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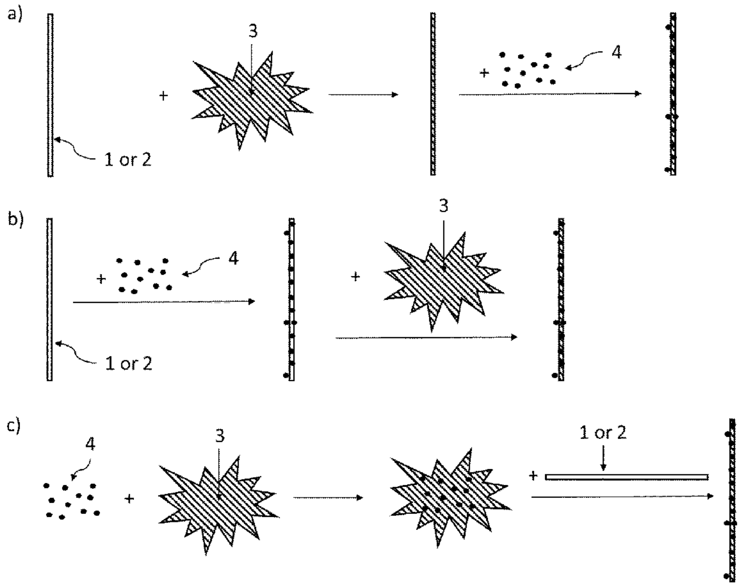

Fig. 2

(57) Abstract: The present invention relates to the technical field of composites. In particular, the invention pertains to a prepreg (0) comprising at least one, preferably more than one, fiber (1) and a resin (3) comprising a filler material (4), wherein the filler material (4) comprises or consists of micronized biochar (5).

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DESCRIPTION

PREPREG, PREPREG BODY AND A METHOD TO PRODUCE A PREPREG

The present invention relates to the technical field of composites. Fiber-reinforced composite materials made of various fibers and resins are characterized by high strength, high stiffness, good constructability, high fatigue resistance, good corrosion resistance, and lightweight. Hence, they have replaced traditional metallic materials in many fields, such as aircraft, shipbuilding, automotive, sports equipment, and many other industrial applications.

Prepregs are known as composite materials made from pre-impregnated fibers and a partially cured polymer matrix. The thermoset matrix is only partially cured to allow an easy handling. In this way, prepregs allow to impregnate a bulk amount of fibers which are then stored in a cooled area (e.g. below 0°C) for an extended period of time to be cured later.

Fiber-reinforced composite materials are often made from prepregs. In the so-called "B-state," the resin is only pre-polymerized or partially polymerized and must be still meltable and curable. The partial polymerization is just high enough to allow easy handling (without gluing) of the prepregs and a certain storage stability, if possible, at room temperature. Usually, it is stored at temperatures below 0°C. In the fully crosslinked state, i.e., after melting and curing at higher temperatures and possibly under pressure, high chemical stability and heat resistance are achieved.

The heterogeneous structure of fiber-reinforced composite materials due to manufacturing causes large differences in physical properties between the direction of the reinforcing fibers and the other directions. For example, the high strength and high specific modulus of elasticity of composite materials are mainly reflected in the fiber direction, while the mechanical properties between fibers are rather poor. In particular, fiber-reinforced composite materials containing a thermosetting resin often tend to fracture when a mechanical stress is caused in a direction (Z-direction) other than the alignment direction of the reinforcing fibers. This is generally due to the low toughness of the matrix resin.

To solve this problem and impart other properties to the composite, it has been proposed to modify the properties of the resin by adding fillers.

For example, EP 0 864 248 B1 discloses that up to 20wt% of inorganic filler material (talc particles) improves the three-dimensional stability of epoxy resin laminates.

US 5 264 065 A describes that inorganic fillers can adjust the coefficient of thermal expansion in the Z-axis of epoxy resin-based laminates.

US 2014/0356613 A1 describes a carbon fiber prepreg in which the carbon fibers are studded with carbon nanotubes to improve the thermal conductivity of the composite.

A process for producing a prepreg from carbon fibers, graphene, carbon nanotubes, and epoxy resin is known from CN 105968717 A. The process comprises the step of generating modified graphene and mixing it with multi-walled carbon nanotubes.

