US 20180251920A1

(19) **United States**

(12) **Patent Application Publication**

(10) **Pub. No.: US 2018/0251920 A1**

(43) **Pub. Date: Sep. 6, 2018**

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(54) **HIGH-PERFORMANCE PPS FIBER STRUCTURE AND PRODUCTION METHOD AND USE THEREOF (AS AMENDED)**

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(21) Appl. No.: **15/754,093**

(22) PCT Filed: **Aug. 23, 2016**

(86) PCT No.: **PCT/CN2016/096309**

§ 371 (c)(1),
(2) Date: **Feb. 21, 2018**

(30) **Foreign Application Priority Data**

Aug. 24, 2015 (CN) 201510521999.9

Publication Classification

(51) **Int. Cl.**

D03D 15/00 (2006.01)
D06M 10/08 (2006.01)
D03D 13/00 (2006.01)
D04H 1/435 (2006.01)

(52) **U.S. Cl.**

CPC ***D03D 15/0083*** (2013.01); ***D06M 10/08*** (2013.01); *D10B 2331/301* (2013.01); ***D04H 1/435*** (2013.01); ***D03D 13/008*** (2013.01)

(57) **ABSTRACT**

The present invention discloses a high-performance PPS fiber structure and production method and use thereof. The high-performance PPS fiber structure is woven fabric made from PPS fibers in 0.1 to 12 μm cross sectional diameter, and the maximum pore size of the PPS fiber structure is 20 μm or smaller. The PPS fiber structure disclosed in the present invention has the advantages of high gas impermeability and good hydrophilicity, also has the advantages of simple process, low energy consumption and zero environmental pollution, and can be used in diaphragms for electrolytic apparatuses, high-temperature liquid filter materials and insulating materials.

HIGH-PERFORMANCE PPS FIBER STRUCTURE AND PRODUCTION METHOD AND USE THEREOF (AS AMENDED)

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This is the U.S. National Phase application of PCT/CN2016/096309, filed Aug. 23, 2016, which claims priority to Chinese Patent Application No. 201510521999.9, filed Aug. 24, 2015, the disclosures of these applications being incorporated herein by reference in their entireties for all purposes.

TECHNICAL FIELD OF THE INVENTION

[0002] The present invention relates to a high-performance polyphenylene sulfide (PPS) fiber structure and production method and use thereof.

BACKGROUND OF THE INVENTION

[0003] Diaphragm cloth is the main core material of water electrolyzers. Water-electrolytic hydrogen generators and oxygen generators are widely applied in military, petrochemical, and iron and steel making fields. At present, major manufacturers of alkaline water-electrolytic hydrogen generators in China still use asbestos cloth as diaphragm. However, as the industrialization process is advanced and the technology is developed further, it is gradually recognized that asbestos diaphragms have some drawbacks in production practice. Though asbestos is non-hazardous in itself, a severe hazard is incurred by the asbestos fibers, which are fibers that are extremely fine and almost invisible to naked eyes. After those fine fibers are released, they will float in the air for a long time and may be inhaled into human body. Therefore, the international community has strengthened the research and development of new diaphragm materials. In China, diaphragm cloth has been used as the main core material of water electrolysis equipment for long. To adapt to the increasingly intense international competition and put the products into international markets, it is imperative to substitute asbestos diaphragms with a new generation of non-asbestos diaphragms. At present, asbestos diaphragms are being replaced with diaphragm cloth made from PPS fibers. Though such a replacement can solve the problems of pollution and low gas impermeability, the obtained diaphragms may have non-uniform pore size and poor gas impermeability if the fineness of the fibers used to weave PPS diaphragm cloth is inappropriate and the ratio of the twist of single yarns to the twist of plied yarns is improper.

[0004] For example, in Chinese Patent Document No. CN101372752, a high temperature-resistant alkaline water electrolyzer diaphragm produced by sulfonating non-woven cloth made from ordinary PPS fibers with 90 to 98% H_2SO_4 at 70 to 130° C. for 20 to 40 min. and then processing the non-woven cloth with 30% KOH is disclosed. In that invention, owing to the fact that the liquid absorption rate of the non-woven cloth is relatively high, a large quantity of valuable water resource and chemicals have to be consumed in the washing process after the non-woven cloth is processed with the strong acid, the washing time is long, the technological operations are complex, and pollution to the environment may occur. Besides, the process is not suitable for use in industrial production owing to its poor safety.

[0005] In Chinese Patent Document No. CN103938337A, a high temperature-resistant and alkali-resistant PPS diaphragm obtained by processing high-density woven fabric made from ordinary 2.2 T PPS fibers through plasma hydrophilic treatment process to endow hydrophilicity to the PPS diaphragm is disclosed. However, the gas impermeability of the obtained diaphragm in that invention is poor, owing to improper fineness of the fibers and improper ratio of the twist of single yarns to the twist of plied yarns. Besides, the PPS diaphragm cloth processed through the plasma hydrophilic treatment process can't truly meet the production demand owing to its poor hydrophilicity and poor durability.

[0006] In Chinese Patent Document No. CN101195944, an asbestos-free environment-friendly and energy-saving diaphragm is disclosed. The diaphragm is a woven fabric woven from a raw material that consists of one, two or three of polyetheretherketone fibers, PPS fibers, and polypropylene fibers. Though the gas impermeability of the diaphragm cloth meets the requirements of the standard for asbestos diaphragms, the obtained diaphragm cloth has poor hydrophilicity and can't truly meet the application requirements, owing to the poor water absorptivity of the above-mentioned chemical fibers.

SUMMARY OF THE INVENTION

[0007] An object of the present invention is to provide a high-performance PPS fiber structure with higher gas impermeability and better hydrophilicity.

[0008] Another object of the present invention is to provide a method for producing a high-performance PPS fiber structure, which employs a simple process, can save energy, and has no pollution to the environment.

[0009] To attain the above objects, embodiments of the present invention may have the following characteristics:

[0010] (1) The PPS fiber structure according to an embodiment of the present invention is a woven fabric formed of PPS fibers in 0.1 to 12 μm cross sectional diameter, wherein, the maximum pore size of the PPS fiber structure is 20 μm or smaller.

[0011] (2) The warp yarns and weft yarns that form the PPS fiber structure described in the item (1) are hydrophilic PPS staple yarns.

[0012] (3) The average pore size of the PPS fiber structure described in the above item (1) is 5 μm or smaller, and pores in 6 μm or smaller diameter account for 90% or a high percentage of all the pores in the fiber structure.

[0013] (4) The yarn count of the single yarns in the PPS fiber structure described in the above item (1) is 21 to 60 s.

[0014] (5) The twist factor of the yarns in the PPS fiber structure described in the above item (1) is 180 to 350.

[0015] (6) The twist of the warp yarns is greater than or equal to the twist of the weft yarns in the PPS fiber structure described in the above item (1).

[0016] (7) In the PPS fiber structure described in any one of the above items (4) to (5), the ratio of the twist of the PPS yarns to the twist of PPS single yarns is 0.2 to 1.0.

[0017] (8) The gas impermeability of the PPS fiber structure described in the above item (1) is 400 mmH_2O or above.

[0018] (9) The area resistance of the PPS fiber structure described in the above item (1) is 60 $m\Omega \cdot cm^2$ or lower.

