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(54) Title: CONDUCTIVE SHEET MATERIAL

(57) **Abrégé/Abstract:**

A conductive microporous sheet material comprises primary carbon fibres having a cross-sectional dimension of at least 1 μm , secondary carbon fibres in the form of carbon nanofibres and a binding agent for binding said primary and secondary fibres. The material may be produced by a wet-laid non-woven (paper-making) process. The sheet material may be used as a gas diffusion layer for a fuel cell or an electrode material for a battery.



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(54) Title: CONDUCTIVE SHEET MATERIAL

(57) Abstract: A conductive microporous sheet material comprises primary carbon fibres having a cross-sectional dimension of at least 1 μm , secondary carbon fibres in the form of carbon nanofibres and a binding agent for binding said primary and secondary fibres. The material may be produced by a wet-laid non-woven (paper-making) process. The sheet material may be used as a gas diffusion layer for a fuel cell or an electrode material for a battery.

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Conductive Sheet Material

The present invention relates to a conductive microporous sheet material for use in electrical devices, particularly but not exclusively for batteries and related devices.

There is an increasing demand for sheet materials which have a microporous structure combined with electrical conductivity and a high level of chemical resistance. Such materials find application as gas diffusion layers for fuel cells and as electrode materials for batteries. The present invention seeks to provide materials which meet these requirements as well as a method for the manufacture of such materials.

According to the present invention there is provided a conductive microporous sheet material comprising primary carbon fibres having a cross-sectional dimension of at least 1 μm , secondary carbon fibres in the form of carbon nanofibres and a binding agent for binding said primary and secondary fibres.

The sheet of the invention has a microporous structure determined primarily by the relative proportions of the first and second fibres. The variation in pore structure with the secondary (nanofibre) content may readily be determined experimentally by a person skilled in the art. Thus, for example, the sheet may be produced by a wet-laying technique (see below) and the experimental determination may be effected by producing and testing laboratory produced single sheets (hard sheets). This information may then be used to select the appropriate blend of primary and secondary fibres for a given microporous structure.

The sheet of the invention may be a thin, flexible material.

The primary fibres preferably have a cross-section of 1 to 15 μm , more preferably 4 to 12 μm , even more preferably 5 to 10 μm . Typically the primary fibres

will have a length of a few millimetres, e.g. 3 to 8 mm (about 6 mm). A preferred example of primary carbon fibre is SGL C25 (available from Technical Fibre Products Ltd.).

The primary fibres may be obtained from acrylonitrile or pitch.

The secondary fibres (nanofibres) preferably have a cross section of between 100 and 500 nanometres, more preferably between 100 and 250 nanometres. The nanofibres may be produced by vapour deposition. A preferred example of a carbon nanofibre is Pyrograf-III (available from ASI).

Preferably the primary carbon fibre constitutes between 10 and 90wt% of the total weight of fibres and secondary fibres constitute between 10 and 90wt% on the same basis. Preferably the fibres together provide at least 90% by weight of the sheet material.

The binding agent is required for adequate bonding strength of the material. The binding agent will generally constitute less than 10% by weight of the sheet material, and more typically less than 5% on the same basis.

The binding agent may for example be a thermoplastic or thermosetting resin, a suitable example of which is a phenolic resin such as GP5520. Whilst the use of resin binding agent is perfectly satisfactory, improved conductivity can generally be achieved by use of carbon as the binding agent. Sheets utilising carbon as the binding agent may be produced by heat treatment in an inert atmosphere of a sheet material incorporating a resin binding agent, said conversion of the resin binding agent to carbon serving to increase conductivity whilst retaining the controlled microporous structure.

A sheet according to the present invention may have any one or any combination of the following properties: -

- A. A weight of between 10 and 200g/m², more preferably about 50g/m².
- B. A thickness of between 0.1 and 2mm, more preferably about 0.3mm.
- C. A Gurley air permeability of between 8 and 50 seconds / 300cm³.
- D. A maximum pore size of less than 22µm, more preferably less than 16µm and most preferably less than 12µm.
- E. A through plane resistance of less than 150Ω/cm, more preferably less than 50Ω/cm.
- F. A tensile strength of between 0.7 and 1.3kN/m.

