which hinders practical-scale usage of graphene- or CNT-based elastic conductors. It is therefore desirable to explore inexpensive, green and scalable processes to lower the fabrication cost for industrial applications.

It is known that lignin constitutes a quarter to a third of wood's dry mass, making it the second most abundant polymer in nature after cellulose. It's generally separated from black liquor, a waste discharged from paper mills in large quantities, the disposal of which poses a major problem. On the other hand, as the production of lignin amounts to more than 50 million tons per year, there has been increasing interest in finding new applications for this natural polymer by conversion into useful chemicals and materials. The unique structure of lignin is composed of three-dimensional interconnected phenolic monomers, which makes it the only large-scale biomass source of aromatic functionality. With high carbon contents (above 60%) and molecular structures similar to bituminous coal, this low-cost and renewable feedstock has been used for making carbonaceous materials. But these materials still have limited uses and it would be desirable to make better use of this source of carbon material.

Lignin has been previously utilized as inexpensive feedstock for producing general purpose carbon fibers with size ranging from 20 to 80 μm through conversional melt processes. There have been previously reported low-cost and renewable lignin-derived electrospun carbon nanofibers (with diameters around 500 nm) as high performance electrode materials for energy storage devices, which demonstrate a good electrical conductivity of the obtainable carbon fibrous mats. Electrospinning was used as the method for generating continuous nanofibers from solutions, dispersions or melts of polymers or polymers blends in this technology. However, there are no electrospun lignin-based carbon fiber materials and processes available that would allow a use of such fibers as conductive material in stretched devices.

Current lignin-based fibres or other conductive fillers therefore show no satisfactory performance for being included in stretchable conductors due to stiffness or lack of conductivity under physical stress cycles.

There is still a need to produce stretchable conductors with good electromechanical properties from low-cost, renewable feedstocks through conventional and straightforward fabrication process which could be conducted in a large commercial scale.

Accordingly, there is a need to provide fibers that overcome, or at least ameliorate, one or more of the disadvantages described above and can be used in stretchable conductors.

Summary

There is provided a conductive carbonaceous fiber, comprising a carbonaceous material obtained from carbonizing an electrospun fiber wherein said electrospun fiber comprises at least one metal precursor.

In a first aspect, there is provided a stretchable, conductive fibrous mesh/elastomer composite material comprising a mesh of conductive carbonaceous fibers comprising a carbonaceous material obtained from carbonizing an electrospun fiber wherein said electrospun fiber is derived from lignin and comprises at least one metal precursor, and wherein said mesh is integrated into an elastomer matrix.

Advantageously, the conductive carbonaceous fibers show good electric conductivity. The metal precursors employed are readily available, low cost manufacturing materials compared to expensive nanoscale metal particles/wires to increase electrical conductivity of the carbonaceous fiber for fabricating hybrid metal/carbon fibrous fillers.

In one embodiment, the fiber is a phenolic fiber that is derived from lignin. Advantageously, lignin is a carbon feedstock from abundant renewable biomass.

In one embodiment, the carbonaceous fibers have a diameter of about 0.1 μm to about 10 μm. These fibers can be spun into meshes which retain the good conductivity even when incorporated into other materials, such as polymer matrices.

Conductive carbonaceous fibers having a diameter of about 0.1 μm to about 10 μm and comprising metallic particles of a size of about 1 nm to about 800 nm, wherein the overall metal content of the fibers is about 5 to 70 % by weight are obtained and represent another aspect of the disclosure.

There is provided a process for making the fibers as defined herein comprising the steps of a) dispersing the conductive metal precursor into a spinning composition, b) electrospinning of the obtained composition and c) carbonizing the obtained fiber to fully or partially convert the metal precursor to conductive metal nanoparticles.

In another aspect, there is provided a process for making the the composite material as defined herein comprising the steps of a) dispersing the conductive metal precursor into a spinning composition; b) electrospinning of the obtained composition; c) carbonizing the obtained fiber to fully or partially convert the metal precursor to conductive metal nanoparticles; d) putting a layer of a fibrous mesh of the obtained fiber on top of a layer of elastomer wherein said elastomer layer is optionally supported by a substrate; e) casting a layer of fully or partially uncured elastomer on top of the fibrous mesh optionally supported by degassing in a vacuum; and f) curing the top elastomer layer, wherein the spinning composition comprises the lignin in admixture with at least one other polymer in a polar solvent.

