

A conductive carbon powder, a method for the manufacturing thereof and use thereof

Field of invention

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The present invention relates to a conductive carbon powder emanating essentially from lignin, a method for the manufacturing thereof and use thereof. Said powder may emanate from an electrically conductive carbon intermediate product, in turn emanating essentially from lignin. Further, uses thereof and compositions comprising said carbon powder are disclosed. Additionally methods for manufacturing said conductive carbon powder, also involving an electrically conductive carbon intermediate product emanating essentially from lignin, are disclosed together with a method for making said compositions.

Background

Conductive plastics are used in many different applications where electromagnetic interference and electrostatic discharge must be avoided. Examples include packaging material for consumer electronics, computer or mobile phone housings, piping and tanks for flammable liquids such as gasoline tanks, wires and cables. Conventional plastics (thermoplastics and thermosets) have poor electrical conductivity and are prone to building up static electricity. They can be rendered dissipative or even conductive by adding pulverized conductive material at levels beyond the so called percolation threshold. The resulting compound comprising the plastic and the conductive material is called conductive plastic. The mechanical performance of the plastic, however, suffers from

adding pulverized conductive material as impact strength and ductility decrease. High-performing conductive materials attain the percolation threshold at low addition levels, retaining the mechanical performance of the plastic. The most commonly used
5 conductive material is conductive carbon black, a special and expensive grade of carbon black.

Carbon black is produced by pyrolysing oil with fuel gas in a furnace. In the production of conductive carbon blacks,
10 pyrolysis is followed by expensive post treatment steps to increase conductivity, notably steam exposure to increase the surface area and extraction to remove contaminants. Carbon blacks and especially conductive carbon blacks have a strongly negative impact on the environment and a high CO₂ footprint due
15 to the fact that fossil raw materials are used in a highly energy intense production process.

There is thus a need for a novel competitive high performing conductive material for the manufacture of conductive plastics.

Additionally, there also exists a need for a conductive
20 material with lower environmental impact and CO₂ footprint.

During chemical pulping cellulosic fibers are separated from softwoods, hardwoods, and annual plant biomass, for further processing to paper, board, tissue products or chemicals. Separation is done in a liquid, e.g. the so called white liquor
25 in Kraft pulping or organic solvent as in organosolv processes. Lignin can be isolated from the spent liquor and thereafter be used as a biofuel, or as raw material for chemicals and materials.

Summary of the invention

The present invention solves one or more of the above problems, by providing according to a first aspect an

electrically conductive carbon powder emanating (i.e. originating) essentially from lignin, preferably emanating fully from lignin.

The present invention also provides according to a second aspect an electrically conductive carbon intermediate product emanating essentially from lignin, having the form of a powder or a shaped body such as, a wafer, bar, rod, film, filament or fleece.

The present invention also provides according to a third aspect a method for manufacturing a conductive carbon powder according to the first and second aspect comprising the following steps:

- a) thermal treatment of a lignin comprising compound to increase the carbon content to at least 80 % to obtain an electrically conductive carbonized lignin intermediate product and
- b) mechanical treatment of the electrically conductive carbonized lignin intermediate product to obtain a carbonized lignin powder which is electrically conductive.

The present invention also provides according to a fourth aspect a method for manufacturing an electrically conductive carbon powder according to the first and second aspect, comprising the following steps:

- i) providing a lignin and at least one additive,
- ii) mixing said components,
- iii) shaping said mixture to form a shaped body,
- iv) performing a thermal treatment of said shaped body in at least one step of which the last step comprises a temperature ramp from room temperature to up to about 2000 °C in inert atmosphere, thus

providing a conductive carbonized intermediate product

- v) pulverizing said conductive carbonized intermediate product, thus providing a conductive carbon powder.

The present invention also provides according to a fifth aspect a method for manufacturing a carbonized intermediate product in filament form, comprising the following steps:

- vi) providing a lignin and at least one additive,
vii) mixing said components and melt spinning said mixture to a monofilament or multifilament bundle component,
viii) performing a thermal treatment of said shaped body in two steps of which the last step comprises a temperature ramp from room temperature to up to about 2000 °C in inert atmosphere thus providing a conductive carbonized intermediate product in filament form.

