128 layers, and the composite polymer flow was discharged in a composite form in which the two kinds of polymers were alternately laminated in multiple layers along one direction as illustrated in FIG. 3. The discharged composite polymer flow was cooled and solidified, and an oil agent was subsequently applied thereto, after which the resultant was wound at a spinning speed of 1,000 m/min to collect a 200 dtex-24 filament as-spun fiber (total discharge amount: 20 g/min). The thus wound as-spun fiber was drawn by a factor of 3.6 between rollers heated to 90°C and 130°C to obtain a 56 dtex-24 filament drawn fiber.
**[0185]** The thus obtained multilayer laminated fiber was cut to a fiber length of 0.6 mm, and the thus cut multilayer laminated fiber was immersed in a 1%-by-weight aqueous sodium hydroxide solution (bath ratio: 1/100) heated to 90°C for 30 minutes to dissolve and remove 99% or more of the easily soluble polymer SSIA-PEG-copolymerized PET, whereby a shortcut fiber having such a flat cross-sectional shape as illustrated in FIG. 1 was obtained.
**[0186]** When the specific surface area of the thus obtained shortcut fiber was measured from a cross section, the specific surface area was found to be extremely large at 0.0108 $nm^{-1}$. The cross section had a ribbon-like form in which the major axis and the minor axis were greatly different in length, with the flatness being 80 and the average minor axis length being 188 nm. The cross section had a variation in minor axis length of 36% and a degree of unevenness of 30% and, therefore, the minor axis length was moderately variable, and the surface had a moderate unevenness. Further, the shortcut fiber was in a state of being sufficiently crystallized at a crystallinity of 36%, and had a melting point of 254°C.
**[0187]** From this shortcut fiber, a fiber dispersed liquid, in which the shortcut fiber was dispersed in an aqueous medium such that the shortcut fiber concentration was 0.01% by weight with respect to a total amount of the fiber dispersed liquid, was prepared, and the dispersion state was evaluated by image processing after stirring the fiber dispersed liquid at each speed. In this process, if the fiber dispersion were uniform, the standard deviation (dispersion index) of the luminance would be small because of the absence of large light-dark difference, while if the fiber dispersion were not uniform, local light-dark differences would lead to a large standard deviation (dispersion index) of the luminance. When the dispersion index was evaluated, it was found that the shortcut fiber was uniformly dispersed regardless of the stirring speed with the dispersion index being 7 at low speed and 8 at high speed, and the shortcut fiber had both satisfactory specific surface area and excellent dispersibility. The results are shown in Table 1.

[Examples 2, 3, and 4]

**[0188]** Examples 2, 3, and 4 were carried out in the same manner as Example 1, except that the composite plate used in the method described in Example 1 was changed to a composite plate provided with a fine flow path in which the components were alternately laminated in 64 layers (Example 2), 32 layers (Example 3), or 16 layers (Example 4). The thus obtained multilayer laminated fibers were each subjected to the same cutting process and dissolution treatment as described above, whereby shortcut fibers having such a flat cross-sectional shape as illustrated in FIG. 1 were obtained. The results of evaluating these shortcut fibers are as shown in Table 1 and, in all of Examples 2 to 4, the shortcut fibers had a larger specific surface area than ordinary ultrafine fibers, and their cross sections had a high-flatness ultrathin ribbon-like shape with a moderate variation in minor axis length and a moderate degree of unevenness. As compared to Example 1, the dispersion index was slightly increased in both low-speed stirring and high-speed stirring as the flatness was reduced and the average minor axis length was increased; however, these shortcut fibers had both satisfactory specific surface area and excellent dispersibility. Further, these shortcut fibers had a crystallinity of 36% and a melting point of 254°C.

[Example 5]

**[0189]** Example 5 was carried out in the same manner as Example 1, except that the composite plate used in the method described in Example 1 was changed to a composite plate provided with a fine flow path in which the components were alternately laminated in 512 layers. The thus obtained multilayer laminated fiber was subjected to the same cutting process and dissolution treatment as described above, whereby a shortcut fiber having a flat cross-sectional shape was obtained. The results of evaluating this shortcut fiber are as shown in Table 1. This shortcut fiber had an extremely large specific surface area far exceeding that of a nanofiber having a fiber diameter of several hundred nanometers, and its cross section had a ribbon-like shape with an extremely high flatness. When the dispersion index was evaluated, it was found that the dispersion index was increased by high-speed stirring with the dispersion index being 5 at low speed and 18 at high speed; however, agglutinate-like dispersion defects that could cause a problem were not observed, and the shortcut fiber had both an extremely large specific surface area and excellent dispersibility. Further, the shortcut fiber had a crystallinity of 36% and a melting point of 254°C.

[Comparative Example 1]

**[0190]** Comparative Example 1 was carried out in the same manner as Example 1, except that in the method described in Example 1, a 15-filament spinning pack integrated with a 1,000 island-type sea-island composite spinneret in which the component A constituted an island component and the component B constituted a sea component was used, and the components A and B were discharged at a composite ratio of 50/50 in a total discharge amount of 42 g/min. The thus obtained sea-island composite fiber was subjected to the same cutting process and dissolution treatment as described above, whereby a nanofiber having a round cross section (crystallinity: 36%, melting point: 254°C) was obtained. The results of evaluating this nanofiber are as shown in Table 1. The nanofiber had a large specific surface area; however, high-speed stirring resulted in the generation of agglutinate-like dispersion defects due to entanglement of the fiber with one another, and the dispersibility was evaluated to be extremely low.

[Comparative Example 2]

**[0191]** Comparative Example 2 was carried out in the same manner as Comparative Example 1, except that the cross-sectional shape of the island component was changed to a flat cross-sectional shape in the method described in Comparative Example 1. A nanofiber having a large specific surface area and a flat cross section (crystallinity: 36%, melting point: 254°C) was obtained; however, since the flatness was low, high-speed stirring caused entanglement of the fiber with one another, and the dispersibility was extremely low as in Comparative Example 1.

[Table 1]

| | | Example 1 | Example 2 | Example 3 | Example 4 | Example 5 | Comparative Example 1 | Comparative Example 2 |
|---|---|---|---|---|---|---|---|---|
| Shortcut Fiber | Polymer Note 1) | PET | PET | PET | PET | PET | PET | PET |
| | Cross-sectional Shape | Flat | Flat | Flat | Flat | Flat | Circle | Flat |
| | Specific Surface Area ($nm^{-1}$) | 0.0108 | 0.0055 | 0.0028 | 0.0015 | 0.0427 | 0.0067 | 0.0050 |
| | Flatness | 80 | 40 | 20 | 10 | 319 | 1 | 2 |
| | Average Minor Axis Length (nm) | 188 | 375 | 750 | 1500 | 47 | 600 Note 2) | 600 |
| | Variation in Minor Axis Length (%) | 36 | 41 | 39 | 37 | 48 | - | 6 |
| | Degree of Unevenness (%) | 30 | 25 | 26 | 25 | 26 | - | 12 |
| | Aspect Ratio | 3191 | 1600 | 800 | 400 | 12766 | 1000 | 1000 |
| Fiber Dispersed Liquid | Disperse Index in Low-Speed Stirring | 7 | 11 | 18 | 19 | 5 | 5 | 9 |
| | Disperse Index in High-Speed Stirring | 8 | 10 | 18 | 20 | 18 | 52 | 53 |
| | Evaluation of Despersibility | Good | Good | Good | Good | Good | Poor | Poor |
| Note 1) PET: Polyethylene terephthalate, Note 2) Fiber Diameter | | | | | | | | |