[0019] Embodiments of the present invention may attain the following beneficial effects: in the present invention, since PPS fibers at 0.1 to 12 μm fineness are used and the ratio of the twist of single yarns to the twist of plied yarns is proper, the drawbacks of non-uniform pore size and low gas impermeability in the prior art may be overcome, and the obtained PPS woven fabric may have small and uniform pore size. Therefore, the PPS fiber structure provided in embodiments of the present invention not only has advantages of high gas impermeability and good hydrophilicity, but also has advantages of simple process, reduced energy consumption, and zero pollution to the environment. The PPS fiber structure provided in the present invention can be applied to diaphragms for electrolytic apparatuses, high-temperature liquid filter materials and insulating materials.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

[0020] The PPS fiber structure in the present invention is a woven fabric formed of PPS fibers in 0.1 to 12 μm cross sectional diameter, wherein, the maximum pore size of the PPS fiber structure is 20 μm or smaller. Among all fabric textures, fabric with tabby has the highest number of interlacing points and the highest compactness. Therefore, woven fabric with tabby is preferred. If the cross sectional diameter of the PPS fibers is smaller than 0.1 μm, the fibers will be difficult for carding in the carding procedure because the fibers are too thin. Consequently, cellfibre may be fractured, a phenomenon of undesirable resultant yarn and excessive neps may occur, and the quality of the yarns may be degraded. If such yarns are used for weaving, the obtained PPS cloth may have excessive flaws on the surface, which will influence the pore size and thickness of the fabric, leading to that the pore size and thickness of the fabric are non-uniform, and the gas impermeability of the fabric is further degraded; if the cross sectional diameter of the PPS fibers is greater than 12 μm, the cellfibre yarn will be too rigid and difficult to produce yarns because the fibers are too thick. Besides, the thick yarns will bring about difficulty in weaving, and the obtained fabric will have increased pore size and poor gas impermeability. Ultimately, the purity of hydrogen or oxygen produced will be poor; in comprehensive consideration of the factors, including the gas impermeability of the PPS fabric and the hydrophilic treatment effect in the post-treatment procedures, the cross sectional diameter of the PPS fibers preferably is 6 to 10 μm, more preferably 6 to 8 μm.

[0021] The warp yarns and weft yarns that form the PPS fiber structure are PPS staple yarns that have suffered from hydrophilic treatment. Both the warp yarns and weft yarns of the PPS fiber structure in the present invention use staple yarns. Compared with filament yarns, staple yarns have higher cohesive property between cellfibres, the voids between the cellfibres will not be increased owing to the structure of the yarns, and the pore size and gas impermeability of the fabric will not be affected. The staple yarns used in the present invention may be single yarns or plied yarns formed of single yarns, preferably are plied yarns. To ensure that the PPS fiber structure has excellent hydrophilicity, preferably PPS staple yarns treated through hydrophilic treatment are used. Here, the hydrophilic treatment refers to increase hydrophilic groups, such as hydroxyl, carboxyl, carbonate, and sulfate groups, etc., on the surface of the PPS fibers by plasma treatment, sulfonation, or grafting. The grafting ratio of the PPS yarns treated through hydrophilic treatment is 0.1 to 3%, preferably is 0.5 to 3%.

[0022] The maximum pore size of the PPS fiber structure in the present invention is 20 μm or smaller. If the maximum pore size of the PPS fiber structure is greater than 20 μm, the pore size of the PPS fiber structure will be too great, hydrogen or oxygen bubbles may penetrate through the voids in the fiber structure easily in the hydrogen generator when the PPS fiber structure is used. Consequently, the purity of single gas may be degraded. Therefore, the maximum pore size of the PPS fiber structure is 20 μm or smaller. To ensure that the PPS fiber structure has uniform pore size and the distribution of the pore sizes is concentrated, the maximum pore size of the PPS fiber structure preferably is 15 μm or smaller; to make the pore size of the fiber structure more uniform and the distribution of pore sizes more concentrated, preferably the maximum pore size of the PPS fiber structure is 12 μm or smaller.

[0023] The average pore size of the PPS fiber structure is 5 μm or smaller, and pores in 6 μm or smaller diameter account for 90% or a high percentage of all the pores in the fiber structure. If the average pore size of the PPS fiber structure is controlled within the above-mentioned range, high gas impermeability can be ensured, and it will be difficult for gas molecules and bubbles to penetrate through the voids, thereby mixing between the gas at the anode size and the gas at the cathode side can be prevented, and the purity and safety of the gas, will be good. If the average pore size of the PPS fiber structure is greater than 5 μm, the woven fabric can't attain an isolation effect when it is used in the hydrogen production equipment since the pore size of the woven fabric is too great. Consequently, the purity of the obtained hydrogen or oxygen may be low and can't meet the application requirements of the customers. To ensure that the gas impermeability of the woven fabric in the present invention meets the application requirements and improve the gas generation efficiency and the purity of the generated gas as well, on the premise that the average pore size is 5 μm or smaller, the weaving conditions are optimized to improve the uniformity of pore size, so that pores in 6 μm or smaller pore size account for 90% or above of all the pores, preferably 95% or above.

[0024] The yarn count of single yarns in the PPS woven fabric is 21 to 60 s, and the twist factor α is 200 to 310. If the yarn count of the single yarns is within the above-mentioned range, the obtained PPS fabric will have small and uniform pore size and high gas impermeability; moreover, the obtained woven fabric can attain a good hydrophilic treatment effect in the post processing. If the yarn count of the single yarns is too low, the yarns will be too thick. Consequently, the pore size of the woven fabric will be great, the gas impermeability of the woven fabric will be low, and ultimately the purity of obtained hydrogen or oxygen will be poor; if the yarn count of the single yarns is too high, extremely thin yarns have to be used. Consequently, the production process will be difficult. In addition, if the twist factor of the single yarns is within the above-mentioned range, the obtained PPS yarn will have moderate fluffiness. Thus, the obtained woven fabric will have small and uniform pore size and high gas impermeability, and the woven fabric can attain a good hydrophilic treatment effect in the post processing. If the twist factor of the yarns is too low, the twist of the yarns will be too low. Consequently, the strength of the yarns will be low, the yarns may be broken easily in the weaving process, and the strength of the obtained fabric will be degraded; on one hand, if the twist factor of the yarns is too high, the twist of the yarns will be too high, and the voids at the interlacing points in the fabric will be obvious, and the pore size will be increased; on the other hand, the voids among the fibers in the yarns will be deceased, and the pore size of the entire woven fabric will be non-uniform and the gas impermeability will be decreased.

[0025] The twist factor of the yarns of the PPS woven fabric is 180 to 350. If the twist factor of the yarns is too low, the twisting angle of the single fibers will be small, the cohesion force among the fibers will be decreased, the strength of the yarns will be decreased, and the weaving operation will be difficult in the weaving process, since the strength of the yarns is too low; if the twist factor of the yarns is too high, the cohesion force among the fibers will be too high, the strength of the yarns will be decreased, and pigtails may occur easily in the weaving process, resulting in that the weaving process will difficult to go on.

[0026] In the weaving process, the tension on the warp yarns is greater than the tension for wefting insertion of the weft yarns. To ensure the weaving efficiency of the PPS fabric, compact fabric structure, and small and uniform pore size, preferably the twist of the warp yarns is greater than or equal to the twist of the weft yarns in the PPS fiber structure in the present invention. If the twist of the warp yarns is slightly greater, the strength of the warp yarns can be ensured, and the shedding rate can be improved, which are beneficial for the weaving operation. If the weft yarns are staple yarns with slightly lower twist, the yarns will be fluffy, and the defect of increased and non-uniform pore size incurred by the increased twist of the warp yarns can be compensated.

[0027] The ratio of the twist of the PPS yarns to the twist of the PPS single yarns in the present invention is 0.2 to 1.0. If the ratio of the twist of the yarns to the twist of the single yarns is within the above-mentioned range, the woven fabric will have uniform pore size, and more hydrophilic groups can be grafted during the hydrophilic treatment on the woven fabric. Thus, the liquid content in the woven fabric will be increased, and the aqueous film formed on the surface layer of the woven fabric will be thicker and can effectively block bubble penetration. Therefore, the purity of the obtained gas will be increased. If the ratio of the twist of the PPS yarns to the twist of the single yarns is too low, the twist of the yarns will certainly be decreased, and the strength of the obtained PPS yarns will be low.

[0028] Consequently, the strength of the obtained PPS woven fabric will be decreased, and the woven fabric may be penetrated more easily; if the ratio of the twist of the PPS yarns to the twist of the single yarns is too high, the voids among the fibers in the yarns will be decreased, so the pore size of the entire woven fabric will be non-uniform, the decreased gas impermeability will lead to non-uniform pore size of the woven fabric, and thereby the hydrophilic groups grafted to the woven fabric will be less.

[0029] The gas impermeability of the PPS fiber structure in the present invention is 400 mmH_2O or above. When the PPS fiber structure is applied to water electrolyzers, on a premise that gas-tight for 2 min. at a pressure equal to or above 400 mmH_2O, the requirement for gas impermeability of diaphragm cloth for water electrolyzers can be met essentially; in addition, the diaphragm cloth has excellent gas impermeability, ion passing efficiency and processability. If the gas impermeability is lower than 400 mmH_2O, the basic requirement for diaphragms can't be met, and the purity of the obtained gas will be affected.