The present invention also provides according to a sixth aspect a conductive carbon powder obtainable by the method of the third or fourth aspect.

The present invention also provides according to a seventh aspect a conductive carbonized intermediate product in filament form obtainable by the method of the fifth aspect.

The present invention also provides according to an eighth aspect use of a conductive carbon powder according to the first, second or fifth aspect as additive for the manufacture of electrically conductive polymer compositions, used in applications such as housings for computers and mobile phones, automotive appliances, wires, cables, pipes and aeronautical appliances.

The present invention also provides according to a ninth aspect use of a conductive carbon powder according to the first, second or fifth aspect as additive for the manufacture of electrically conductive polymer compositions for protection against electromagnetic interference or electrostatic discharge.

The present invention also provides according to a tenth aspect a composition comprising a conductive carbon powder according to the first, second or fifth aspect and a polymer, preferably a thermoplastic or a thermoset or a mixture of such polymers. Said polymer(s) may be of fossil origin.

The present invention also provides according to an eleventh aspect a method for the manufacturing of a composition according to a tenth aspect comprising mixing a conductive carbon powder with a polymer, preferably a thermoplastic or a thermoset or a mixture of such polymers.

The present invention also provides according to a twelfth aspect a polymer composition obtainable by a method according to the eleventh aspect.

The present invention also provides according to a thirteenth aspect use of a polymer composition according to the tenth or twelfth aspect in an electrically conductive material, such as a material used in computers, mobile phones, automotive appliances, wires, cables, pipes and aeronautical appliances.

The present invention also provides according to a fourteenth aspect a polymer composition for a semi-conductive layer of a cable comprising a conductive carbon powder according to the first, second or fifth aspect and a thermoplastic or a thermoset or a mixture of such polymers.

Detailed description of the invention

It is intended throughout the present description that the expression "lignin" embraces any lignin which may be used for making a conductive carbon powder. Examples on said lignin are, but are not limited to softwood lignin, hardwood lignin, lignin from one-year plants or lignins obtained through different fractionation methods such as, organosolv lignin or kraft lignin. The lignin may e.g. be obtained by using the process disclosed in EP 1794363.

It is intended throughout the present description that the expression "a conductive carbon powder" embraces a powdery matter which consists of 80% or more of carbon, with a capability of rendering e.g. a thermoplastic or thermoset electrically conductive. Said thermoplastic or thermoset may further be a polymer of fossil origin. Said powder may further be a substitute for carbon black obtained from fossil sources.

It is intended throughout the present description that the expression "additive" embraces any additive that facilitates the manufacturing of a lignin-containing composition in e.g. melt-extrusion or melt-spinning for further processing to conductive carbonized lignin powder. Examples are, but are not limited to plasticizers (such as PEG, an example is PEG400), reactive agents that render lignin melt-extrudable such as aliphatic acids or lignin solvents. A lignin solvent may be an aprotic polar solvent, such as an aliphatic amide, such as dimethylformamide (DMF) or dimethylacetamide (DMAc), a tertiary amine oxide, such as N-methylmorpholine-N-oxide (NMMO), dimethylsulfoxide (DMSO), ethylene glycol, di-ethylene glycol, low-molecular-weight poly ethylene glycol (PEG) having a molecular weight between 150 to 20.000 g/mol or ionic liquids or any combination of said solvents and liquids.

It is intended throughout the present description that the expression "thermoplastic" embraces any thermoplastic polymer (which may be of fossil origin) that may be useful in the context of using a conductive carbon powder (which also includes contexts where carbon black is used). Said polymer may be, but is not limited to acrylates such as PMMA, PP (Polypropylene), PE (Polyethylene) such as HDPE (high density PE), MDPE (medium density PE), LDPE (low density PE), PA (Polyamide) such as nylon, PS (Polystyrene), Polyvinylchloride (PVC), polysulfone, ether ketone or polytetrafluoroethylene (PTFE). The PE may further be cross-linked (PEX). It may further be co-polymers comprising two or more of said polymers or mixtures comprising two or more of said polymers.