Advantageously, the addition of metal precursors into the spinning solution during electrospinning and carbonization results in metal nanoparticles in the fiber matrix. The resultant metal nanoparticles are dispersed uniformly in the carbon fibers.

There is provided a fibrous mesh comprising the fibers as defined herein. Advantageously, the electrospun carbon fibrous mesh with improved conductivity is suitable as electrical conductive filler for stretchable electrical conductors. The electrospun carbon fibrous meshes are easy to handle and do not have the problem of agglomeration when being incorporated into a polymer matrix. In order to further improve the electrical conductivity, highly conductive metals may be introduced uniformly into the carbon fibers simply via incorporation of low-cost metal precursors in the solutions for electrospinning.

In another aspect, there is provided a stretchable electrical conductor comprising of the composite material as defined herein.

There is provided a use of a fiber or a mesh according to the disclosure as conductive filler of a polymer composite.

There is provided a polymer composite material comprising the fibers or the mesh according to the disclosure together with an elastomer. Advantageously, the composite material exhibits good electrical conductivity (higher than most reported carbon nanotube/PDMS composites) and electromechanical stability under various mechanical deformations. The resultant composites, especially as films, exhibit good electrical conductivity

(with sheet resistance less than 1 kΩ/□) and excellent electromechanical stability under various mechanical deformations.

There is provided a process for making a fibrous mesh/polymer composite, comprising the steps of a) putting a layer of fibrous mesh on top of a layer of elastomer wherein said elastomer layer is optionally supported by a substrate b) casting a layer of fully or partially uncured elastomer on top of the fibrous mesh optionally supported by degassing in a vacuum; and c) curing the top elastomer layer. Advantageously, this process allows in a simpler and more cost-effective way to make the composites according to the disclosure when being compared with the known art for making conductive fillers.

There is provided a stretchable electrical conductor comprising the fibers, the fibrous mesh, or the fibrous mesh/polymer composite material of the disclosure. Advantageously, the stretchable electrical conductors comprising the fibers, meshes and composite materials have great potential for a wide range of practical applications including

Claims

1. A stretchable, conductive fibrous mesh/elastomer composite material comprising a mesh of conductive carbonaceous fibers comprising a carbonaceous material obtained from carbonizing an electrospun fiber

   wherein said electrospun fiber is derived from lignin and comprises at least one metal precursor, and

   wherein said mesh is integrated into an elastomer matrix.

2. The composite material according to claim 1, wherein the metal precursor is converted to a conductive metal particle.

3. The composite material according to claim 1, wherein the metal precursor is selected from the group consisting of a copper and nickel salt.

4. The composite material according to claim 1, wherein the lignin is selected from the group consisting of organosolv lignin, softwood kraft lignin, hardwood kraft lignin and lignosulfonate.

5. The composite material according to any one of claims 1 to 4, wherein the precursor partly or fully converts to a corresponding conductive metal nanoparticle via pre-oxidation and reduction during a stabilization and carbonization process.

6. A process for making the composite material according to claim 1 comprising the steps of

   a) dispersing the conductive metal precursor into a spinning composition;

   b) electrospinning of the obtained composition;

   c) carbonizing the obtained fiber to fully or partially convert the metal precursor to conductive metal nanoparticles;

   d) putting a layer of a fibrous mesh of the obtained fiber on top of a layer of elastomer wherein said elastomer layer is optionally supported by a substrate;

   e) casting a layer of fully or partially uncured elastomer on top of the fibrous mesh

optionally supported by degassing in a vacuum; and

f) curing the top elastomer layer,

wherein the spinning composition comprises the lignin in admixture with at least one other polymer in a polar solvent.

7. The process according to claim 6 wherein the carbonization step comprises a stabilization as pre-step.

8. The process according to claim 7 wherein the stabilization pre-step comprises heat treating the electrospun fibers in an inert atmosphere optionally supported by annealing steps.

9. The composite material according to claim 1 wherein the elastomer is selected from one or more polysiloxanes, polyurethanes, rubbers or a combination thereof.

10. The composite material according to claim 9 wherein the mesh is formed to a layer which is integrated in an elastomer layer.

11. The composite material according to claim 10 wherein the thickness of the integrated composite layer is about 0.1 to 10 mm.

12. The process according to claim 6, wherein the elastomer is pre-stretched in step d) when putting the fibrous mesh on top of the elastomer.

13. A stretchable electrical conductor comprising of the composite material according any one of claims 1 to 5.