[0030] The area resistance of the PPS fiber structure in the present invention is 60 $m\Omega\cdot cm^2$ or lower, preferably is 10 $m\Omega\cdot cm^2$ or lower. If the area resistance of the PPS fiber structure is higher than 60 $m\Omega\cdot cm^2$, the resistance of the fabric will be great, the electric power consumption will be increased, and the production cost will be increased accordingly.

[0031] The alkali absorption ratio of the PPS fiber structure in the present invention is 70 to 200%. If the alkali absorption ratio of the PPS fiber structure is too low, it will be difficult to form an aqueous film or the aqueous film will be too thin in alkaline liquor, and can't effectively block gas bubble penetration, and the purity of the obtained gas will be decreased; if the alkali absorption ratio of the PPS fiber structure is too high, the structure of the woven fabric will be certainly too loose, the voids in the woven fabric will be greater, and the performance of the diaphragm will be affected. In consideration of the hydrophilicity and structure of the PPS fiber structure, the alkali absorption ratio of the PPS fiber structure in the present invention preferably is 85 to 180%, more preferably is 100 to 160%.

[0032] The high-performance PPS fiber structure in the present invention is applied to hydrogen generator, and its function is mainly for preventing penetration of gas molecules while allowing penetration of ions. Since different customers have different requirements for the purity of produced hydrogen and oxygen, the requirements for the pore size and gas impermeability of the fabric may be different, but such requirements are irrelevant to the type and texture of the fabric. The fabric can meet the requirements of the customers as long as interpenetration among gas molecules will not happen.

[0033] The method for producing a high-performance PPS fiber structure in the present invention comprises the following steps:

(1) cotton spinning process: processing PPS fibers in 0.1 to 12 μm cross sectional diameter by opening and cleaning, carding, drawing and roving, drafting the roving to obtain PPS single yarns with yarn count equal to 20 to 60 s and twist factor α equal to 200 to 310, processing the PPS single yarns by winding, doubling, twisting and thermoforming into PPS yarns with ply number equal to 1 to 6;

(2) weaving process: processing the obtained PPS yarns by warp beaming, drafting, reeding, and weaving, to obtain PPS woven fabric with cover factor equal to 2400 to 2900; the cover factor of woven fabric is a parameter that represents the compactness of the fabric. The higher the cover factor is, the more compact the fabric is, the lower the gas permeability and the smaller the pore size are. If the cover factor of woven fabric with tabby is lower than 2400, the gas impermeability of the fabric will be low because of inadequate compactness of the fabric.

Consequently, it will be difficult for the woven fabric to block gas penetration, and the purity of the obtained gas and the safety of the production process can't be ensured; if the cover factor of woven fabric with tabby is higher than 2900, the requirement for the loom will be high, and the weaving process will be difficult. Therefore, the cover factor of the woven fabric preferably is 2600 to 2800;

(3) post-finishing process: processing the obtained PPS woven fabric by scouring, water washing, drying, and thermoforming at 180 to 200° C.; the optimal experiment conditions for the above-mentioned scouring and thermoforming are as follows:

a. Scouring agents used: YK30 12 g/L, YS66 3.0 g/L, and YK37 2.0 g/L
b. Temperatures in scouring tanks: tank 1: 40 to 50° C., tank 2: 70 to 80° C., and tank 3: 95 to 105° C.
c. Rate: 10 to 14 m/min.
d. Thermoforming temperature: 180° C. to 210° C.
e. Thermoforming rate: 10 to 14 m/min.

(4) hydrophilic treatment process: processing the thermoformed fabric by plasma hydrophilic treatment and/or sulfonated hydrophilic treatment, to obtain a finished product finally. By processing the fabric by plasma hydrophilic treatment and/or sulfonated hydrophilic treatment, hydrophilic groups can be grafted to the surfaces of the PPS fibers, the wetting rate of the PPS woven fabric can be increased, and the liquid content in the PPS woven fabric can be increased. Thus, the gas production efficiency and gas purity can be improved in the application process. The grafting ratio of the obtained fabric after plasma hydrophilic treatment and/or sulfonated hydrophilic treatment may be different. Preferably the grafting ratio of the PPS woven fabric is 3.0 to 8.0%.

[0034] The method for plasma hydrophilic treatment includes normal pressure plasma treatment and low pressure plasma treatment. Normal pressure plasma treatment methods include glow discharge, silent discharge, and corona discharge, wherein, the glow discharge includes direct current, high frequency current, and microwave radiation; the gasses processed by low pressure plasma treatment include oxygen, argon, and nitrogen, etc. In consideration of the possibility, stability, and efficiency of the processing, the plasma hydrophilic treatment preferably is normal pressure plasma DC glow discharge, the conditions of which include: voltage: 5 to 15 V, current: 12 to 18 A, and the content of grated oxygen element accounts for 15 to 25% of the measured element content. After the plasma treatment, concavo-convex pits will be created on the surfaces of the PPS fibers. Thus, the capillary effect and water absorptivity of the PPS woven fabric can be improved. Besides, the hydrophilic groups grafted to the surface layer of the PPS fibers includes sulfate, carboxylate, carbonate, hydroxyl, and carbonyl, etc., these grafted hydrophilic groups can improve the water absorption rate of the PPS fibers and improve the purity of hydrogen and oxygen.

[0035] In the case that the thermoformed fabric is processed by plasma treatment and sulfonation processing, the thermoformed fabric is processed by plasma treatment to physically etch the PPS yarns and form concavo-convex pits on the surface layer of the fibers to increase the specific surface area of the PPS fibers; then, the PPS fabric is processed by sulfonation processing after the plasma treatment, such that the number of grafted hydrophilic groups can be increased and the hydrophilic property of the PPS fabric will be better.

[0036] To make the obtained PPS fabric have a better hydrophilic property, preferably the PPS yarns prepared in the step (1) is processed by at least one of plasma treatment, sulfonation processing, and graft copolymerization methods, to obtain hydrophilic PPS yarns. If the yarn is processed merely by plasma treatment, the fabric may have poor durability, and the hydrophilicity of the fabric after scouring may be degraded. The hydrophilicity of the fabric may be decreased owing to the impact of chemicals and high temperature in post-treatment when the graft copolymerization process is used. Therefore, preferably the PPS yarns are sulfonation processing, or more preferably the PPS yarns are sulfonation processing after the plasma treatment.

[0037] The sulfonation processing method is to treating the yarns in a sulfonation treatment liquid (85 to 98% chlorosulfonic acid or concentrated sulfuric acid) at 80 to 120° C. for 1 to 5 min., to graft hydrophilic groups (sulfate, etc.) to the surface layer of the PPS fibers. The plasma treatment method may be normal pressure plasma treatment or vacuum plasma treatment. Through plasma treatment, concavo-convex pits are formed on the surface of the PPS fibers, and thereby the capillary effect and water absorptivity of the PPS fibers are improved. Besides, hydrophilic groups, including sulfate, carboxylate, carbonate, hydroxyl, and carbonyl, etc., are grafted to the surface layer of the PPS fibers, so that the water absorption rate of the PPS fibers can be improved, and the purity of hydrogen and oxygen can also be improved.

[0038] The present invention will be further detailed in the following Examples. However, the protection scope of the present invention is not limited to those Examples.

[0039] In the Examples, the properties of the materials are measured with the following methods or calculated with the following formulae.

[Cover Factor]

[0040] The cover factor of the woven fabric is calculated with the following formula:

$$CF=N_w\times\sqrt{D_w}+N_f\times\sqrt{D_f},$$

[0041] Where, N_w: Density of the fabric in warp direction (yarns/inch);

[0042] D_w: Fineness of warp filament yarns in the fabric (dtex);

[0043] N_f: Density of the fabric in weft direction (yarns/inch);

[0044] D_f: Fineness of weft filament yarns in the fabric (dtex)

[Average Pore Size]

[0045] The pore sizes of the fabric are measured with a capillary flow void measuring instrument (model: CFP-1100-AE, from PMI) in a wet-up/dry-down work mode according to the standard ASTMF316-03. The testing environment is 23° C. and 50% RH. A fabric sample is placed in a sample chamber, and is wetted with silwick silicone fluid with 19.1 dynes/cm surface tension. The bottom fixture in the sample chamber has a porous metal disc in 2.54 cm diameter and 3.175 mm thickness, and the top fixture in the sample chamber has pores in 3.175 mm diameter. The average pore size of the fabric can be read out directly. The average value of measurements in two times is taken as the final average pore size value.