It is intended throughout the present description that the expression "thermoset" embraces any thermoset polymer (which may be of fossil origin) that may be useful in the context of using a conductive carbon powder (which also includes contexts where carbon black is used). Said polymer may be, but is not limited to polyurethanes, polyesters, phenol-formaldehyde, urea-formaldehyde, melamine, epoxy, cyanate esters, vulcanized rubber and polyimides. It may further be co-polymers comprising two or more of said polymers or mixtures comprising two or more of said polymers.

According to a preferred embodiment of the fourth aspect of the invention the additive is poly ethylene glycol.

According to a preferred embodiment of the fourth aspect of the invention the temperature ramp from room temperature is up to 1600 °C.

According to a preferred embodiment of the fourth aspect of the invention the temperature ramp from room temperature is up to 1400 °C.

5 According to a preferred embodiment of the tenth aspect of the invention the polymer is a thermoplastic or thermoset used for the manufacture of electrically conductive compounds, or a mixture of such polymers.

10 According to a preferred embodiment of the tenth aspect of the invention the polymer is a polyolefin, a co-polymer comprising a polyolefin or a mixture of polyolefins.

According to a preferred embodiment of the tenth aspect of the invention the polymer is a polypropylene (PP).

15 According to a preferred embodiment of the tenth aspect of the invention the conductive carbon powder when compounded gives a percolation threshold in the polymer compound at 1-40% addition level. Said compounding involves mixing (blending) polymers and said carbon powder in a molten state.

20 According to a preferred embodiment of the tenth aspect of the invention the conductive carbon powder when compounded lowers the volume resistivity of the polymer compound after the percolation point to $10^0 - 10^6 \Omega \cdot \text{cm}$.

According to a preferred embodiment of the fourteenth aspect of the invention the thermoplastic is a polyolefin, a co-polymer comprising a polyolefin or a mixture of polyolefins.

25 According to the fifth aspect of the invention the temperature range in the second thermal step may also be from room temperature up to 1600 °C, or up to 1200 °C or up to 1000

°C. In the first thermal step, the temperature may be up to 300 °C.

Preferred features of each aspect of the invention are as for each of the other aspects mutatis mutandis. The prior art

document(s) mentioned herein are incorporated to the fullest extent permitted by law. The invention is further described in the following examples, together with the appended figures, which do not limit the scope of the invention in any way.

Embodiments of the present invention are described as mentioned in more detail with the aid of examples of embodiments, together with the appended figures, the only purpose of which is to illustrate the invention and are in no way intended to limit its extent.

Figure

Figure 1 discloses volume resistivity of compounds comprised of PP (HP 561R from Lyondell Basell) and 5% respectively 10% of the conductive carbon powder described in this invention. For comparison percolation curves are shown for reference compositions comprising PP and three different commercial conductive carbon blacks, respectively.

Figure 2 discloses a comparison of volume resistivity of compressed carbon powder (applied pressure 31MPa).

Figure 3 discloses a comparison of volume resistivity of carbonized fibers.

Examples

Examples on lignin-containing compound in form of a shaped body

Example 1

A fiber was melt-spun from a mixture comprising of 88 w% softwood Kraft lignin, 7 w% Phthalic anhydride acid and 5 w% DMSO (97% purity, Sigma-Aldrich) using a laboratory twin-screw extruder with a single capillary (DSM Xplore micro-compounder). The obtained lignin-containing compound had the form of a filament with a diameter of 150 μm .

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Example 2

The mixture from example 1 was extruded with a laboratory twin screw extruder (KEDSE 20/40" from Brabender GmbH & CO. KG) using a multifilament die with 62 capillaries. The obtained lignin-containing compound had the form of a multi-filament bundle with a single filament diameter of 72 μm .