For resin compositions consisting of a suspension of particles in a viscous medium, uniform and bubble-free introduction of the resin between the carbon fibers is a challenge. Liquefied resin compositions, such as the melt of a thermoplastic polymer, often have a much higher viscosity than water. A highly viscous melt makes impregnation and wetting of the carbon fibers with the resin composition difficult. Increasing the temperature to reduce the viscosity of the melt can lead to undesirable reactions or decomposition of the resin.

In some cases, the resin can be mixed with or dissolved in a solvent to reduce its viscosity and facilitate the wetting of the fibers. However, many thermoplastics do not dissolve easily. Moreover, additional time and steps may be required to separate a solvent from the fiber and/or the resin (e.g., by evaporation) following the impregnation process.

The objective of the present invention is to provide an alternative method for producing a prepreg and an alternative prepreg. In addition, a composite body comprising or consisting of prepregs is provided.

The present objective is solved by a prepreg according to claim 1. The inventive prepreg comprises at least one, preferably more than one, fiber and a resin comprising a filler material, wherein the filler material comprises or consists of micronized biochar.

In the context of the present invention, "prepreg" is the term used to describe pre-impregnated fiber semi-finished products. Most often an epoxy resin is used as resin for the pre-impregnation of the fiber, however also other types of resins can be used.

In the context of the present invention, a "fiber" refers to natural or synthetic fiber, in particular to fibers such as carbon fibers, polymer fibers (e.g., aramid fibers, HMPE fibers, UHMWPE fibers, HDPE fibers, nylon fibers, PTFE fibers), glass fibers, basalt fibers, and/or mixtures thereof. In a preferred embodiment, the prepreg comprises more than one fiber, e.g., 2 to 10 fibers, more than 10 fibers, more than 100 fibers, more than 1.000.000 fibers, or more than 1.000.000.000 fibers.

The "resin" refers to a substance of natural or synthetic origin that is convertible into polymers. Suitable resin examples are a thermoplastic resin, an epoxy resin, a vinyl ester, a silicone, a cyanate ester, bismaleimide (BMI), a polyimide, a polyolefin, a polyurethane, a phenol, an acrylic, a polyester and mixtures thereof. Nevertheless, also other resins known by a person skilled in the art can be applied.

The term "filler material" is herein used to describe a material which is combined with the resin in order to improve its properties and/or to improve the properties of the prepreg. In most cases, epoxy resin filler materials will be applied. However, also any substance milled to powder may be used as a filler material. In particular, a filler material selected from calcium carbonate, magnesium hydroxide, calcium silicate, glass, ashes, nanofillers, talc particles, polymer foam beads, and/or their mixtures can be applied.

The combination of a filler material with the resin generally increases the viscosity of the resin. However, it has been found that due to the mixed material, the resin system becomes thixitropic or more thixotropic. A thixotropic fluid, even if thick or viscous under static conditions, will flow and become thinner and less viscous when shaken, agitated, shear-stressed, or otherwise stressed. Therefore, the combination of the filler material with the resin can increase the shear thinning of the resin and thus can improve the resin distribution and the impregnation of the fibers.

In the context of the present invention, "biochar" describes a carbonaceous, in particular porous carbonaceous material. The term "micronized" refers to a material having a particle size in the µm-range, such as in the range of 0.1 µm to 999µm. Moreover, this term refers to the process of reducing the average particle size by mechanical means, in particular milling, grinding, and crushing, and by screening means or separation means, such as sieving, filtration, sonication, centrifugation, chromatography, etc.

Micronized biochar can reduce the surface energy of the resin, thereby improving the wettability of the reinforcing fibers. Without being bound by theory, micronized biochar can also increase the interfacial bonding between the resin and the fiber(s), thereby improving the resin distribution upon the fiber(s).

In one embodiment of the inventive prepreg, which can be combined with any other embodiment(s) unless in contradiction, the filler material and/or the micronized biochar have a particle size below 50µm, in particular below 30µm or below 10µm, further in particular below 1µm.

In a preferred embodiment, the particles of the filler material and/or of biochar have a suitable particle size which allows them to be effectively inserted between the fibers, causing an improved bonding between the fibers. Due to the porous surface of the particles of the filler material and/or of biochar, the resin can penetrate the pores of biochar, which contributes to the formation of strong interfacial bond between the filler material and the resin, thus leading to an increased strength of the prepreg(s). It affects the flexural and tensile strength as well as the hardness of the prepreg(s) after the curing of the resin.