[Examples 6 and 7]

**[0192]** Examples 6 and 7 were carried out in the same manner as Example 1, except that a composite plate having a flow path configuration different from that of the fine flow path G was used in the method described in Example 1. The results of evaluating the thus obtained shortcut fibers are as shown in Table 2. These shortcut fibers had a high-flatness ultrathin cross-sectional shape as in Example 1; however, because of the change in the flow path configuration of the composite plate, these shortcut fibers were uniform, having a small variation in minor axis length and a low degree of unevenness. When the dispersion index was evaluated, it was found that, as compared to Example 1, the value of the dispersion index was slightly increased due to a reduction in the variation in minor axis length and the degree of unevenness; however, these shortcut fibers were not observed with conspicuous agglutinate-like dispersion defects and had excellent dispersibility. Further, these shortcut fibers had a crystallinity of 36% and a melting point of 254°C.

[Examples 8 and 9]

**[0193]** Examples 8 and 9 were carried out in the same manner as Example 1, except that the cutting process was performed to a fiber length of 1.8 mm (Example 8) or 5.0 mm (Example 9) in the method described in Example 1. In Example 8, because of the dispersion effect attributed to the cross-sectional shape, the thus obtained shortcut fiber did not entangle with one another and exhibited excellent dispersibility even when the aspect ratio was high. In Example 9, the dispersibility in high-speed stirring tended to be slightly deteriorated due to a higher aspect ratio than in Example 8; however, agglutinate-like dispersion defects that could cause a problem were not observed, and the thus obtained shortcut fiber had both satisfactory specific surface area and excellent dispersibility. Further, these shortcut fibers had a crystallinity of 36% and a melting point of 254°C.

[Comparative Example 4]

**[0194]** Comparative Example 4 was carried out in the same manner as Comparative Example 1, except that the cutting process was performed to a fiber length of 5.0 mm in the method described in Comparative Example 1. In Comparative Example 4, due to a higher aspect ratio than in Comparative Example 1, the thus obtained shortcut fiber notably entangled with one another to generate agglutinate-like dispersion defects even in low-speed stirring, and thus had very poor dispersibility. This shortcut fiber had a crystallinity of 36% and a melting point of 254°C.

[Table 2]

| | | Example 6 | Example 7 | Example 8 | Example 9 | Comparative Example 3 |
|---|---|---|---|---|---|---|
| Shortcut Fiber | Polymer Note 1) | PET | PET | PET | PET | PET |
| | Cross-sectional Shape | Flat | Flat | Flat | Flat | Circle |
| | Specific Surface Area ($nm^{-1}$) | 0.0108 | 0.0108 | 0.0108 | 0.0108 | 0.0067 |
| | Flatness | 80 | 80 | 80 | 80 | 1 |
| | Average Minor Axis Length (nm) | 188 | 188 | 188 | 188 | 600 Note 2) |
| | Variation in Minor Axis Length (%) | 20 | 7 | 39 | 37 | - |
| | Degree of Unevenness (%) | 14 | 12 | 31 | 30 | - |
| | Aspect Ratio | 3191 | 3191 | 9574 | 26596 | 8333 |
| Fiber Dispersed Liquid | Disperse Index in Low-Speed | 11 | 15 | 11 | 11 | 40 |
| | Disperse Index in High-Speed | 10 | 15 | 12 | 22 | 52 |
| | Evaluation of Despersibility | Good | Good | Good | Good | Poor |
| Note 1) PET: Polyethylene terephthalate Note 2) Fiber Diameter | | | | | | |

[Example 10]

**[0195]** A multilayer laminated fiber, in which a component A was composed of a polyethylene terephthalate (PET, melting point: 254°C), a component B was composed of a polyethylene terephthalate (SSIA-PEG-copolymerized PET) copolymerized with 8.0% by mole of sodium 5-sulfoisophthalate and 9% by weight of polyethylene glycol, and these two kinds of polymers were alternately laminated in one direction as illustrated in FIG. 3, was cut to a fiber length of 0.6 mm, and the thus cut multilayer laminated fiber was immersed in a 1%-by-weight aqueous sodium hydroxide solution (bath ratio: 1/100) heated to 90°C to elute the component B, whereby a dispersion liquid containing a flat fiber having a flatness of 20 (minor axis length: 1,000 nm) as a functional fiber was obtained. The thus obtained flat fiber was in a state of being sufficiently crystallized at a crystallinity of 36%, and had a melting point of 254°C.

**[0196]** Next, a dispersion liquid containing a cut fiber (fiber diameter of core component: 10 μm, fiber length: 5.0 mm) of a thermally fusible core-sheath composite fiber (core component: PET, sheath component: polyester (copolymerized polyester) having a melting point of 110°C, obtained by copolymerizing 60% by mole of terephthalic acid, 40% by mole of isophthalic acid, 85% by mole of ethylene glycol, and 15% by mole of diethylene glycol), was prepared. Then, a fiber dispersed liquid for papermaking was prepared by uniformly mixing and dispersing the above dispersion liquid containing a flat fiber with the above dispersion liquid containing a cut fiber, by pulping and refining processes. The mixing ratio of cut fiber was adjusted to 30 % and the mixing ration of flat fiber was adjusted to 70%.

**[0197]** Using a square sheet machine (250-mm square) manufactured by Kumagai Riki Kogyo Co., Ltd., the fiber dispersed liquid for papermaking was made into a paper having a basis weight of 50 g/m$^2$, which was subsequently dried and heattreated in a rotary dryer having a roller temperature set at 110°C, whereby a nonwoven fabric was obtained.

**[0198]** The thus obtained nonwoven fabric had a structure in which the flat fiber was uniformly oriented and dense in the cross-sectional direction, and this nonwoven fabric had a thickness of 105 $\mu$m and a density of 0.48 g/cm$^3$. In the nonwoven fabric, the average pore size determined by a bubble point method was 0.5 $\mu$m, the maximum frequency of the pore size distribution was 17.9%, and dense spaces having various micropores were formed. Further, the nonwoven fabric had a smooth surface with an Ra value of 2.96 $\mu$m. The nonwoven fabric also had a sound absorption coefficient of 82% at 1,000 Hz, exhibiting excellent sound absorption performance in a low-frequency band. The results are shown in Table 3.

[Examples 11 and 12]

**[0199]** Examples 11 and 12 were carried out in the same manner as Example 10, except that the basis weight of the nonwoven fabric was changed to 25 g/m$^2$ (Example 11) or 5 g/m$^2$ (Example 12).

**[0200]** The thus obtained nonwoven fabrics had a structure in which the flat fiber (crystallinity: 36%, melting point: 254°C) was uniformly oriented and dense in the cross-sectional direction in the same manner as in Example 10. The results of evaluating these nonwoven fabrics are as shown in Table 3, and it was found that, when the basis weight was reduced, the denseness was reduced as compared to Example 10 due to a decrease in the nonwoven fabric density and an increase in the average pore size. However, both of the nonwoven fabrics had a sound absorption coefficient of 66% or more at 1,000 Hz, and were thus nonwoven fabrics having excellent sound absorption performance that is effective in practical use as well.