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Example 3

A mixture comprising 90 w% softwood lignin and 10% PEG 400 (Polyethylene Glycol from Sigma-Aldrich with a molecular weight of 400 Da) was prepared.

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The mixture was extruded on a laboratory twin screw extruder using a die with 62 capillaries. The obtained lignin-containing compound had the form of a multi-filament bundle with a single filament diameter of 90 μm .

25

Example 4

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A mixture was prepared as described in example three and put in a flat metal tube. Pressure was applied using a piston and as a result the lignin-containing compound attained the shape of a wafer.

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Examples on conductive carbon intermediate products

Example 5

10 The lignin-containing filament from example 1 was converted in a two-step thermal treatment to obtain a conductive carbon intermediate product. In a first step the filament was heated in air from room temperature to 250 °C with a varying heating rate of between 0.2 °C/min and 5 °C/min and then heated in the
15 second step in nitrogen from room temperature to 1600°C with a heating rate of 1°C/min. The obtained conductive carbon intermediate product had the shape of a filament with a diameter of about 60 µm and yielded an electrical volume resistivity of 1.4×10^{-3} Ohm*cm. Volume resistivity was
20 measured using a LCR meter.

Example 6

25 The obtained spun filaments from example 2 were heat-treated in the same manner as described in example 5. The resulting carbonized multifilaments had a diameter of about 80 µm and yielded an electrical volume resistivity of 0.5×10^{-3} Ohm*cm.

30 Example 7

The obtained filaments from example 3 were where heat-treated in the same manner as described in example 5. The resulting carbonized multifilaments had a diameter of about 75 μm and yielded an electrical volume resistivity of 0.6×10^{-3} Ohm*cm.

Example 8

The obtained filaments from example 3 were heat-treated according to the following steps. In a first step the filament was heated in air from room temperature to 250 °C with a varying heating rate between 0.2 °C/min and 5 °C/min and then heated in the second step in nitrogen from room temperature to 1000°C with a heating rate of 2°C/min. The obtained carbonized fiber yielded an electrical volume resistivity of 0.72×10^{-3} Ohm*cm.

Example 9

The obtained filaments from example 3 were heat-treated according to the following steps. In a first step the filament was heated in air from room temperature to 250 °C with a varying heating rate between 0.2 °C/min and 5 °C/min and then heated in the second step in nitrogen from room temperature to 1200°C with a heating rate of 2°C/min. The obtained carbonized fiber yielded an electrical volume resistivity of 0.33×10^{-3} Ohm*cm.

Example 10

The obtained filaments from example 3 were heat-treated according to the following steps. In a first step the filament

was heated in air from room temperature to 250 °C with a varying heating rate between 0.2 °C/min and 5 °C/min and then heated in the second step in nitrogen from room temperature to 1400°C with a heating rate of 2°C/min. The obtained carbonized fiber yielded an electrical volume resistivity of 0.23×10^{-3} Ohm*cm.

Example 11

The obtained filaments from example 3 were heat-treated according to the following steps. In a first step the filament was heated in air from room temperature to 250 °C with a varying heating rate between 0.2 °C/min and 5 °C /min and then heated in the second step in nitrogen from room temperature to 1600°C with a heating rate of 2°C/min. The obtained carbonized fiber yielded an electrical volume resistivity of 0.54×10^{-3} Ohm*cm.

Example 12

The wafer from example 4 was heat treated in nitrogen atmosphere by increasing temperature from room temperature to 1600 °C at a heating rate of 1 °C/min to obtain a carbonized wafer.

Examples on conductive carbon powder

Example 13

The carbonized wafer from example 12 was manually crushed utilizing a laboratory mortar to obtain a conductive carbonized lignin powder.