[Gas Impermeability]

[0046] The gas impermeability is measured according to the Article 4.5.2 "Gas Impermeability Test" in the Chinese Building Material Industry Standard JCT 211-2009 "Diaphragm Asbestos Cloth".

[Water Absorption]

[0047] The water absorption of diaphragm cloth before and after hydrophilic treatment is measured according to GB/T21655.1-2008.

[Water Absorption Rate]

[0048] The water absorption rate is tested according to the Article 7.1.1 "falling-drop method" in JIS L1907-2010 "Water Absorption Testing Method for Fiber Products".

[Area Resistance]

[0049] An apparatus for testing the area resistance of PPS diaphragm is set up according to the Electronics Industry Standard SJ/T 10171.5-91 "Measurement Methods for Performance of Separator of Alkaline Batteries—Determination of Area-Resistance of Separator" in PRC. The parameters of the apparatus are as follows:

(1) Low-temperature thermostat bath controller

a. The low-temperature thermostat bath controller is set to −5 to 100° C. temperature range and ±0.05 temperature control deviation (the instrument is Model DC0506 from Shanghai Genggeng Instruments and Equipment Co., Ltd.);

(b. Operating temperature: 60° C., the liquid medium is usually dimethyl silicon oil.

(2) Battery internal resistance tester

a. Model: AT526 (from Changzhou Applent Precision Instruments Co., Ltd.);

b. Resistance test accuracy: 0.5%; voltage test accuracy: 0.01%;

c. Test range: resistance: 0.0005 mΩ to 33Ω; voltage: 0.00001 to 120 V DC;

d. Internal resistance fittings: 1 m test probe: ATL502A; 1 m test wire: ATL502; 1.8Mrs232 serial cable: ATL108; fuse (in the power socket): 0.5 A SB.

(3) Parameters of resistance test tank

a. Material of tank: PTFE material;

b. Material of electrodes: pure silver (99.9999%);

c. Spacing between electrodes: 23 mm;

d. Area of PPS diaphragm: 4 cm (L)*2 cm (W);

e. KOH liquor: temperature: 60° C.; mass concentration: 30 wt %.

(4) Chemicals used in the experiment

a. 30 wt % KOH (potassium hydroxide: guaranteed reagent);

b. Water used for preparing the alkaline liquor: Grade 2 super-pure deionized water

(5) Testing environment: temperature: 20° C., humidity: 60% RH, constant temperature and constant humidity

[Grafting Ratio]

[0050] The sulfonated PPS woven fabric is titrated with 0.1 mol/L NaOH standard solution (phenolphthalein is used as the indicator), and the grafting ratio of the woven fabric is calculated with the following formula according to the quantity of consumed NaOH:grafting ratio %=(0.01V*108)/1000 W*100%, where, V is the volume of consumed NaOH, in mL; W is the mass of sulfonated PPS diaphragm cloth involved in the titration; 108 is the relative molecular weight of the PPS monomer.

[Alkali Absorption Ratio]

[0051] A piece of woven fabric in 40 mm*40 mm size is obtained and the weight G_1 of the woven fabric is weighed; the woven fabric is immersed in 30% KOH solution for 4 h and then is taken out. The woven fabric is hung for half minute, so that the alkaline liquor in the woven fabric drops out; then, the weight G_2 is weighed, and the alkali absorption ratio is calculated. The alkali absorption ratio is calculated with the following formula:

$$A=(G_1-G_2)/G_1*100\%,$$

[0052] Where, A: alkali absorption ratio of the diaphragm, %;

[0053] G_1: the mass of the sample before the sample is immersed in the alkaline liquor, g;

[0054] G_2: the mass of the sample after the sample is immersed in the alkaline liquor, g.

Example 1

[0055] Round PPS fibers in 10 μm cross sectional diameter are processed through scutching—carding—drawing—roving—fine yarns—winding—thermoforming procedures to obtain PPS single yarns with yarn count equal to 40 s, twist equal to 81 T/10 cm, and twist factor equal to 311; the obtained PPS single yarns are span through a cotton spinning process including winding—doubling—twisting—thermoforming procedures to obtain PPS yarns with ply number equal to 4, warp twist and weft twist equal to 45 T/10 cm respectively, and twist factor equal to 346, wherein, the ratio of the twist of the PPS yarns to the twist of the single yarns is 0.56; the obtained PPS yarns are used as warp yarns and weft yarns and woven on a loom to obtain grey cloth with tabby having density in warp direction equal to 55.3 yarns/inch and density in weft direction equal to 48.0 yarns/inch; the obtained grey cloth is processed by scouring, water washing, drying and thermoforming at 180° C., and then the thermoformed PPS woven fabric is sulfonated. Finally, a PPS fiber structure with cover factor equal to 2510, thickness equal to 0.64 mm, maximum pore size equal to 16 μm, average pore size equal to 3.0 μm (pores in 6 μm or smaller diameter account for 94% or above of all pores in the woven fabric), area resistance R equal to 2.2 mΩ·cm^2, and strength in warp direction and strength in weft direction equal to 900 N/3 cm and 602 N/3 cm respectively is obtained. The properties of the PPS fiber structure obtained in the present invention are assessed and shown in Table 1.

Example 2

[0056] The PPS yarns obtained in the Example 1 are treated with 98% concentrated sulfuric acid at 90° C. for 3 min. to obtain, hydrophilic PPS yarns with grafting ratio equal to 1.8%. The obtained hydrophilic PPS yarns are used as warp yarns and weft yarns and woven on a loom to obtain grey cloth with tabby having density in warp direction equal to 55.0 yarns/inch and density in weft direction equal to 48.7 yarns/inch; the obtained grey cloth is processed by scouring, water washing, drying, and thermoforming at 180° C.; and then the thermoformed PPS woven fabric is sulfonated. Finally, a PPS fiber structure with cover factor equal to 2520, thickness equal to 0.63 mm, maximum pore size equal to 15 μm, average pore size equal to 3.0 vim (pores in 6 μm or smaller diameter account for 95% or above of all pores in the woven fabric), area resistance R equal to 1.3 mΩ·cm^2, and strength in warp direction and strength in weft direction equal to 750 N/3 cm and 521 N/3 cm respectively is obtained. The properties of the PPS fiber structure obtained in the present invention are assessed and shown in Table 1.

Example 3

[0057] Round PPS fibers in 8 μm cross sectional diameter are processed through scutching—carding—drawing—roving—fine yarns—winding—thermoforming procedures to obtain PPS single yarns with yarn count equal to 60 s, twist equal to 90 T/10 cm, and twist factor equal to 282; the obtained PPS single yarns are span through a cotton spinning process including winding—doubling-twisting—thermoforming procedures to obtain PPS yarns with ply number equal to 6, warp twist and weft twist equal to 44 T/10 cm respectively, and twist factor equal to 338, wherein, the ratio of the twist of the PPS yarns to the twist of the single yarns is 0.49; the obtained PPS yarns are used as warp yarns and weft yarns and woven on a loom to obtain grey cloth with tabby having density in warp direction equal to 66.3 yarns/inch and density in weft direction equal to 39.0 yarns/inch; the obtained grey cloth is processed by scouring, water washing, drying and thermoforming at 180° C., and then the thermoformed PPS woven fabric is sulfonated. Finally, a PPS fiber structure with cover factor equal to 2559, thickness equal to 0.64 mm, maximum pore size equal to 17 μm, average pore size equal to 4.9 μm (pores in 6 μm or smaller diameter account for 92% or above of all pores in the woven fabric), area resistance R equal to 1.5 mΩ·cm^2, and strength in warp direction and strength in weft direction equal to 991 N/3 cm and 654 N/3 cm respectively is obtained. The properties of the PPS fiber structure obtained in the present invention are assessed and shown in Table 1.