[Examples 13 to 15]

**[0201]** Examples 13 to 15 were carried out in the same manner as Example 10, except that, as shown in Table 3, various changes were made to the flatness and the minor axis length of the functional fiber (flat fiber) constituting the respective nonwoven fabrics.

**[0202]** The thus obtained nonwoven fabrics had a structure in which the flat fiber (crystallinity: 36%, melting point: 254°C) was uniformly oriented and dense in the cross-sectional direction in the same manner as in Examples 10 to 12. The results of evaluating these nonwoven fabrics are as shown in Table 3, and it was found that, when the flatness was increased from Example 10, since the nonwoven fabric density and the average pore size were both increased, the denseness was improved as compared to Example 10. Further, these nonwoven fabrics exhibited a reduced maximum frequency of the pore size distribution, and had a more complex void structure. Moreover, a reduction in the minor axis length of the flat fiber resulted in a decrease in Ra, and these nonwoven fabrics thus had a lower surface roughness as compared to Example 10.

[Example 16]

**[0203]** Example 16 was carried out in the same manner as Example 10, except that the flatness of the flat fiber constituting the nonwoven fabric was changed to 10. The thus obtained nonwoven fabric had a structure in which the flat fiber was uniformly oriented and dense in the cross-sectional direction in the same manner as in Examples 10 to 15. The results of evaluating this nonwoven fabric are as shown in Table 3, and it was found that, when the flatness was reduced from Example 10, since the nonwoven fabric density and the average pore size were both increased, the denseness was slightly reduced as compared to Example 10; however, this nonwoven fabric presented no problem in practical use, satisfying the requirements of the nonwoven fabric of the present invention. The results are shown in Table 3. Further, the flat fiber had a crystallinity of 36% and a melting point of 254°C.

[Example 17]

**[0204]** Example 17 was carried out in the same manner as Example 10, except that: the flat fiber used in Example 10 (crystallinity: 36%, melting point 254°C) was used as the functional fiber constituting the nonwoven fabric, along with the binder fiber used in Example 10 and an ultrafine PET fiber having a fiber diameter of 0.3 $\mu$m as other fiber; and papermaking was performed using a fiber dispersed liquid for papermaking that was prepared by mixing these fibers at a mixing ratio of functional fiber (flat fiber)/binder fiber/other fiber (ultrafine fiber) = 60% by weight/30% by weight/10% by weight.

**[0205]** Similarly to Examples 10 to 16, the thus obtained nonwoven fabric had a dense structure in which flat fiber were disposed in layers with their minor axes being perpendicular to the thickness direction, and ultrafine fibers existed in a cross-linking manner using skeleton fibers as scaffold. The results of evaluating this nonwoven fabric are as shown in

Table 3 and, because of the presence of the ultrafine fibers in a cross-linking manner, this nonwoven fabric had a denser structure than the nonwoven fabric of Example 10. On the other hand, the void structure was homogenized by the ultrafine fibers, and the maximum frequency of the pore size distribution was thus higher than in Example 10. Particularly, in Example 17, in addition to the densification of the nonwoven fabric structure by the flat fibers mixed as functional fibers, the nonwoven fabric had a structure in which the ultrafine fibers mixed as other fibers were arranged in the voids; therefore, the nonwoven fabric exhibited an extremely excellent sound absorption performance. Further, the nonwoven fabric had a special void structure with a small pore size, and is thus expected to exhibit excellent performance also in filtration, separation, and the like.

[Table 3]

| | | | | Example 10 | Example 11 | Example 12 | Example 13 | Example 14 | Example 15 | Example 16 | Example 17 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Constituent Fibers | Shortcut Fiber (Functional Fiber) | Polymer Note 1) | - | PET | PET | PET | PET | PET | PET | PET | PET |
| | | Fiber Cross-section | - | Flat | Flat | Flat | Flat | Flat | Flat | Flat | Flat |
| | | Flatness | - | 20 | 20 | 20 | 40 | 80 | 400 | 10 | 20 |
| | | Minor Axis Length | nm | 1000 | 1000 | 1000 | 500 | 250 | 50 | 2000 | 1000 |
| | | Major Axis Length | nm | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 |
| | | Fiber Length | mm | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 |
| | | Mixed Rate | % | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 60 |
| | Binder Fiber | Polymer (Core) Note 1) | - | PET | PET | PET | PET | PET | PET | PET | PET |
| | | Polymer (Seath) | - | Copolymerized Polyester | Copolymerized Polyester | Copolymerized Polyester | Copolymerized Polyester | Copolymerized Polyester | Copolymerized Polyester | Copolymerized Polyester | Copolymerized Polyester |
| | | Fiber Diameter | μm | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | | Fiber Length | mm | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 |
| | | Mixed Rate | % | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| | | Polymer Note 1) | - | - | - | - | - | - | - | - | PET |

(continued)

| | | | | Example 10 | Example 11 | Example 12 | Example 13 | Example 14 | Example 15 | Example 16 | Example 17 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Other Fiber | Fiber Cross-section | - | - | - | - | - | - | - | - | **Circle** Note 2) |
| | | Fiber Length | mm | - | - | - | - | - | - | - | 0.6 |
| | | Mixed Rate | % | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 |
| Nonwoven Fabric Properties | Basis Weight | | $g/m^2$ | 50 | 25 | 5 | 50 | 50 | 50 | 50 | 50 |
| | Thickness | | μm | 105 | 54 | 12 | 97 | 92 | 71 | 113 | 98 |
| | Density of Nonwoven Fabric | | $g/cm^3$ | 0.48 | 0.46 | 0.42 | 0.52 | 0.54 | 0.70 | 0.44 | 0.51 |
| | Average Pore Size | | μm | 1.3 | 1.7 | 5.7 | 1.1 | 0.8 | 0.5 | 2.1 | 0.8 |
| | Maximum Frequency of Pore Size Distribution | | % | 17.9 | 25.3 | 29.2 | 17.4 | 16.6 | 15.4 | 23.4 | 28.4 |
| | Arithmetic Mean Roughness (Ra) | | μm | 2.96 | 3.14 | 4.53 | 2.54 | 1.83 | 0.52 | 3.64 | 2.34 |
| | Sound Absorption Coefficient | | % | 82 | 77 | 66 | 85 | 90 | 96 | 75 | 100 |

Note 1) PET: Polyethylene terephthalate, Note 2) Fiber Diameter: 0.3 μm

[Comparative Example 4]

**[0206]** Comparative Example 4 was carried out in the same manner as Example 10, except that the fiber constituting the nonwoven fabric (skeleton fiber) was changed to an ultrafine fiber having a fiber diameter of 3.0 μm (PET, crystallinity: 36%, melting point: 254°C).

**[0207]** The thus obtained nonwoven fabric had a thickness of 220 μm, a density of 0.23 g/cm$^3$, and an average pore size, which was determined by a bubble point method, of 14.3 μm, and was thus a nonwoven fabric having a lower denseness with coarser voids as compared to the nonwoven fabric of Example 10. Further, the nonwoven fabric had a rough surface with an Ra value of 13.62 μm. The results are shown in Table 4.