Examples on conductive polymer compoundsExample 14

5 The conductive carbonized lignin powder from example 14 was compounded into a polypropylene matrix (HP 561R from Lyondell Basell) using a DSM Xplore micro-compounder. The MFR was 25 g/10min (@230 °C/ 2.16kg/10 min). The composition consisted of 95 w% polypropylene and 5% of conductive carbonized lignin powder. The extruded strands showed a volume resistivity of 5.2×10^5 Ohm*cm, which was many magnitudes lower than the volume resistivity of pure PP, reported in the literature, about 1×10^{17} Ohm*cm (Debowska, M. et.al.: Positron annihilation in carbon black-polymer composites, Radiation Physics and Chemistry 58 (2000), H. 5-6, S. 575-579). This example showed that the conductive carbonized lignin powder from example 13 was in fact electrically conductive.

Example 15

20 The conductive carbon powder from example 14 was compounded into a Polypropylene matrix (HP 561R from Lyondell Basell) using a DSM Xplore micro-compounder. The composition consisted of 90 w% (PP) and 10% conductive carbonized lignin powder. The extruded strands yielded a volume resistivity of 2.6×10^5 Ohm*cm.

Examples on reference conductive polymer compounds

30 Example 16

Figure 1 reflects literature data (Debowska, M. et.al.: Positron annihilation in carbon black-polymer composites, Radiation Physics and Chemistry 58 (2000), H. 5-6, S. 575-579) regarding volume resistivity of conductive polymer compositions comprising different commercial conductive carbon blacks. The commercial carbon blacks were SAPAC-6 (from CarboChem), Printex XE-2 (from Degussa) and Vulcan XC-72 (Cabot).

Figure 1 discloses also, additionally, volume resistivity of compositions comprising PP (HP 561R from Lyondell Basell) and 5% and 10%, respectively, of conductive carbon powder described above.

The figure shows that conductive carbonized lignin powder provided by the present invention has at least the same conductivity performance as the best commercial carbon black (Printex XE-2).

Example 17

In order to measure the electrical conductivity of the powder samples, the powder was filled into a hollow cylinder. This cylinder was made of non-conductive PMMA which was cleaned thoroughly between each measurement. The inner diameter was 5 mm. At the bottom of the cylinder there was a gold plated copper plate as a base electrode. The second electrode was a copper stamp which was also gold plated and formed the second electrode. The stamp was then inserted into the cylinder thus slowly compressing the powder. Through a force measurement and online position measurement the applied pressure as well as the volume within the powder filled chamber was plotted. Through applying a DC voltage to the two electrodes the absolute resistance could be measured. Together with the documented position of the stamp a volume resistivity could be calculated.

In order to compare various samples with potentially varying specific volumes the resistivity values could only be compared at equal pressure levels. In the presented results the chambers were filled with powder and compressed to the maximal pressure of 31 MPa. The measured value is indicated in Figure 2.

The results presented in the figure clearly state that the lignin based carbonized powders (CLP) exhibit the same conductivity/resistivity performance as the commercially available grade of Cabot (Cabot Vulcan XC-72-R).

In the figure:

Example 13-1 = Example 13 as mentioned above

Example 13-2 = Example 13, but not manually crushed with a lab mortar but cryo milled.

Example 18

The products in examples 8 - 11 set out above earlier was also compared with commercial grade carbon fibres (Toho Tenax HTA40 6k and Mitsubishi Dialead K13C, respectively - their values were taken from a product sheet and the internet, respectively). The results are given in Figure 3.

Various embodiments of the present invention have been described above but a person skilled in the art realizes further minor alterations, which would fall into the scope of the present invention. The breadth and scope of the present invention should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents. For example, any of the above-noted compositions or methods may be combined

with other known methods. Other aspects, advantages and modifications within the scope of the invention will be apparent to those skilled in the art to which the invention pertains.

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Claims

1. An electrically conductive carbon powder emanating
5 essentially from lignin.

2. An electrically conductive carbon intermediate product
emanating essentially from lignin, having the form of a
powder or a shaped body such as, a wafer, a bar, rod, film,
10 filament or fleece.