Particularly with respect to improving the resin distribution in the fiber reinforcement structure, it has been shown to be advantageous if the micronized biochar has a particle size below 50µm, e.g., 1nm to 999nm, 0.1µm to 49.5µm, 1µm to 40µm, 10µm to 30µm, or 20µm to 25µm.

In another embodiment of the inventive prepreg, which can be combined with any other embodiment(s) unless in contradiction, the prepreg comprises a plurality of fibers forming a unidirectional or woven fabric, a mat, a felt, a foil, or a stripe, in particular selected from the group consisting of a carbon fiber fabric, a carbon fiber mat, a carbon fiber stipe, a carbon fiber foil, a glass fiber fabric, a glass fiber mat, a glass fiber stripe, an aramid paper, an aramid fiber fabric, an aramid fiber mat, an aramid fiber stripe, a basalt fiber fabric, a basalt fiber mat, and a basalt fiber stripe.

The fibers can be arranged unidirectional, multiaxial, or can be woven before the impregnation. They form a directional assembly or a unidirectional assemblage. As an example, a loose irregular scrim, conglomerate, non-woven, felt, or a regular arrangement of fibers such as in the form of nets, woven fabrics, or knitted fabrics.

In another embodiment of the inventive prepreg, which can be combined with any other embodiment(s) unless in contradiction, the resin comprises or consists of a thermosetting resin.

Preferably, the resin comprises the thermosetting resin as its main component, wherein the term "main component" refers to a component being in the highest weight percentage (wt%) relatively to the total weight of the resin.

In a preferred embodiment which can be combined with any other embodiment(s) unless in contradiction, the resin reacts very slowly at room temperature, or if cooled below the room temperature, so that it can be stored for many days and even months before it cures. Therefore, the storage and/or transport should preferably occur at temperatures below 0°C. Curing occurs at higher temperatures (usually above 60°C, e.g., in the range of 60°C to 85°C, in particular in the range of 65°C to 80°C) and/or at room temperature and/or under higher pressure, usually in an autoclave.

In another embodiment of the inventive prepreg, which can be combined with any other embodiment(s) unless in contradiction, the thermosetting resin is selected from the group consisting of an epoxy, a polyester, a vinyl ester, a polyurethane, and a mixture thereof.

In another embodiment of the inventive prepreg, which can be combined with any other embodiment(s) unless in contradiction, the resin further comprises a catalyst and/or a curing agent.

Any suitable catalyst and/or curing agent known to those skilled in the art can be applied.

In particular, the curing agent can for example be selected from one or more compound groups consisting of aliphatic amines and modified aliphatic amines, polyamides, aromatic amines and modified aromatic amines, anhydrides, catalytic and latent hardeners, and polysulfides and mercaptans.

In addition, some curing agents can also be used to form adducts with the resin.

In general, the catalyst refers to a chemical substance which lowers the activation barrier of the curing reaction thus fastening the curing process.

A catalyst is an organic, organometallic, or inorganic substance, which can for example be selected from the group consisting of a metal complex (e.g., an aluminum complex), a Lewis acid-base adduct, a Lewis acid, a Lewis base, a Brønsted acid, a Brønsted base, a sulfonic acid derivative (e.g., p-toluenesulfonic acid PTSA, dodecylbenzenesulfonic acid DDBSA, dinonylnaphthylsulfonic acid DNNSA, or dinonylnaphthalenedisulphonic acid DNNDSA), and a weak acid (e.g., phosphate-based acids, in particular phosphoric acid).

In another embodiment of the inventive prepreg, which can be combined with any other embodiment(s) unless in contradiction, the weight percentage of the micronized biochar with respect to the resin is in the range of 0.1wt% to 99wt%, in particular in the range of 0.1wt% to 20wt%, further in particular in the range of 10wt% to 15wt% or 1wt% to 3wt%.

In another embodiment of the inventive prepreg, which can be combined with any other embodiment(s) unless in contradiction, the weight percentage of the combined filler material and the micronized biochar with respect to the resin is in the range of 0.1wt% to 99wt%, in particular in the range of 0.1wt% to 20wt%, further in particular in the range of 10wt% to 15wt% or 1wt% to 3wt%.