[Comparative Example 5]

**[0208]** Comparative Example 5 was carried out in the same manner as Example 10, except that: as the fibers constituting the nonwoven fabric, an ultrafine fiber having a fiber diameter of 3.0 μm was used for the skeleton fiber, and the flat fiber used in Example 10 (crystallinity: 36%, melting point: 254°C) was used for the functional fiber; and papermaking was performed at a ratio of skeleton fiber/binder fiber/flat fiber = 60% by weight/30% by weight/10% by weight.

**[0209]** Due to a low mixing ratio of the flat fiber, the thus obtained nonwoven fabric had a thickness of 197 μm, a density of 0.25 g/cm$^3$, and an average pore size, which was determined by a bubble point method, of 12.3 μm, and was thus a nonwoven fabric having a low denseness with coarse voids in the same manner as in Comparative Example 4. The results are shown in Table 4.

[Comparative Example 6]

**[0210]** Comparative Example 6 was carried out in the same manner as Example 10, except that the flatness of the flat fiber constituting the nonwoven fabric was changed to 2. It is noted here that the flat fiber had a crystallinity of 36% and a melting point of 254°C.

**[0211]** Due to a low flatness of the flat fiber, the thus obtained nonwoven fabric had a thickness of 264 μm, a density of 0.19 g/cm$^3$, and an average pore size, which was determined by a bubble point method, of 29.6 μm, and was thus a nonwoven fabric having a lower denseness with coarser voids as compared to Comparative Examples 4 and 5. The results are shown in Table 4.

[Table 4]

| | | | | Comparative Example 4 | Comparative Example 5 | Comparative Example 6 |
|---|---|---|---|---|---|---|
| Constituent Fibers | Shortcut Fiber (Functional Fiber) | Polymer Note 1) | - | - | PET | PET |
| | | Fiber Cross-section | - | - | Flat | Flat |
| | | Flatness | - | - | 20 | 2 |
| | | Minor Axis Length | nm | - | 1000 | 10000 |
| | | Major Axis Length | nm | - | 20000 | 20000 |
| | | Fiber Length | mm | - | 0.6 | 0.6 |
| | | Mixed Rate | % | 0 | 10 | 70 |
| | Binder Fiber | Polymer (Core) Note 1) | - | PET | PET | PET |
| | | Polymer (Seath) | - | Copolymerized Polyester | Copolymerized Polyester | Copolymerized Polyester |
| | | Fiber Diameter | µm | 10 | 10 | 10 |
| | | Fiber Length | mm | 5.0 | 5.0 | 5.0 |
| | | Mixed Rate | % | 30 | 30 | 30 |
| | Other Fiber | Polymer Note 1) | - | PET | PET | - |
| | | Fiber Cross-section | - | Circle Note 2) | Circle Note 2) | - |
| | | Fiber Length | mm | 30 | 40 | - |
| | | Mixed Rate | % | 70 | 60 | 0 |
| Nonwoven Fabric Properties | Basis Weight | | $g/m^2$ | 50 | 50 | 50 |
| | Thickness | | µm | 220 | 197 | 264 |
| | Density of Nonwoven Fabric | | $g/cm^3$ | 0.23 | 0.25 | 0.19 |
| | Average Pore Size | | µm | 14.3 | 12.3 | 29.6 |
| | Maximum Frequency of Pore Size Distribution | | % | 44.3 | 38.5 | 36.4 |
| | Arithmetic Mean Roughness (Ra) | | µm | 13.62 | 10.43 | 15.47 |
| | Sound Absorption Coefficient | | % | 25 | 21 | 15 |

Note 1) PET: Polyethylene terephthalate, Note 2) Fiber Diameter: 0.3 µm

[Example 18]

**[0212]** Example 18 was carried out in the same manner as Example 10, except that: an ultrafine fiber having a fiber diameter of 3.0 μm was used as the skeleton fiber constituting the nonwoven fabric, and the flat fiber (crystallinity: 36%, melting point: 254°C) as the functional fiber with the binder fiber, used in Example 13, were used; and papermaking was performed at a ratio of functional fiber/binder fiber/other fiber = 40% by weight/30% by weight/30% by weight.
**[0213]** As a result, a nonwoven fabric having a structure in which ultrafine fibers serving as skeleton fibers were cross-linked by flat fibers was obtained, and complex void structures were formed between the fibers; therefore, this nonwoven fabric had superior rigidity than the nonwoven fabric of Example 10. The results are shown in Table 5.

[Examples 19 and 20]

**[0214]** A multilayer laminated fiber, in which a component A was composed of a polyethylene terephthalate (PET), a component B was composed of a polyethylene terephthalate (SSIA-PEG-copolymerized PET) copolymerized with 8.0% by mole of sodium 5-sulfoisophthalate and 9% by weight of polyethylene glycol, and these two kinds of polymers were alternately laminated in one direction as illustrated in FIG. 3, was cut to a fiber length of 1.0 mm (Example 19) and 5.0 mm (Example 20), and the component B was eluted from each of the thus cut multilayer laminated fibers in the same manner as in Example 10, whereby dispersion liquids containing flat fibers having different fiber lengths with a flatness of 40 (minor axis length: 500 nm) were obtained. Using each of the thus obtained dispersion liquids, papermaking was performed in the same manner as in Example 12 such that a basis weight of 5.0 g/m$^2$ was obtained.
**[0215]** The thus obtained nonwoven fabrics had a structure in which the respective flat fibers (crystallinity: 36%, melting point: 254°C) were uniformly oriented and dense in the cross-sectional direction. In these nonwoven fabrics, despite their extremely small thickness, not only the rigidity as a sheet but also the smoothness of the sheet surface were improved as the length of functional fibers was increased. The results are shown in Table 5.

[Table 5]

| | | | | Example 18 | Example 19 | Example 20 |
|---|---|---|---|---|---|---|
| Constituent Fibers | Shortcut Fiber (Functional Fiber) | Polymer Note 1) | - | PET | PET | PET |
| | | Fiber Cross-section | - | Flat | Flat | Flat |
| | | Flatness | - | 40 | 40 | 40 |
| | | Minor Axis Length | nm | 500 | 500 | 500 |
| | | Major Axis Length | nm | 20000 | 20000 | 20000 |
| | | Fiber Length | mm | 1.0 | 1.0 | 5.0 |
| | | Mixed Rate | % | 40 | 70 | 70 |
| | Binder Fiber | Polymer (Core) Note 1) | - | PET | PET | PET |
| | | Polymer (Seath) | - | Copolymerized Polyester | Copolymerized Polyester | Copolymerized Polyester |
| | | Fiber Diameter | μm | 10 | 10 | 10 |
| | | Fiber Length | mm | 5.0 | 5.0 | 5.0 |
| | | Mixed Rate | % | 30 | 30 | 30 |
| | Other Fiber (Skeleton Fiber) | Polymer Note 1) | - | PET | - | - |
| | | Fiber Cross-section | - | Circle Note 2) | - | - |
| | | Fiber Length | mm | 3.0 | - | - |
| | | Mixed Rate | % | 30 | 0 | 0 |
| Nonwoven Fabric Properties | Basis Weight | | $g/m^2$ | 50 | 5 | 5 |
| | Thickness | | μm | 112 | 13 | 15 |
| | Density of Nonwoven Fabric | | $g/cm^3$ | 0.32 | 0.43 | 0.44 |
| | Average Pore Size | | μm | 3.3 | 3.3 | 2.2 |
| | Maximum Frequency of Pore Size Distribution | | % | 26 | 22.4 | 20.1 |
| | Arithmetic Mean Roughness (Ra) | | μm | 5.32 | 3.32 | 1.52 |
| | Sound Absorption Coefficient | | % | 62 | 70 | 73 |