Example 4

[0058] Round PPS fibers in 8 μm cross sectional diameter are processed through scutching—carding—drawing—roving—fine yarns—winding—thermoforming procedures to obtain PPS single yarns with yarn count equal to 40 s, twist equal to 57 T/10 cm, and twist factor equal to 219; the obtained PPS single yarns are span through a cotton spinning process including winding—doubling-twisting—thermoforming procedures to obtain. PPS yarns with ply number equal to 4, warp twist and weft twist equal to 47 T/10 cm respectively, and twist factor equal to 361, wherein, the ratio of the twist of the PPS yarns to the twist of the single yarns is 0.82; the obtained PPS yarns are used as warp yarns and weft yarns and woven on a loom to obtain grey cloth with tabby having density in warp direction equal to 68.8 yarns/inch and density in weft direction equal to 43.7 yarns/inch; the obtained grey cloth is processed by scouring, water washing, drying and thermoforming at 180° C., and then the thermoformed PPS woven fabric is processed by plasma treatment. Finally, a PPS fiber structure with cover factor equal to 2734, thickness equal to 0.62 mm, maximum pore size equal to 18 μm, average pore size equal to 4.5 μm (pores in 6 μm or smaller diameter account for 93% or above of all pores in the woven fabric), area resistance R equal to 1.6 m·cm^2, and strength in warp direction and strength in weft direction equal to 1014 N/3 cm and 711 N/3 cm respectively is obtained. The properties of the PPS fiber structure obtained in the present invention are assessed and shown in Table 1.

Example 5

[0059] Round PPS fibers in 9 μm cross sectional diameter are processed through scutching—carding—drawing—roving—fine yarns—winding—thermoforming procedures to obtain PPS single yarns with yarn count equal to 20 s, twist equal to 48 T/10 cm and twist factor equal to 261; the obtained PPS single yarns are span through a cotton spinning process including winding—doubling—twisting—thermoforming procedures to obtain PPS yarns with ply number equal to 2, warp twist and weft twist equal to 40 T/10 cm respectively, and twist factor equal to 307, wherein, the ratio of the twist of the PPS yarns to the twist of the single yarns is 0.83; the obtained PPS yarns are processed with 98% concentrated sulfuric acid at 90° C. for 3 min to obtain hydrophilic PPS yarns with grafting ratio equal to 1.3%. The obtained hydrophilic PPS yarns are used as warp yarns and weft yarns and woven on a loom to obtain grey cloth with tabby having density in warp direction equal to 68.3 yarns/inch and density in weft direction equal to 45.2 yarns/inch; the obtained grey cloth is processed by scouring, water washing, drying, and thermoforming at 180° C.; and then the thermoformed PPS woven fabric is sulfonated. Finally, a PPS fiber structure with cover factor equal to 2758, thickness equal to 0.61 mm, maximum pore size equal to 19 μm, average pore size equal to 3.3 μm (pores in 6 μm or smaller diameter account for 95% or above of all pores in the woven fabric), area resistance R equal to 2.0 mΩ·cm^2, and strength in warp direction and strength in weft direction equal to 1031 N/3 cm and 846 N/3 cm respectively is obtained. The properties of the PPS fiber structure obtained in the present invention are assessed and shown in Table 1.

Example 6

[0060] Round PPS fibers in 10 μm cross sectional diameter are processed through scutching—carding—drawing—roving—fine yarns—winding—thermoforming procedures to obtain PPS single yarns with yarn count equal to 40 s, twist equal to 81 T/10 cm and twist factor equal to 311; the obtained PPS single yarns are span through a cotton spinning process including winding—doubling—twisting—thermoforming procedures to obtain PPS yarns with ply number equal to 2, warp twist and weft twist equal to 71 T/10 cm respectively, and twist factor equal to 386, wherein, the ratio of the twist of the PPS yarns to the twist of the single yarns is 0.88; the obtained PPS yarns are processed by plasma treatment at normal pressure and then processed with 85% concentrated sulfuric acid at 95° C. for 3 min. to obtain hydrophilic PPS yarns with grafting ratio equal to 2.6%. The obtained hydrophilic PPS yarns are used as warp yarns and weft yarns and woven on a loom to obtain grey cloth with tabby having density in warp direction equal to 88.0 yarns/inch and density in weft direction equal to 64.0 yarns/inch; the obtained grey cloth is processed by scouring, water washing, drying, and thermoforming at 180° C.; and then the thermoformed PPS woven fabric is processed by plasma treatment and then processed by sulfonated hydrophilic processing. Finally, a PPS fiber structure with cover factor equal to 2612, thickness equal to 0.41 mm, maximum pore size equal to 16 μm, average pore size equal to 3.0 μm (pores in 6 μm or smaller diameter account for 94% or above of all pores in the woven fabric), area resistance R equal to 2.2 mΩ·cm^2, and strength in warp direction and strength in weft direction equal to 900 N/3 cm and 602 N/3 cm respectively is obtained. The properties of the PPS fiber structure obtained in the present invention are assessed and shown in Table 1.

Example 7

[0061] Round PPS fibers in 11 μm cross sectional diameter are processed through scutching—carding—drawing—roving—fine yarns—winding—thermoforming procedures to obtain PPS single yarns with yarn count equal to 60 s, twist equal to 90 T/10 cm and twist factor equal to 282; the obtained PPS single yarns are span through a cotton spinning process including winding—doubling—twisting—thermoforming procedures to obtain PPS yarns with ply number equal to 2, warp twist and weft twist equal to 76 T/10 cm respectively, and twist factor equal to 337, wherein, the ratio of the twist of the PPS yarns to the twist of the single yarns is 0.84; the obtained PPS yarns are processed by steaming with polyester hydrophilic resin to obtain hydrophilic PPS yarns with grafting ratio equal to 0.6%. The obtained hydrophilic PPS yarns are used as warp yarns and weft yarns and woven on a loom to obtain grey cloth with tabby having density in warp direction equal to 113.0 yarns/inch and density in weft direction equal to 60.0 yarns/inch; the obtained grey cloth is processed by scouring, water washing, drying, and thermoforming at 180° C.; and then the thermoformed PPS woven fabric is processed by plasma treatment and then is sulfonated. Finally, a PPS fiber structure with cover factor equal to 2427, thickness equal to 0.35 mm, maximum pore size equal to 18 μm, average pore size equal to 4.3 μm (pores in 6 μm or smaller diameter account for 91.5% or above of all pores in the woven fabric), area resistance R equal to 2.4 $m\Omega\cdot cm^2$, and strength in warp direction and strength in weft direction equal to 640 N/3 cm and 400 N/3 cm respectively is obtained. The properties of the PPS fiber structure obtained in the present invention are assessed and shown in Table 1.

Example 8

[0062] Round PPS fibers in 4 μm cross sectional diameter are processed through scutching—carding—drawing—roving—fine yarns—winding—thermoforming procedures to obtain PPS single yarns with yarn count equal to 60 s, twist equal to 90 T/10 cm, and twist factor equal to 282; the obtained PPS single yarns are span through a cotton spinning process including winding—doubling—twisting-thermoforming procedures to obtain PPS yarns with ply number equal to 2, warp twist and weft twist equal to 76 T/10 cm respectively, and twist factor equal to 337, wherein, the ratio of the twist of the PPS yarns to the twist of the single yarns is 0.84; the obtained PPS yarns are used as warp yarns and weft yarns and woven on a loom to obtain grey cloth with tabby having density in warp direction equal to 113.0 yarns/inch and density in weft direction equal to 65.0 yarns/inch; the obtained grey cloth is processed by scouring, water washing, drying and thermoforming at 180° C., and then the thermoformed PPS woven fabric is sulfonated. Finally, a PPS fiber structure with cover factor equal to 2497, thickness equal to 0.30 mm, maximum pore size equal to 16 μm, average pore size equal to 4.2 μm (pores in 6 μm or smaller diameter account for 90% or above of all pores in the woven fabric), area resistance R equal to 1.4 $m\Omega\cdot cm^2$, and strength in warp direction and strength in weft direction equal to 625 N/3 cm and 378 N/3 cm respectively is obtained. The properties of the PPS fiber structure obtained in the present invention are assessed and shown in Table 1.