In particular, it has been found that the use of a) micronized biochar as the filler material, or of b) the combined filler material (being different from micronized biochar) with the micronized biochar, leads to highly qualitative and mechanically robust prepregs, especially when the weight percentage of a) or of b) is in the range of 1wt% to 3wt%, with respect to the resin.

In another embodiment of the inventive prepreg, which can be combined with any other embodiment(s) unless in contradiction, the biochar presents a high carbon content. In this context, a high carbon content means a carbon content of at least 50wt%, preferably at least 65wt%, and most preferred at least 80wt%, based on the total weight of the micronized biochar material.

In another embodiment of the inventive prepreg, which can be combined with any other embodiment(s) unless in contradiction, the at least one fiber is selected from the group consisting of carbon fibers, glass fibers, basalt fibers, and aramid fibers.

The carbon fiber refers to a fiber with a carbon weight percentage of 90wt% or more, e.g., 90wt% to 99wt%, or 90wt% to 95wt%, or 95wt% to 99wt%. In this context, a carbon fiber composited with other materials, such as for example graphite, to form reinforced carbon-(carbon) composites also falls within the definition of the carbon fiber, as long as the carbon weight percentage of 90wt% or more is observed. In this regard, also a carbon fiber combined with a polymer, ceramic, or other matrices is referred to as "carbon fiber", as long as the carbon weight percentage of 90wt% or more is observed.

The glass fiber describes a fiber consisting of numerous fine fibers of glass. For example, the glass fiber can consist of different glass types such as E-glass, A-glass, E-CR-glass, C-glass, D-glass, R-glass, S-glass, or T-glass.

Basalt continuous, staple and super-thin fibers fall within the definition of a basalt fiber.

Both the para-aramid and the meta-aramid are referred to as aramid and, analogously, the fibers consisting of para-aramid and/or meta-aramid are referred to as aramid fibers.

In general, the fibers can be about 5µm to 10µm in diameter and be a single fiber, or part of a more complex fibral structure, such as for example fiber conglomerates, felts, or be part of a regular arrangement of fibers such as nets, woven fabrics, mats, or knitted fabrics.

In another embodiment of the inventive prepreg, which can be combined with any other embodiment(s) unless in contradiction, the micronized biochar is obtained by pyrolysis of a biomass, and/or products of organic or fossil origin.

The pyrolysis is herein defined as a process of thermal decomposition of a material at elevated temperatures in an oxygen-free or oxygen-poor atmosphere. As products, solids, liquid, and gases can be obtained. Analogously, the "pyrolysis of a biomass" describes a process in which the biomass is treated thermally and, in an oxygen-free or oxygen-poor atmosphere.

Herein, the biomass is any source of organic carbon, generally defined as the biological (material) mass of recently living (but now dead) organisms (such as plants, animals, archaea, protozoa, chromista, fungi, and/or their parts), or natural products directly or indirectly produced by the living organisms. Such biomass may for example be parts of plants (for example dried wood, dried grass, roots, or leaves), parts of animals (for example exoskeletons of shrimps, furs, or dead animals as whole), the excrements of organisms including humans, or commercial products consisting of biomass (for example products made from cellulose, wood, wool, hemp, reed, cork, seagrass, bones, or shells). Additionally, a biomass enriched with a mineral additive also falls within the definition of a "biomass" as understood in the context of the present invention.

Additionally, municipal, and/or other waste products of organic and fossil origin, such as for example plastics, may also be considered as pyrolysis feedstock.

In an advantageous embodiment, the biomass and/or products of organic or fossil origin are pretreated prior to the pyrolysis in order to eliminate, or to reduce, the amount of water incorporated in the biomass and/or products of organic or fossil origin and/or to enlarge the surface area to be pyrolyzed. Suitable means are known to those skilled in the art, for example drying, cutting in small pieces, grinding, or dehydrating.

In another embodiment of the inventive prepreg, which can be combined with any other embodiment(s) unless in contradiction, the micronized biochar is obtained by gasification of a biomass and/or products of organic or fossil origin.