[Reference Example 1]

**[0216]** A polyethylene terephthalate (PET, melt viscosity: 120 Pa·s, melting point: 254°C, SP value: 21.4 $MPa^{1/2}$) was melt-spun at 290°C. A discharged polymer flow was cooled and solidified, and an oil agent was subsequently applied thereto, after which the resultant was wound at a spinning speed of 1,000 m/min to collect a 200 dtex-72 filament as-spun fiber (total discharge amount: 20 g/min). The thus wound as-spun fiber was drawn by a factor of 3.6 between rollers heated to 90°C and 130°C to obtain a 56 dtex-72 filament drawn fiber. The thus obtained drawn fiber was cut using a cutter, whereby a shortcut fiber having an average fiber length of 5 mm was obtained.

[Reference Example 2]

**[0217]** A polyphenylene sulfide consisting of only *p*-phenylene sulfide units (PPS, melt viscosity: 130 Pa·s, melting point: 283°C, SP value: 25.8 $MPa^{1/2}$) was melt-spun at 310°C. A discharged polymer flow was cooled and solidified, and an oil agent was subsequently applied thereto, after which the resultant was wound at a spinning speed of 1,000 m/min to collect a 200 dtex-72 filament as-spun fiber (total discharge amount: 20 g/min). The thus wound as-spun fiber was drawn by a factor of 3.6 between rollers heated to 90°C and 200°C to obtain a 56 dtex-72 filament drawn fiber. The thus obtained drawn fiber was cut using a cutter, whereby a shortcut fiber having an average fiber length of 5 mm was obtained.

[Example 21]

**[0218]** A polyethylene terephthalate (PET, melt viscosity: 120 Pa·s, melting point: 254°C, SP value: 21.4 $MPa^{1/2}$), and a polyethylene terephthalate (SSIA-PEG-copolymerized PET, melt viscosity: 95 Pa·s, melting point: 233°C, SP value: 22.9 $MPa^{1/2}$) copolymerized with 8.0% by mole of sodium 5-sulfoisophthalate and 9% by weight of polyethylene glycol were prepared as components A and B, respectively. It is noted here that the difference in solubility parameter between these polymers was 1.5 $MPa^{1/2}$.

**[0219]** The components A and B were separately melted at 290°C and then introduced to a spinning pack integrated with the composite spinneret illustrated in FIG. 4 at a component A/component B composite ratio of 80/20, and the resulting composite polymer flow was discharged from the discharge holes. The composite plate was provided with a fine flow path G in which the components were alternately laminated in 64 layers, and the composite polymer flow was discharged in a composite form in which the two kinds of polymers were alternately laminated in multiple layers along one direction as illustrated in FIG. 3. The discharged composite polymer flow was cooled and solidified, and an oil agent was subsequently applied thereto, after which the resultant was wound at a spinning speed of 1,000 m/min to collect a 100 dtex-24 filament as-spun fiber (total discharge amount: 10 g/min).

**[0220]** The thus obtained multilayer laminated fiber was cut to a fiber length of 5.0 mm, and the thus cut multilayer laminated fiber was immersed in a 1%-by-weight aqueous sodium hydroxide solution (bath ratio: 1/100) heated to 70°C for 30 minutes to dissolve and remove 99% or more of the easily soluble polymer SSIA-PEG-copolymerized PET, whereby a shortcut fiber (melting point: 254°C) having such a flat cross-sectional shape as illustrated in FIG. 1 was obtained.

**[0221]** When the specific surface area of the thus obtained shortcut fiber was measured from a cross section, the specific surface area was found to be extremely large at 0.0041 $nm^{-1}$. The cross section had a ribbon-like form in which the major axis and the minor axis were greatly different in length, with the flatness being 40 and the minor axis length and the major axis length being 500 nm and 20,000 nm, respectively. The cross section had a variation in minor axis length of 32% and a degree of unevenness of 21% and, therefore, the minor axis length was moderately variable, and the surface had a moderate unevenness. Further, the shortcut fiber was in an amorphous state having a crystallinity of 6%, and exhibited a high fluidity with a tan$\delta$ value of 0.25.

**[0222]** In a papermaking dispersion liquid, 50% by mass of the above-obtained shortcut fiber serving as a binder fiber and 50% by mass of the shortcut fiber obtained in Reference Example 1 serving as an skeleton fiber of an adherend were mixed such that the fiber concentration was 0.4% by mass. The thus obtained papermaking liquid was supplied to a square sheet machine (250-mm square) manufactured by Kumagai Riki Kogyo Co., Ltd. to obtain a wet nonwoven fabric having a basis weight of 5 $g/m^2$. Further, this wet nonwoven fabric was subjected to 1-minute thermal compression bonding using a 200°C flat-plate hot press machine at a press pressure of 1.0 MPa, whereby a nonwoven fabric was obtained.

**[0223]** The thus obtained nonwoven fabric had a good texture without any agglutinates such as fiber lumps, and exhibited a good strength of 2.40 N/15 mm despite being thin and having a low basis weight. The results are shown in Table 6.

[Examples 22 and 23]

**[0224]** Examples 22 and 23 were carried out in the same manner as Example 21, except that the composite plate used in the method described in Example 21 was changed to a composite plate provided with a fine flow path in which the components were laminated in 32 layers (Example 22) or 16 layers (Example 23). The thus obtained multilayer laminated fibers were each subjected to the same cutting process and dissolution treatment as described above, whereby shortcut fibers (melting point: 254°C) having such a flat cross-sectional shape as illustrated in FIG. 1 were obtained. The results of evaluating these shortcut fibers are as shown in Table 6 and, in both of Examples 22 and 23, the shortcut fibers had a large specific surface area, and their cross sections had a high-flatness ultrathin ribbon-like shape with a moderate variation in minor axis length and a moderate degree of unevenness. When these shortcut fibers were evaluated in the form of sheet-like materials, as compared to Example 21, the bonding ratio was slightly reduced and the variation in bonding ratio was slightly increased as the flatness was reduced and the average minor axis length was increased; however, the sheet-like materials exhibited excellent strength despite being thin and having a low basis weight.

[Examples 24 and 25]

**[0225]** Examples 24 and 25 were carried out in the same manner as Example 22, except that the temperature of the dissolution treatment for the removal of the easily soluble polymer in the method described in Example 22 was changed to 75°C (Example 24) or 80°C (Example 25). The evaluation results are as shown in Table 6 and, as compared to Example 22, due to the higher temperature of the dissolution treatment, the crystallinity of the shortcut fiber (melting point: 254°C) was increased and the tanδ was reduced. When the shortcut fiber was made into a nonwoven fabric, as compared to Example 22, the bonding ratio was reduced and the variation in bonding ratio was increased due to the increased crystallinity and the reduced fluidity; however, the nonwoven fabric maintained excellent strength.