Example 9

[0063] Round PPS fibers in 7 μm cross sectional diameter are processed through scutching—carding—drawing—roving—fine yarns—winding—thermoforming procedures to obtain PPS single yarns with yarn count equal to 60 s, twist equal to 90 T/10 cm, and twist factor equal to 282; the obtained PPS single yarns are span through a cotton spinning process including winding—doubling—twisting—thermoforming procedures to obtain PPS yarns with ply number equal to 4, warp twist and weft twist equal to 54 T/10 cm respectively, and twist factor equal to 339, wherein, the ratio of the twist of the PPS yarns to the twist of the single yarns is 0.60; the obtained PPS yarns are used as warp yarns and weft yarns and woven on a loom to obtain grey cloth with tabby having density in warp direction equal to 90.0 yarns/inch and density in weft direction equal to 60.0 yarns/inch; the obtained grey cloth is processed by scouring, water washing, drying and thermoforming at 180° C., and then the thermoformed PPS woven fabric is sulfonated. Finally, a PPS fiber structure with cover factor equal to 2976, thickness equal to 0.40 mm, maximum pore size equal to 16 μm, average pore size equal to 4.4 μm (pores in 6 μm or smaller diameter account for 91% or above of all pores in the woven fabric), area resistance R equal to 1.4 $m\Omega\cdot cm^2$, and strength in warp direction and strength in weft direction equal to 900 N/3 cm and 570 N/3 cm respectively is obtained. The properties of the PPS fiber structure obtained in the present invention are assessed and shown in Table 1.

Example 10

[0064] Round PPS fibers in 11 μm cross sectional diameter are processed through scutching—carding—drawing—roving—fine yarns—winding—thermoforming procedures to obtain PPS single yarns with yarn count equal to 20 s, twist equal to 56 T/10 cm and twist factor equal to 304; the obtained PPS single yarns are span through a cotton spinning process including winding—doubling—twisting—thermoforming procedures to obtain PPS yarns with ply number equal to 2, warp twist and weft twist equal to 24 T/10 cm respectively, and twist factor equal to 184, wherein, the ratio of the twist of the PPS yarns to the twist of the single yarns is 0.43; the obtained PPS yarns are processed by plasma treatment at normal pressure and then processed with 85% concentrated sulfuric acid at 95° C. for 3 min. to obtain hydrophilic PPS yarns with grafting ratio equal to 2.8%. The obtained hydrophilic PPS yarns are used as warp yarns and weft yarns and woven on a loom to obtain grey cloth with tabby having density in warp direction equal to 58.0 yarns/inch and density in weft direction equal to 54.0 yarns/inch; the obtained grey cloth is processed by scouring, water washing, drying, and thermoforming at 180° C.; and then the thermoformed PPS woven fabric is sulfonated. Finally, a PPS fiber structure with cover factor equal to 2722, thickness equal to 0.51 mm, maximum pore size equal to 19 μm, average pore size equal to 4.8 μm (pores in 6 μm or smaller diameter account for 90.5% or above of all pores in the woven fabric), area resistance R equal to 3.6 $m\Omega\cdot cm^2$, and strength in warp direction and strength in weft direction equal to 780 N/3 cm and 602 N/3 cm respectively is obtained. The properties of the PPS fiber structure obtained in the present invention are assessed and shown in Table 1.

Example 11

[0065] Round PPS fibers in 8 μm cross sectional diameter are processed through scutching—carding—drawing—roving—fine yarns—winding—thermoforming procedures to obtain PPS single yarns with yarn count equal to 20 s, twist equal to 48 T/10 cm and twist factor equal to 261; the obtained PPS single yarns are span through a cotton spinning process including winding—doubling—twisting—thermoforming procedures to obtain PPS yarns with ply number equal to 2, warp twist equal to 40 T/10 cm and twist factor equal to 307, wherein, the ratio of the twist of the warp yarns to the twist of the single yarns is 0.83; and weft twist equal to 36 T/10 cm and twist factor equal to 277, wherein, the ratio of the twist of the weft yarns to the twist of the single yarns is 0.75. The obtained PPS yarns are processed with 98% concentrated sulfuric acid at 90° C. for 3 min. to obtain hydrophilic PPS yarns with grafting ratio equal to 1.5%. The obtained hydrophilic PPS yarns are used as warp yarns and weft yarns and woven on a loom to obtain grey cloth with tabby having density in warp direction equal to 68.3 yarns/inch and density in weft direction equal to 44.0 yarns/inch; the obtained grey cloth is processed by scouring, water washing, drying, and thermoforming at 180° C.; and then the thermoformed PPS woven fabric is sulfonated. Finally, a PPS fiber structure with cover factor equal to 2729, thickness equal to 0.62 mm, maximum pore size equal to 18 μm, average pore size equal to 2.9 μm (pores in 6 μm or smaller diameter account for 96% or above of all pores in the woven fabric), area resistance R equal to 2.0 mΩ·cm^2, and strength in warp direction and strength in weft direction equal to 820 N/3 cm and 658 N/3 cm respectively is obtained. The properties of the PPS fiber structure obtained in the present invention are assessed and shown in Table 1.

Example 12

[0066] Round PPS fibers in 8 μm cross sectional diameter are processed through scutching—carding—drawing—roving—fine yarns—winding—thermoforming procedures to obtain PPS single yarns with yarn count equal to 40 s, twist equal to 81 T/10 cm and twist factor equal to 311; the obtained PPS single yarns are span through a cotton spinning process including winding—doubling-twisting—thermoforming procedures to obtain PPS yarns with ply number equal to 2, warp twist equal to 80 T/10 cm and twist factor equal to 435, wherein, the ratio of the twist of the warp yarns to the twist of the single yarns is 0.99; and weft twist equal to 60 T/10 cm and twist factor equal to 326, wherein, the ratio of the twist of the weft yarns to the twist of the single yarns is 0.74. The obtained PPS yarns are processed with 98% concentrated sulfuric acid at 90° C. for 3 min. to obtain hydrophilic PPS yarns with grafting ratio equal to 1.8%. The obtained hydrophilic PPS yarns are used as warp yarns and weft yarns and woven on a loom to obtain grey cloth with tabby having density in warp direction equal to 88.0 yarns/inch and density in weft direction equal to 62.0 yarns/inch; the obtained grey cloth is processed by scouring, water washing, drying, and thermoforming at 180° C.; and then the thermoformed PPS woven fabric is sulfonated. Finally, a PPS fiber structure with cover factor equal to 2577, thickness equal to 0.42 mm, maximum pore size equal to 15 μm, average pore size equal to 3.0 μm (pores in 6 μm or smaller diameter account for 94% or above of all pores in the woven fabric), area resistance R equal to 2.1 mΩ·cm^2, and strength in warp direction and strength in weft direction equal to 769 N/3 cm and 512 N/3 cm respectively is obtained. The properties of the PPS fiber structure obtained in the present invention are assessed and shown in Table 1.

Example 13

[0067] Round PPS fibers in 6 μm cross sectional diameter are processed through scutching—carding—drawing—roving—fine yarns—winding—thermoforming procedures to obtain PPS single yarns with yarn count equal to 60 s, twist equal to 90 T/10 cm and twist factor equal to 282; the obtained PPS single yarns are span through a cotton spinning process including winding—doubling-twisting—thermoforming procedures to obtain PPS yarns with ply number equal to 3, warp twist equal to 54 T/10 cm and twist factor equal to 293, wherein, the ratio of the twist of the warp yarns to the twist of the single yarns is 0.60; and weft twist equal to 40 T/10 cm and twist factor equal to 217, wherein, the ratio of the twist of the weft yarns to the twist of the single yarns is 0.44. The obtained PPS yarns are woven on a loom to obtain grey cloth with tabby having density in warp direction equal to 95.0 yarns/inch and density in weft direction equal to 68.0 yarns/inch; the obtained grey cloth is processed by scouring, water washing, drying, and thermoforming at 180° C.; and then the thermoformed. PPS woven fabric is sulfonated. Finally, a PPS fiber structure with cover factor equal to 2801, thickness equal to 0.48 mm, maximum pore size equal to 12 μm, average pore size equal to 2.3 μm (pores in 6 μm or smaller diameter account for 96% or above of all pores in the woven fabric), area resistance R equal to 1.9 mΩ·cm^2, and strength in warp direction and strength in weft direction equal to 611 N/3 cm and 457 N/3 cm respectively is obtained. The properties of the PPS fiber structure obtained in the present invention are assessed and shown in Table 1.