The gasification is herein defined as a process to convert carbonaceous materials, in particular biomass and/or products of organic or fossil origin, into gases (e.g., CO, CO_2, CH_4, or H_2) by heating in air, pure oxygen, or water steam at temperatures higher than 800°C, with or without catalyst. This process, which can but doesn`t have to be conducted in a gasifier, comprises a step of pyrolysis or devolatilization, in which volatiles are released from the carbonaceous material and a solid residue named char, optionally biochar feedstock, optionally micronized biochar, is obtained. In a further treatment process, the combustion, the volatiles, and some of the char can react with O_2 to primarily form CO_2 and some small amounts of CO. In the next step, the char can react with air, H_2O steam, and/or CO_2 to produce CO and H_2. Hence, the biochar feedstock, optionally micronized biochar, is usually not the main product of gasification. However, a gasification process of a biomass and/or products of organic or fossil origin that gives biochar as its main product (e.g., by stopping the combustion at the right moment) also falls within the claimed gasification.

In an embodiment of the invention, the biomass and/or products of organic or fossil origin are pretreated prior to the gasification in order to eliminate, or to reduce, the amount of water incorporated in the biomass and/or products of organic or fossil origin and/or to enlarge the surface area to be gasified. Suitable means are known to those skilled in the art, for example drying, cutting in small pieces, grinding, dehydrating, or mixing with an activation agent.

In another embodiment of the inventive prepreg, which can be combined with any other embodiment(s) unless in contradiction, the biomass is selected from the group consisting of wood, parts of plants, organic waste, packaging material, sewage sludge, and a combination thereof.

The term "organic waste" refers herein to an industrial and/or natural waste that is composed of biomass, as defined above and may contain plastic residues.

In another embodiment of the inventive prepreg, which can be combined with any other embodiment(s) unless in contradiction, the micronized biochar comprises clusters of aromatic carbon rings, in particular polycyclic aromatic hydrocarbons (PAHs) having more than seven aromatic rings, and wherein the content of the clusters of aromatic carbon rings, in particular polycyclic aromatic hydrocarbons (PAHs) having more than seven aromatic carbon rings is in the range of 1wt% to 49wt%, an/or 50wt% to 75wt%, and/or 76wt% to 90wt% and/or 91wt% to 100wt%.

Preferably, the micronized biochar used as the filler material, or part of the filler material, should mainly comprise clusters of several aromatic carbon rings, in particular clusters of more than seven aromatic carbon rings. It has been found that a high content of aromatic rings in the micronized biochar greatly contributes to the electrical conductivity of the prepreg. Therefore, micronized biochar comprising mainly clusters of aromatic carbon rings having more than seven aromatic rings is highly desirable for electrically conductive prepregs. In an advantageous embodiment, the amount of polycyclic aromatic hydrocarbons (PAHs) in the micronized biochar is less than 1µg of 8EFSA PAHs per 1kg of biochar, in line with the low health risk requirements.

Preferably, the micronized biochar does not contain significant amounts of aliphatic carbon compounds, and/or small clusters of aromatic carbon rings (1-4 rings). The latter can for example originate from pyrolytic gases and precipitate as pyrolytic condensates on the biochar surfaces.

The concentration of such pyrolytic condensates is preferably less than 3wt%, more preferably less than 1wt%, based on the total weight of the micronized biochar material. If the biochar contains more than 3wt% of such pyrolytic condensates, this may degrade its bond with the resin system. It has been found that almost condensate-free biochar surfaces show the optimal bonding to the resin and can allow the resin to partly enter the porous interiors of the biochar and can thus contribute to the improved force transmission between the fiber(s), the resin, and the biochar.

An advantageous electrical conductor effect is achieved when the electrical conductivity of the solid biochar is 100 mS/cm or more, measured at a pressure of 5t, according to the analytical methods of the European Biochar Certificate (EBC).

In another embodiment of the inventive prepreg, which can be combined with any other embodiment(s) unless in contradiction, the micronized biochar comprises at least two, preferably more than two, of the following carbon allotropes: graphene, fullerene, carbon nanotubes, carbon nanobuds, and graphene nanoribbons.

It has been found that the addition of micronized biochar to the resin reduces the electrostatic charge of the resulting composite materials, in particular prepreg. Moreover, it has been found that composite materials, in particular prepregs, which comprise biochar have electromagnetic shielding properties.