Conductive sheet material in accordance with the invention has a variety of end uses, including: -

- (1) Gas diffusion layers for fuel cells
- (2) Electrode materials for batteries.

The conductive sheet material, according to the invention is preferably produced using a wet-laid non-woven (papermaking) process. The use of a wet-laid production process allows a wide range of proportions of carbon fibres and carbon nanofibres to be used and thus lends itself to production of materials with highly specific pore structures.

The preferred method of manufacture is to form a slurry of the two fibre types with binder by mixing the materials in water at a concentration of up to 1% by weight (e.g. between 0.02 and 0.5wt%). Mixing is preferably carried out using a high speed agitator and the resulting slurry is formed into a suitable sheet material by passing through a papermaking former.

Fibre distribution and sheet forming may be aided by the use of viscosity modifiers and/or drainage aids.

After forming liquid may be removed from the sheet by vacuum and/or hot air drying. Where both liquid removal methods are used it is preferred that hot air drying

is applied ultimately as it may be used to melt or cure the binder. It is preferred that the final stage of the production process is the carbonisation of the binding agent.

Following the carbonisation stage the sheet material is preferably formed into a continuous roll in order to facilitate further automated processing.

Both continuous of batch processing of the sheet material are envisaged.

Preferably in the production process the binder is initially the form of a powder although the use of a binder in any other physical form is not precluded.

According to an aspect of the present invention there is provided a conductive microporous sheet material comprising primary carbon fibres having a cross-sectional dimension of at least 1 μm , secondary carbon fibres in the form of carbon nanofibres and a binding agent for binding said primary and secondary fibres, wherein the binding agent constitutes less than 10wt% of the sheet material, the binding agent comprises a thermoplastic resin or a thermosetting resin and the sheet has a tensile strength of between 0.7 and 1.3kN/m.

According to another aspect of the present invention there is provided a battery which includes a portion of the sheet material as described hereinabove.

According to a further aspect of the present invention there is provided a method of producing a conductive microporous sheet material as described hereinabove, the method comprising:

- (a) forming an aqueous slurry of the primary and secondary carbon fibres with the binding agent;
- (b) applying the slurry to a paper forming screen to produce the sheet thereof; and
- (c) drying the sheet.

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The invention will now be described further with reference to the following non-limiting Examples.

Example 1

A sheet was formed by mixing the following elements in water using a high speed agitator at a combined concentration of 0.5wt%.

Carbon fibre (SGL C25), 6mm chopped length	24wt%
Carbon nanofibre (Pyrograf [®] -III, ex ASI)	73wt%
Phenolic resin (GP 5520)	2wt%

The resulting material was converted into sheet form using a papermaking former. The sheet was dried using a combination of vacuum and hot air and then carbonised by heating in an inert atmosphere until the phenolic binder was completely converted to carbon.

Sheets formed from the above mixture had the following characteristics :

Weight	50g/m ²
Thickness	0.3mm

Tensile strength	0.7kN/m
Gurley air permeability	50seconds / 300cm ³
Maximum pore size	12µm
Through plane resistance	150Ω/cm

Example 2

A sheet was formed by mixing the following elements using the same technique as in Example 1.

Carbon fibre (SGL C25) , 6mm chopped length	49wt%
Carbon nanofibre (Pyrograf – III, ex ASI)	49wt%
Phenolic resin (GP 5520)	2wt%

Sheets formed from the above mixture had the following characteristics :-

Weight	50g/m ²
Thickness	0.3mm
Tensile strength	1.0kN/m
Gurley air permeability	20 seconds / 300 cm ³
Maximum pore size	16µm
Through plane resistance	150 Ω/cm

Example 3

A sheet was formed by mixing the following elements using the same technique as in Example 1.