Example 14

[0068] Round PPS fibers in 10 μm cross sectional diameter are processed through scutching—carding—drawing—roving—fine yarns—winding—thermoforming procedures to obtain PPS single yarns with yarn count equal to 20 s, twist equal to 48 T/10 cm and twist factor equal to 261; the obtained PPS single yarns are span through a cotton spinning process including winding—doubling—twisting—thermoforming procedures to obtain PPS yarns with ply number equal to 2, warp twist equal to 36 T/10 cm and twist factor equal to 277, wherein, the ratio of the twist of the warp yarns to the twist of the single yarns is 0.75; and weft twist equal to 40 T/10 cm and twist factor equal to 307, wherein, the ratio of the twist of the weft yarns to the twist of the single yarns is 0.83. The obtained PPS yarns are processed with 98% concentrated sulfuric acid at 90° C. for 3 min. to obtain hydrophilic PPS yarns with grafting ratio equal to 1.3%. The obtained hydrophilic PPS yarns are used as warp yarns and weft yarns and woven on a loom to obtain grey cloth with tabby having density in warp direction equal to 58.2 yarns/inch and density in weft direction equal to 50.3 yarns/inch; the obtained grey cloth is processed by scouring, water washing, drying, and thermoforming at 180° C.; and then the thermoformed PPS woven fabric is sulfonated. Finally, a PPS fiber structure with cover factor equal to 2637, thickness equal to 0.59 mm, maximum pore size equal to 17 μm, average pore size equal to 3.9 μm (pores in 6 μm or smaller diameter account for 95% or above of all pores in the woven fabric), area resistance R equal to 2.3 mΩ·cm^2, and strength in warp direction and strength in weft direction equal to 698 N/3 cm and 856 N/3 cm respectively is obtained. The properties of the PPS fiber structure obtained in the present invention are assessed and shown in Table 1.

Example 15

[0069] Round PPS fibers in 0.8 μm cross sectional diameter are processed through scutching—carding—drawing—roving—fine yarns—winding—thermoforming procedures to obtain PPS single yarns with yarn count equal to 60 s, twist equal to 90 T/10 cm and twist factor equal to 282; the obtained PPS single yarns are span through a cotton spinning process including winding—doubling—twisting—thermoforming procedures to obtain PPS yarns with ply number equal to 6, twist equal to 45 T/10, and twist factor equal to 346, wherein, the ratio of the twist of the yarns to the twist of the single yarns is 0.50; the obtained PPS yarns are processed by plasma treatment to obtain hydrophilic PPS yarns with grafting ratio equal to 0.8%. The obtained hydrophilic PPS yarns are used as warp yarns and weft yarns and woven on a loom to obtain grey cloth with tabby having density in warp direction equal to 65.0 yarns/inch and density in weft direction equal to 51.5 yarns/inch; the obtained grey cloth is processed by scouring, water washing, drying, and thermoforming at 180° C.; and then the thermoformed PPS woven fabric is processed by plasma treatment. Finally, a PPS fiber structure with cover factor equal to 2831, thickness equal to 0.63 mm, maximum pore size equal to 15 μm, average pore size equal to 3.2 μm (pores in 6 μm or smaller diameter account for 91% or above of all pores in the woven fabric), area resistance R equal to 6.4 mΩ·cm^2, and strength in warp direction and strength in weft direction equal to 780 N/3 cm and 692 N/3 cm respectively is obtained. The properties of the PPS fiber structure obtained in the present invention are assessed and shown in Table 1.

[0070] The PPS fiber structures obtained in the Examples 1 to 15 can be applied in diaphragms for electrolytic apparatuses, high-temperature liquid filter materials and insulating materials.

Comparative Example 1

[0071] Round PPS fibers in 13 μm cross sectional diameter are processed through scutching—carding—drawing—roving—fine yarns—winding—thermoforming procedures to obtain PPS single yarns with yarn count equal to 20 s, twist equal to 56 T/10 cm, and twist factor equal to 304; the obtained PPS single yarns are span through a cotton spinning process including winding—doubling—twisting—thermoforming procedures to obtain PPS yarns with ply number equal to 2, warp twist and weft twist equal to 60 T/10 cm respectively, and twist factor equal to 461, wherein, the ratio of the twist of the PPS yarns to the twist of the single yarns is 1.07; the obtained PPS yarns are used as warp yarns and weft yarns and woven on a loom to obtain grey cloth with tabby having density in warp direction equal to 67.0 yarns/inch and density in weft direction equal to 46.0 yarns/inch; the obtained grey cloth is processed by scouring, water washing, drying and thermoforming at 180° C., and then is processed by plasma treatment for hydrophilic treatment. Finally, a PPS fiber structure with cover factor equal to 2746, thickness equal to 0.50 mm, maximum pore size equal to 30 μm, average pore size equal to 5.2 μm (pores in 6 μm or smaller diameter account for 80% or above of all pores in the woven fabric), area resistance R equal to 4.8 mΩ·cm^2, and strength in warp direction and strength in weft direction equal to 1280 N/3 cm and 903 N/3 cm respectively is obtained. The properties of the PPS fiber structure are assessed and shown in Table 1.

Comparative Example 2

[0072] Round PPS fibers in 14 μm cross sectional diameter are processed through scutching—carding—drawing—roving—fine yarns—winding—thermoforming procedures to obtain PPS single yarns with yarn count equal to 20 s, twist equal to 56 T/10 cm, and twist factor equal to 304; the obtained PPS single yarns are span through a cotton spinning process including winding—doubling-twisting—thermoforming procedures to obtain PPS yarns with ply number equal to 4, warp twist and weft twist equal to 40 T/10 cm respectively, and twist factor equal to 435, wherein, the ratio of the twist of the PPS yarns to the twist of the single yarns is 0.71; the obtained PPS yarns are used as warp yarns and weft yarns and woven on a loom to obtain grey cloth with tabby having density in warp direction equal to 45.0 yarns/inch and density in weft direction equal to 30.0 yarns/inch; the obtained grey cloth is processed by scouring, water washing, drying and thermoforming at 180° C., and then is processed by plasma treatment for hydrophilic treatment. Finally, a PPS fiber structure with cover factor equal to 2577, thickness equal to 0.80 mm, maximum pore size equal to 40 μm, average pore size equal to 8.3 μm (pores in 6 μm or smaller diameter account for 40% or above of all pores in the woven fabric), area resistance R equal to 3.4 mΩ·cm^2, and strength in warp direction and strength in weft direction equal to 1691 N/3 cm and 1319 N/3 cm respectively is obtained. The properties of the PPS fiber structure are assessed and shown in Table 1.

TABLE 1

Item	Example 1	Example 2	Example 3	Example 4	Example 5	Example 6	Example 7	Example 8	Example 9
Cross sectional diameter (μm)	10	10	8	8	9	10	11	4	7
Yarn count of single yarns (s)	40	40	60	40	20	40	60	60	60
Twist of single yarns (T/10 cm)	81	81	90	57	48	81	90	90	90
Twist factor of single yarns (α)	311	311	282	219	261	311	282	282	282
Ply number (ply)	4	4	6	4	2	2	2	2	4
Yarn count of plied yarns (s)	10	10	10	10	10	20	30	30	15