[Examples 26 and 27]

**[0226]** Examples 26 and 27 were carried out in the same manner as Example 22, except that a composite plate having a flow path configuration different from that of the fine flow path G was used in the method described in Example 22. The results thereof are as shown in Table 6. As a result of the change in the flow path configuration of the composite plate, a shortcut fiber having a cross section with a small variation in minor axis length (Example 26) and a shortcut fiber having a cross section with a low degree of unevenness (Example 27) were obtained, although these shortcut fibers had a high-flatness ultrathin cross-sectional shape as in Example 22. When these shortcut fibers were evaluated in the form of nonwoven fabrics, it was found that the nonwoven fabrics were uniform containing no fiber agglutinate therein, and had excellent strength although the bonding ratio was slightly reduced and the variation in bonding ratio was increased as compared to Example 22. Further, the shortcut fibers of Examples 26 and 27 had a melting point of 254°C.

[Comparative Example 7]

**[0227]** Comparative Example 7 was carried out in the same manner as in Example 21, except that the as-spun fiber (melting point: 254°C) described in Reference Example 1 was used as the binder fiber. The evaluation results are as shown below, and the thus obtained shortcut fiber had a round cross-sectional shape with a small specific surface area. When the shortcut fiber was made into a nonwoven fabric, the nonwoven fabric was not uniform having breakage and pinholes everywhere, and had an extremely large variation in bonding ratio and a markedly low strength. It is noted here that, since the nonwoven fabric was not uniform, the average pore size and the arithmetic mean roughness were not measured.

[Comparative Example 8]

**[0228]** Comparative Example 8 was carried out in the same manner as in Example 22, except that, in the method described in Example 22, the multilayer laminated fiber was left to stand in a hot-air dryer heated to 120°C for 30 minutes and thereby thermally crystallized in advance, and then subjected to a 30-minute dissolution treatment at 90°C. The evaluation results are as shown in Table 6, and the thus obtained shortcut fiber (melting point: 254°C) had a high crystallinity of 36%. When this shortcut fiber was made into a nonwoven fabric, the nonwoven fabric was not uniform having breakage and pinholes everywhere, and had an extremely large variation in bonding ratio and a markedly low strength.

[Table 6]

| | | | | | Example 21 | Example 22 | Example 23 | Example 24 | Example 25 | Example 26 | Example 27 | Comparative Example 7 | Comparative Example 8 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Constituent Fibers | Binder Fiber | Polymer Note 1) | | - | PET | PET | PET | PET | PET | PET | PET | PET | PET |
| | | Cross-section | Fiber Cross-section | - | Flat | Flat | Flat | Flat | Flat | Flat | Flat | Circle | Flat |
| | | | Flatness | - | 40 | 20 | 10 | 20 | 20 | 20 | 20 | 1 | 20 |
| | | | Minor Axis Length | nm | 500 | 1000 | 2000 | 1000 | 1000 | 1000 | 1000 | 16000 Note 2) | 1000 |
| | | | Major Axis Length | nm | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 | 16000 Note 2) | 20000 |
| | | | Variation of Minor Axis Length | % | 32 | 37 | 35 | 37 | 37 | 18 | 37 | - | 37 |
| | | | Degree of Unevenness | % | 21 | 25 | 22 | 25 | 25 | 25 | 16 | - | 25 |
| | | Shape | Specific Surface Area | $nm^{-1}$ | 0.0041 | 0.0021 | 0.0011 | 0.0021 | 0.0021 | 0.0021 | 0.0021 | 0.0003 | 0.0021 |
| | | | Fiber Length | mm | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 |
| | | | Aspect Ratio | - | 10000 | 5000 | 2500 | 5000 | 5000 | 5000 | 5000 | 333 | 5000 |
| | | Structure | Crystallinity | % | 6 | 6 | 6 | 9 | 18 | 6 | 6 | 6 | 36 |
| | | | $\tan\delta$ | - | 0.25 | 0.25 | 0.25 | 0.18 | 0.14 | 0.25 | 0.25 | 0.25 | 0.10 |

(continued)

| | | | Example 21 | Example 22 | Example 23 | Example 24 | Example 25 | Example 26 | Example 27 | Comparative Example 7 | Comparative Example 8 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nonwoven Fabric Properties | Mixed Rate of Binder Fiber | % | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| | Basis Weight | g/m$^2$ | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| | Thickness | μm | 15 | 16 | 17 | 17 | 16 | 16 | 16 | 28 | 20 |
| | Density of Nonwoven Fabric | g/cm$^3$ | 0.33 | 0.31 | 0.29 | 0.29 | 0.31 | 0.31 | 0.31 | 0.18 | 0.25 |
| | Average Pore Size | μm | 3.3 | 4.2 | 5.6 | 4.9 | 5.2 | 4.0 | 3.9 | - | - |
| | Maximum Frequency of Pore Size Distribution | % | 26 | 25 | 26 | 25 | 27 | 23 | 23 | - | - |
| | Arithmetic Mean Roughness (Ra) | μm | 4.0 | 4.6 | 5.2 | 5.2 | 5.6 | 4.2 | 4.5 | - | - |
| | Void Ratio | % | 76 | 78 | 79 | 79 | 78 | 78 | 78 | 87 | 81 |
| | Bonding Ratio | % | 40 | 39 | 35 | 35 | 32 | 34 | 35 | 22 | 24 |
| | Variation in Bonding Ratio | % | 50 | 53 | 58 | 58 | 60 | 61 | 63 | 90 | 82 |
| | Uniformity | - | A | A | A | A | A | A | A | C | C |
| | Strength | N/15mm | 2.40 | 2.10 | 2.04 | 1.50 | 1.20 | 1.86 | 1.86 | 0.30 | 0.44 |

Note 1) PET: Polyethylene terephthalate, Note 2) Fiber Diameter

[Examples 28 and 29]

**[0229]** In the method described in Examples 22 and 23, a polyphenylene sulfide (PPS, melt viscosity: 130 Pa·s, melting point: 283°C, SP value: 25.8 $MPa^{1/2}$) consisting of only *p*-phenylene sulfide units, and a polyethylene terephthalate (SSIA-copolymerized PET, melt viscosity: 130 Pa·s, melting point: 245°C) copolymerized with 5.0% by mole of sodium 5-sulfoisophthalate were discharged at 310°C as components A and B, respectively. The thus discharged polymer flow was cooled and solidified, and an oil agent was subsequently applied thereto, after which the resultant was wound at a spinning speed of 1,000 m/min to collect a 100 dtex-24 filament as-spun fiber (total discharge amount: 10 g/min).

**[0230]** The thus obtained as-spun fiber was immersed in a 3%-by-weight aqueous sodium hydroxide solution (bath ratio: 1/100) heated to 60°C for 40 minutes to perform a dissolution treatment so as to dissolve and remove 99% or more of the easily soluble polymer SSIA-copolymerized PET, whereby a shortcut fiber having such a flat cross-sectional shape as illustrated in FIG. 1 was obtained. It is noted here that, in the aqueous sodium hydroxide solution, DY-1125K manufactured by Lion Specialty Chemicals Co., Ltd. (quaternary ammonium salt-type cationic surfactant) was added as a dissolution accelerator in an amount of 0.5% by weight with respect to the mass of the aqueous sodium hydroxide solution.