3. A method for manufacturing a conductive carbon powder
according to claim 1 or 2 comprising the following steps:

15 a) thermal treatment of a lignin comprising compound to
increase the carbon content to at least 80 % to
obtain an electrically conductive carbonized lignin
intermediate product and

b) mechanical treatment of the electrically conductive
20 carbonized lignin intermediate product to obtain a
carbonized lignin powder which is electrically
conductive.

4. A method for manufacturing an electrically
25 conductive carbon powder according to claim 1 or 2,
comprising the following steps:

i) providing a lignin and at least one additive,

ii) mixing said components,

iii) shaping said mixture to form a shaped body,

30 iv) performing a thermal treatment of said shaped body
in at least one step of which the last step

comprises a temperature ramp from room temperature to up to about 2000 °C in inert atmosphere, thus providing a conductive carbonized intermediate product

- 5 v) pulverizing said conductive carbonized intermediate product, thus providing a conductive carbon powder.

10 5. A method according to claim 4 wherein the additive is a poly ethylene glycol

15 6. A method according to claim 4 wherein the temperature ramp from room temperature is up to about 1600 °C.

7. A method for manufacturing a carbonized intermediate product according to claim 2 in filament form, comprising the following steps:

- 20 vi) providing a lignin and at least one additive,
vii) mixing said components and melt spinning said mixture to a monofilament or multifilament bundle component,
viii) performing a thermal treatment of said shaped
25 body in two steps of which the last step comprises a temperature ramp from room temperature to up to about 2000 °C in inert atmosphere thus providing a conductive carbonized intermediate product in filament form.

8. A method according to claim 4 wherein the temperature ramp from room temperature is up to about 1400 °C.

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9. An electrically conductive carbon powder obtainable by the method according to any one of claims 3 - 6 or 8

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10. A conductive carbonized intermediate product in filament form obtainable by the method according to claim 7 .

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11. Use of a conductive carbon powder according to any one of claims 1-2 or 9 as additive for the manufacture of electrically conductive polymer compositions, used in applications such as housings for computers and mobile phones, automotive appliances, wires, cables, pipes and aeronautical appliances.

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12. Use of a conductive carbon powder according to any one of claims 1-2 or 9 as additive for the manufacture of electrically conductive polymer compositions for protection against electromagnetic interference or electrostatic discharge.

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13. A composition comprising a conductive carbon powder according to any one of claims 1-2 or 9 and a polymer, preferably a thermoplastic or thermoset or a mixture of such polymers.

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14. A composition according to claim 13 wherein the polymer is a thermoplastic or thermoset used for the

manufacture of electrically conductive compounds, or a mixture of such polymers.

5 15. A composition according to claim 13 or 14 wherein the polymer is a polyolefin, a co-polymer comprising a polyolefin or a mixture of polyolefins.

10 16. A composition according to any one of claims 13- 15 wherein the polymer is a polypropylene (PP).

15 17. A composition according to any one of claims 13 - 16 wherein the conductive carbon powder when compounded gives a percolation threshold in the polymer compound at 1-40% addition level.

20 18. A composition according to any one of claims 13 - 17 wherein the conductive carbon powder when compounded lowers the volume resistivity of the polymer compound after the percolation point to $10^0 - 10^6 \Omega \cdot \text{cm}$.

25 19. A method for the manufacturing of a composition according to any one of claims 13 - 18 comprising mixing a conductive carbon powder with a polymer, preferably a thermoplastic or thermoset or a mixture thereof.

20. A polymer composition obtainable by a method according to claim 19.

30 21. Use of a polymer composition according to any one of claims 13 - 18 or claim 20 in an electrically conductive material, such as a material used in computers, mobile phones,

automotive appliances, wires, cables, pipes and aeronautical appliances.

22. A polymer composition for a semi-conductive layer of a
5 cable comprising a conductive carbon powder according to any
one of claims 1-2 or 9 and a thermoplastic or a thermoset or a
mixture thereof.

23. A polymer composition for a semi-conductive layer of a
10 cable according to claim 22 wherein the thermoplastic is a
polyolefin, a co-polymer comprising a polyolefin or a mixture
of polyolefins.