Carbon fibre (SGL C25), 6mm chopped length	74wt%
Carbon nanofibre (Pyrograf – III, ex ASI)	24wt%
Phenolic resin (GP 5520)	2wt%

Sheets formed from the above mixture had the following characteristics :-

Weight	50g/m ²
Thickness	0.3mm
Tensile strength	1.3kN/m
Gurley air permeability	8 seconds / 300 cm ³
Maximum pore size	22 μm
Through plane resistance	150 Ω/cm

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A conductive microporous sheet material comprising primary carbon fibres having a cross-sectional dimension of at least 1 μm , secondary carbon fibres in the form of carbon nanofibres and a binding agent for binding said primary and secondary fibres, wherein the binding agent constitutes less than 10wt% of the sheet material, the binding agent comprises a thermoplastic resin or a thermosetting resin and the sheet has a tensile strength of between 0.7 and 1.3kN/m.
2. A sheet material according to claim 1, wherein the primary carbon fibres have a cross-sectional dimension of between 4 and 12 μm .
3. A sheet material according to claim 2, wherein the primary carbon fibres have a cross-sectional dimension of between 5 and 10 μm .
4. A sheet material according to claim 1, 2 or 3, wherein the primary carbon fibres are between 3 and 8mm in length.
5. A sheet material according to claim 4, wherein the primary carbon fibres are about 6mm in length.
6. A sheet material according to any one of claims 1 to 5, wherein the secondary carbon fibres have a cross-sectional diameter of between 100 and 500 nanometres.
7. A sheet material according to claim 6, wherein the secondary carbon fibres have a cross-sectional diameter of between 100 and 250 nanometres.
8. A sheet material according to any one of claims 1 to 7, wherein the primary carbon fibres constitute between 10 and 90wt% of the total weight of fibres.

9. A sheet material according to any one of claims 1 to 8, wherein the secondary carbon fibres constitute between 10 and 90wt% of the total weight of fibres.
10. A sheet material according to claim 1, wherein the binding agent constitutes less than 5wt% of the sheet material.
11. A sheet material according to claim 1, wherein the binding agent is a phenolic binder.
12. A sheet material according to any one of claims 1 to 11, wherein the sheet has a weight of between 10 and 200g/m².
13. A sheet material according to claim 12, wherein the sheet has a weight of about 50g/m².
14. A sheet material according to any one of claims 1 to 13, wherein the sheet has a thickness of between 0.1 and 2mm.
15. A sheet material according to claim 14, wherein the sheet has a thickness of about 0.3mm.
16. A sheet material according to any one of claims 1 to 15, wherein the sheet has a Gurley air permeability of between 8 and 50 seconds / 300cm³.
17. A sheet material according to any one of claims 1 to 16, wherein the sheet has a maximum pore size of less than 22µm.
18. A sheet material according to claim 17, wherein the sheet has a maximum pore size of less than 16µm.
19. A sheet material according to claim 18, wherein the sheet has a maximum pore size of less than 12µm.

20. A sheet material according to any one of claims 1 to 19, wherein the sheet has a through plane resistance of less than $150\Omega/\text{cm}$.
21. A sheet material according to claim 20, wherein the sheet has a through plane resistance of less than $50\Omega/\text{cm}$.
22. A battery which includes a portion of the sheet material defined by any one of claims 1 to 21.
23. A method of producing a conductive microporous sheet material defined by any one of claims 1 to 21, the method comprising:
- (a) forming an aqueous slurry of the primary and secondary carbon fibres with the binding agent;
 - (b) applying the slurry to a paper forming screen to produce the sheet thereof; and
 - (c) drying the sheet.
24. A method according to claim 23, wherein in step (a) the combined weight of the primary and secondary fibres and the binding agent constitutes between 0.02 and 0.5wt% of the aqueous slurry.
25. A method according to claim 23 or 24, wherein the drying step is carried out by hot air heating or vacuum technique.
26. A method according to claim 23, 24 or 25, which also includes an additional step (d) of carbonising the sheet material.
27. A method according to claim 26, wherein the carbonisation is carried out by heating the material in an inert atmosphere.
28. A method according to any one of claims 23 to 27, wherein the fibre distribution and sheet forming is aided by the use of viscosity modifiers, drainage aids or a combination of both.