**[0231]** In a papermaking dispersion liquid, 50% by mass of the above-described thermoplastic fiber serving as a binder fiber and 50% by mass of the shortcut fiber obtained in Reference Example 2 serving as an skeleton fiber of an adherend were mixed such that the fiber concentration was 0.4% by mass. The thus obtained papermaking liquid was supplied to a simple papermaking machine to obtain a wet nonwoven fabric having a basis weight of 5 $g/m^2$. Further, this wet nonwoven fabric was subjected to 1-minute thermal compression bonding using a 220°C flat-plate hot press machine at a press pressure of 1.0 MPa.

**[0232]** The results of evaluating the above-obtained shortcut fiber (melting point: 283°C) are as shown in Table 7 and, in both of Examples 28 and 29, the shortcut fiber had a large specific surface area, as well as a high-flatness ultrathin ribbon-like cross-sectional shape with a moderate variation in minor axis length and a moderate degree of unevenness. When the shortcut fiber was evaluated in the form of a nonwoven fabric, it was found that the nonwoven fabric was uniform containing no fiber agglutinate therein, and had a high bonding ratio, a low variation in bonding ratio, and excellent strength.

[Example 30]

**[0233]** Example 30 was carried out in the same manner as in Example 28, except that the temperature of the dissolution treatment for the removal of the easily soluble polymer was changed to 90°C. The evaluation results are as shown in Table 7 and, as compared to Example 28, due to the higher temperature of the dissolution treatment, the crystallinity of the shortcut fiber (melting point: 283°C) was increased and the tan$\delta$ was reduced. When the shortcut fiber was made into a nonwoven fabric, as compared to Example 28, the bonding ratio was reduced and the variation in bonding ratio was increased due to the increased crystallinity; however, the nonwoven fabric maintained excellent strength.

[Comparative Example 9]

**[0234]** Comparative Example 9 was carried out in the same manner as in Example 28, except that the as-spun fiber (melting point: 283°C) described in Reference Example 2 was used as the binder fiber. The evaluation results are as shown below, and the thus obtained shortcut fiber had a round cross-sectional shape with a small specific surface area. When the shortcut fiber was made into a nonwoven fabric, the nonwoven fabric was not uniform having breakage and pinholes everywhere, and had an extremely large variation in bonding ratio and a markedly low strength.

[Table 7]

| | | | | | Example 28 | Example 29 | Example 30 | Comparative Example 9 |
|---|---|---|---|---|---|---|---|---|
| Constituent Fibers | Binder Fiber | Polymer Note 1) | | - | PPS | PPS | PPS | PPS |
| | | Cross-section | Fiber Cross-section | - | Flat | Flat | Flat | Circle |
| | | | Flatness | - | 20 | 10 | 20 | 1 |
| | | | Minor Axis Length | nm | 1000 | 2000 | 1000 | 16000 Note 2) |
| | | | Major Axis Length | nm | 20000 | 20000 | 20000 | 16000 Note 2) |
| | | | Variation of Minor Axis Length | % | 37 | 35 | 37 | |
| | | | Degree of Unevenness | % | 25 | 22 | 25 | |
| | | Shape | Specific Surface Area | $nm^{-1}$ | 0.0021 | 0.0011 | 0.0021 | 0.0003 |
| | | | Fiber Length | mm | 5.0 | 5.0 | 5.0 | 5.0 |
| | | | Aspect Ratio | - | 5000 | 2500 | 5000 | 333 |
| | | Structure | Crystallinity | % | 8 | 8 | 18 | 6 |
| | | | $\tan\delta$ | - | 0.25 | 0.25 | 0.14 | 0.25 |
| Nonwoven Fabric Properties | Mixed Rate of Binder Fiber | | | % | 30 | 30 | 30 | 30 |
| | Basis Weight | | | $g/m^2$ | 5 | 5 | 5 | 5 |
| | Thickness | | | µm | 16 | 17 | 16 | 28 |
| | Density of Nonwoven Fabric | | | $g/cm^3$ | 0.31 | 0.29 | 0.31 | 0.18 |
| | Average Pore Size | | | µm | 4.2 | 5.6 | 5.2 | - |
| | Maximum Frequency of Pore Size Distribution | | | % | 25 | 26 | 27 | - |
| | Arithmetic Mean Roughness (Ra) | | | µm | 4.6 | 5.2 | 5.6 | - |
| | Void Ratio | | | % | 77 | 79 | 78 | 87 |
| | Bonding Ratio | | | % | 39 | 35 | 32 | 22 |
| | Variation in Bonding Ratio | | | % | 53 | 58 | 60 | 90 |
| | Uniformity | | | - | A | A | A | C |
| | Strength | | | N/15mm | 2.04 | 1.95 | 1.20 | 0.24 |
| Note 1) PPS: Polyethylene terephthalate, Note 2) Fiber Diameter | | | | | | | | |

Description of Symbols

**[0235]**

A: shortcut fiber
B: component A
C: component B
D: measuring plate
E: composite plate
F: discharge plate

G: fine flow path

Industrial Applicability

**[0236]** A fiber dispersed liquid in which the shortcut fiber of the present invention is uniformly dispersed in a medium not only can be used as-is and developed as a high-performance adsorbent or reinforcing material, but also can be developed into a wide range of industrial materials, such as high-performance filter media, separation membranes, and sound-absorbing materials, when the fiber dispersed liquid is made into a sheet by removing the medium by a wet-laid papermaking process, a spray process, or the like.

## Claims

1. A shortcut fiber, having a flatness, which is a value obtained by dividing a major axis length of a fiber cross section by a minor axis length of the fiber cross section, of 5 or more, and an average minor axis length of 2,000 nm or less.

2. The shortcut fiber according to claim 1, wherein a variation (CV value) in minor axis length of the fiber cross section is 10% or more.

3. The shortcut fiber according to claim 1 or 2, wherein a degree of unevenness of the fiber cross section is 20% or more.

4. The shortcut fiber according to claim 1, having a crystallinity of 20% or less.

5. The shortcut fiber according to claim 4, having a melting point of 180°C or higher.

6. A fiber dispersed liquid, comprising the shortcut fiber according to claim 1 or 4 dispersed in an aqueous medium.

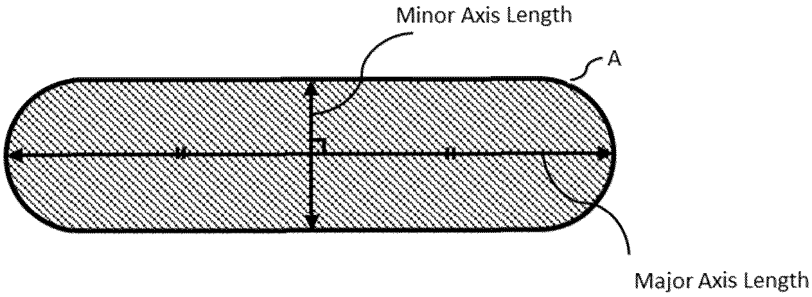
7. A nonwoven fabric, at least partially comprising the shortcut fiber according to claim 1 or 4.

8. A nonwoven fabric, having a density of 0.4 g/cm$^3$ or more, an average pore size of 6 μm or less, and a pore size distribution with a maximum frequency of 30% or less.