TABLE 1-continued

Twist of plied yarns (T/10 cm)	Warp yarn	45	45	44	47	40	71	76	76	54
	Weft yarn	45	45	44	47	40	71	76	76	54
Twist factor of plied yarns (α)	Warp yarn	346	346	338	361	307	386	337	337	339
	Weft yarn	346	346	338	361	307	386	337	337	339
Ratio of twist of yarns to twist of single yarns	Warp yarn	0.56	0.56	0.49	0.82	0.83	0.88	0.84	0.84	0.60
	Weft yarn	0.56	0.56	0.49	0.82	0.83	0.88	0.84	0.84	0.60
Hydrophilic treatment of yarns		—	Sulfo-nation	—	—	Sulfo-nation	Plasma treatment + sulfonation	Hydrophilic resin	—	—
Grafting ratio of yarns (%)		—	1.8	—	—	1.3	2.6	0.6	—	—
Hydrophilic treatment of fabric		Sulfo-nation	Sulfo-nation	Sulfo-nation	Plasma treatment	Sulfo-nation	Plasma treatment + sulfonation	Plasma treatment + sulfonation	Sulfo-nation	Sulfo-nation
Thickness (mm)		0.64	0.63	0.64	0.62	0.61	0.41	0.35	0.30	0.40
Gram weight (g/m^2)		293	292	290	328	338	293	169	154.2	210
Density (yarns/inch)	Warp direction	55.3	55.0	66.3	68.8	68.3	88.0	113.0	113.0	90.0
	Weft direction	48.0	48.7	39.0	43.7	45.2	64.0	60.0	65.0	60.0
Strength (N/3 cm)	Warp direction	900	750	991	1014	1031	900	640	625	900
	Weft direction	602	521	654	711	846	602	400	378	570
Cover factor		2510	2520	2559	2734	2758	2612	2427	2497	2976
Average pore size (μm)		3.0	3.0	4.9	4.5	3.3	3.0	4.3	4.2	4.4
Maximum pore size (μm)		16	15	17	18	19	16	18	16	16
Percentage of pores in diameter ≤6 μm (%)		94	95	92	93	95	94	91.5	90	91
Gas impermeability after scouring (mmH$_2$O)		320	420	410	405	400	420	405	400	430
Grafting ratio of fabric (%)		4.8	7.2	4.5	3.8	5.5	6.0	6.5	4.0	4.3
Gas impermeability after hydrophilic treatment (mmH$_2$O)		510	600	550	480	450	510	580	590	570
Alkali absorption ratio after processing (%)		131	152	134	85	136	131	115	88	99
Water absorption rate of fabric before processing (s)		300	120	300	300	153	300	205	300	300
Water absorption rate after processing (s)		≤1 s	≤1 s	≤1 s	≤1 s	≤1 s	≤1 s	≤1 s	≤1 s	≤1 s
Area resistance R (mΩ · cm^2)		2.2	1.3	1.5	1.6	2.0	2.2	2.4	1.4	1.4

Item		Example 10	Example 11	Example 12	Example 13	Example 14	Example 15	Comparative Example 1	Comparative Example 2
Cross sectional diameter (μm)		11	8	8	6	10	0.8	13	14
Yarn count of single yarns (s)		20	20	40	60	20	60	20	20
Twist of single yarns (T/10 cm)		56	48	81	90	48	90	56	56
Twist factor of single yarns (α)		304	261	311	282	261	282	304	304
Ply number (ply)		2	2	2	3	2	6	2	4
Yarn count of plied yarns (s)		10	10	20	20	10	10	10	5
Twist of plied yarns (T/10 cm)	Warp yarn	24	40	80	54	36	45	60	40
	Weft yarn	24	36	60	40	40	45	60	40
Twist factor of plied yarns (α)	Warp yarn	184	307	435	293	277	346	461	435
	Weft yarn	184	277	326	217	307	346	461	435
Ratio of twist of yarns to twist of single yarns	Warp yarn	0.43	0.83	0.99	0.60	0.75	0.50	1.07	0.71
	Weft yarn	0.43	0.75	0.74	0.44	0.83	0.50	1.07	0.71
Hydrophilic treatment of yarns		Plasma treatment + sulfonation	Sulfo-nation	Sulfo-nation	—	Sulfo-nation	Plasma treatment	—	—
Grafting ratio of yarns (%)		2.8	1.5	1.8	—	1.3	0.8	—	—
Hydrophilic treatment of fabric		Sulfo-nation	Sulfo-nation	Sulfo-nation	Sulfo-nation	Sulfo-nation	Plasma treatment	—	—
Thickness (mm)		0.51	0.62	0.42	0.48	0.59	0.63	0.50	0.80
Gram weight (g/m^2)		334	335	289	219	307	363	308	414
Density (yarns/inch)	Warp direction	58.0	68.3	88.0	95.0	58.2	65.0	67.0	45.0
	Weft direction	54.0	44.0	62.0	68.0	50.3	51.5	46.0	30.0
Strength (N/3 cm)	Warp direction	780	820	769	611	698	780	1280	1691
	Weft direction	602	658	512	457	856	692	903	1319

TABLE 1-continued

Cover factor	2722	2729	2577	2801	2637	2831	2746	2577
Average pore size (μm)	4.8	2.9	3.0	2.3	3.9	3.2	5.2	8.3
Maximum pore size (μm)	19	18	15	12	17	15	30	40
Percentage of pores in diameter ≤6 μm (%)	90.5	96	94	96	95	91	80	40
Gas impermeability after scouring (mmH_2O)	499	482	506	380	356	361	304	250
Grafting ratio of fabric (%)	6.6	6.2	6.9	5.5	5.8	3.4	2.3	3.9
Gas impermeability after hydrophilic treatment (mmH_2O)	602	520	592	603	399	476	477	320
Alkali absorption ratio after processing (%)	149	153	173	135	113	74	68	109
Water absorption rate of fabric before processing (s)	182	162	182	109	203	265	300	300
Water absorption rate after processing (s)	≤1 s	≤1 s	≤1 s	≤1 s	≤1 s	≤1 s	1.8 s	1.8 s
Area resistance R ($m\Omega \cdot cm^2$)	3.6	2.0	2.1	1.9	2.3	6.4	4.8	3.4

1. A high-performance PPS fiber structure, characterized in that, the PPS fiber structure is a woven fabric made from PPS fibers in 0.1 to 12 μm cross sectional diameter, and the maximum pore size of the PPS fiber structure is 20 μm or smaller.

2. The high-performance PPS fiber structure according to claim **1**, characterized in that, the warp yarns and weft yarns that form the PPS fiber structure are PPS staple yarns that have been suffered from hydrophilic treatment.

3. The high-performance PPS fiber structure according to claim **1**, characterized in that, the average pore size of the PPS fiber structure is 5 μm or smaller, and pores in 6 μm or smaller diameter account for 90% or above of all the pores in the fiber structure.

4. The high-performance PPS fiber structure according to claim **1**, characterized in that, the yarn count of PPS single yarns forming the woven fabric is 21 to 60 s.

5. The high-performance PPS fiber structure according to claim **1**, characterized in that, the twist factor of the PPS yarns forming the woven fabric is 180 to 350.

6. The high-performance PPS fiber structure according to claim **1**, characterized in that, the twist of the warp yarns is greater than or equal to the twist of the weft yarns in the PPS fiber structure.

7. The high-performance PPS fiber structure according to claim **4**, characterized in that, the ratio of the twist of the PPS yarns to the twist of the PPS single yarns is 0.2 to 1.0.

8. The high-performance PPS fiber structure according to claim **1**, characterized in that, the gas impermeability of the PPS fiber structure is 400 mmH_2O or above.

9. The high-performance PPS fiber structure according to claim **1**, characterized in that, the area resistance of the PPS fiber structure is 60 $m\Omega \cdot cm^2$ or lower.

10. A method for producing the high-performance PPS fiber structure according to claim **1**, characterized in comprising the following steps:

(1) cotton spinning process: processing PPS fibers in 0.1 to 12 μm cross sectional diameter by opening and cleaning, carding, drawing, roving, drafting the roving to obtain PPS single yarns with yarn count equal to 20 to 60 s and twist factor α equal to 200 to 310, processing the PPS single yarns by winding, doubling, twisting and thermoforming into PPS yarns with ply number equal to 1 to 6;

(2) weaving process: processing the obtained PPS yarns by warp beaming, drafting, reeding, and weaving, to obtain PPS woven fabric with cover factor equal to 2400 to 2900;

(3) post-finishing process: processing the obtained PPS woven fabric by scouring, water washing, drying, and thermoforming at 180 to 200° C.;

(4) hydrophilic treatment process: processing the thermoformed fabric by plasma hydrophilic treatment and/or sulfonated hydrophilic treatment, to obtain a finished product finally.

11. The method for producing the high-performance PPS fiber structure according to claim **10**, characterized in that, the PPS yarns obtained in the step (1) is processed by at least one of plasma treatment, sulfonation processing, and graft copolymerization, to obtain hydrophilic PPS yarns.

12. Use of the high-performance PPS fiber structure according to claim **1** in diaphragms for electrolytic apparatuses, high-temperature liquid filter materials and insulating materials.

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