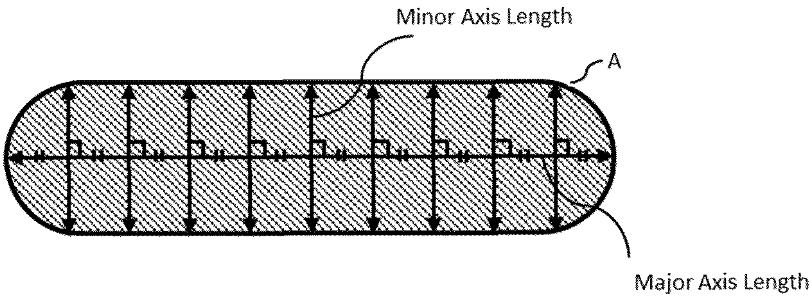
9. The nonwoven fabric according to claim 8, having a surface arithmetic mean roughness (Ra) of 5.00 μm or less.

10. A fiber product, at least partially comprising the nonwoven fabric according to claim 7 or 8.

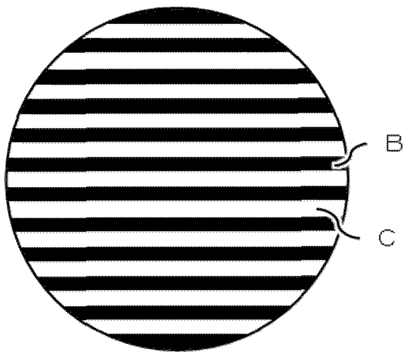
[Fig. 1]



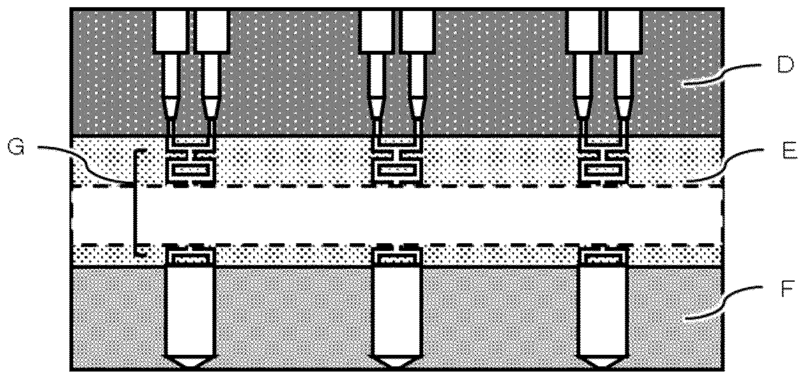

[Fig. 2]



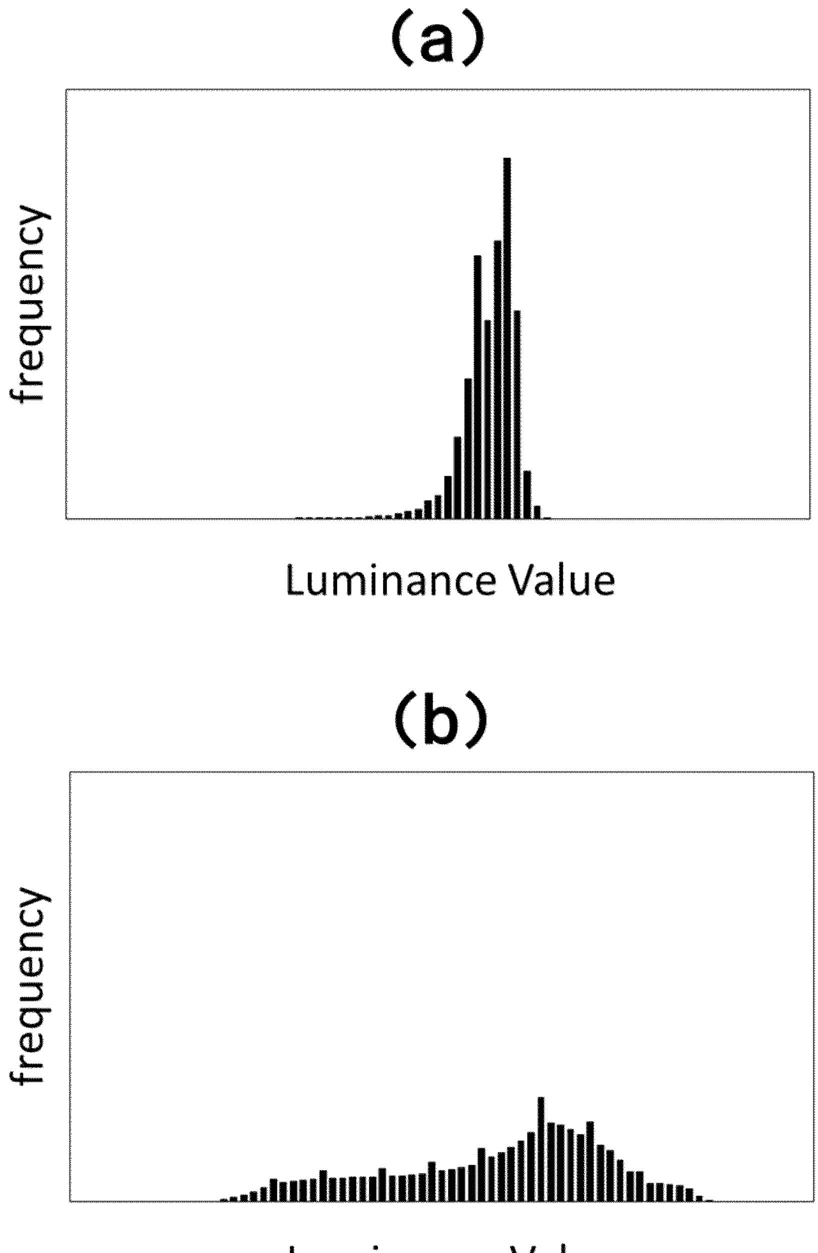

[Fig. 3]



[Fig. 4]



[Fig. 5]



## INTERNATIONAL SEARCH REPORT

International application No.
**PCT/JP2023/020061**

**A. CLASSIFICATION OF SUBJECT MATTER**

***D01F 6/00***(2006.01)i; ***D01F 6/62***(2006.01)i; ***D01F 8/14***(2006.01)i; ***D21H 15/02***(2006.01)i
FI: D01F6/00 A; D01F6/62 303F; D01F8/14; D21H15/02

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

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

D01D1/00-13/02, D01F1/00-9/04, D04H1/00-18/04, D21B1/00-1/38, D21C1/00-11/14, D21D1/00-99/00, D21F1/00-13/12, D21G1/00-9/00, D21H11/00-27/42, D21J1/00-7/00

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

Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2023
Registered utility model specifications of Japan 1996-2023
Published registered utility model applications of Japan 1994-2023

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

JSTPlus/JMEDPlus/JST7580 (JDreamIII)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
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☐ Further documents are listed in the continuation of Box C. ☑ See patent family annex.

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| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| **01 August 2023** | **15 August 2023** |

| Name and mailing address of the ISA/JP | Authorized officer |
|---|---|
| **Japan Patent Office (ISA/JP)**<br>**3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915**<br>**Japan** | Telephone No. |

Form PCT/ISA/210 (second sheet) (January 2015)

**INTERNATIONAL SEARCH REPORT**
**Information on patent family members**

International application No.
**PCT/JP2023/020061**

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