Without being bound by this explanation, these beneficial effects can be attributed to the fact that biochar, in the micronized form also referred to as nano-carbon, is rich in carbon allotropes such as graphene, fullerene, nanotubes, nanobuds, and nanoribbons. These carbon components differ from each other in surface texture, porosity, and morphology and may contribute to the better interpenetration of the fiber with the resin. The carbon allotropes may absorb kinetic energy when the cured composite material is put under mechanic stress (dynamic deformation) and they may render the absorbed energy with timely microseconds delay to the material, thus improving the energy distribution within the composite material, in particular prepreg, as well as the dampening and rebound properties.

In one embodiment, to produce composite materials with high electromagnetic shielding properties and good thermal insulation, as well as a biochar with a high carbon allotropes content, at least one, in particular more than one, and further in particular all the above-defined biochar properties should be fulfilled.

In another embodiment of the inventive prepreg, which can be combined with any other embodiment(s) unless in contradiction, the micronized biochar (5) comprises or consists of at least two micronized biochar batches having different physical and/or chemical qualities, optionally of at least two micronized biochar batches being obtained at different temperatures.

In particular, it has been found that (micronized) biochar which has been obtained at relatively low temperatures, such as for example below 600°C, e.g. at 500°C, or at 400°C, has good thermic insulation properties while (micronized) biochar which has been obtained at relatively high temperatures, such as for example above 600°C, e.g. at 601°C, at 700°C or at 800°C, is a good electric conductor, increases electromagnetic shield and reduces electrostatic charging.

In one embodiment, at least two (micronized) biochar batches having different physical and/or chemical properties and/or being obtained at different temperatures are mixed together to obtain a prepreg being a thermic insulator with electromagnetic shield properties.

Regarding the process, the technical problem is solved according to a generic method in which the filler material comprises or consists of micronized biochar.

The present objective is further solved by a method for producing a prepreg, according to claim 17. In one embodiment the method comprises the following steps:

- providing at least one, preferably more than one, fiber;
- providing a resin;

- providing particles of a filler material, which comprises or consists of micronized biochar;
- combining the at least one fiber with the resin and the filler material;
- optionally partially curing the at least one fiber combined with the resin and the filler material; and
- storing the fiber combined with the resin and the filler material, optionally the partially cured at least one fiber combined with the resin and the filler material, in a deep-frozen state.

The above method steps can be conducted in any order, or in particular in the exact written order.

The "fiber" to be provided can be a natural or a synthetic fiber and in particular be selected from the group consisting of a carbon fiber, a glass fiber, a basalt fiber, and an aramid fiber. Also a plurality of fibers forming a fabric, a mat, a felt, a foil, or a stripe can be provided, in particular being selected from the group consisting of a carbon fiber fabric, a carbon fiber mat, a carbon fiber stripe, a carbon fiber foil, a glass fiber fabric, a glass fiber mat, a glass fiber stripe, an aramid paper, an aramid fiber fabric, an aramid fiber mat, an aramid fiber stripe, a basalt fiber fabric, a basalt fiber mat, and a basalt fiber stripe.

The "resin" to be provided can be any resin or resin composition, wherein the resin refers to a substance of natural or synthetic origin that is convertible into polymers. Suitable resin examples are a thermoplastic resin, an epoxy resin, a vinyl ester, a silicone, a cyanate ester, bismaleimide (BMI), a polyimide, a polyolefin, a polyurethane, a phenol, an acrylic, a polyester and mixtures thereof. Nevertheless, also other resins known by a person skilled in the art can be applied. Furthermore, the resin can contain organic or inorganic solvents, for example to facilitate its handling, as well as other additives, binders, and/or colorants known by those skilled in the art.

The term "filler material" is herein used to describe a material which, after being combined with the resin, improves its properties and/or improves the properties of the prepreg. The filler material comprises or consists of micronized biochar.

By combining micronized biochar with the resin system, the necessary temperature and/or the amount of solvents can be reduced, compared to the conventional solution-based impregnation. In addition to that, the necessary temperature and/or pressure in the hot melt processing of fiber impregnation can be reduced. It has been found that the addition of biochar can increase the viscosity of the resin and can render it thixotropic or more thixotropic. The addition of micronized biochar can increase the shear thinning of the resin and thus improve the resin distribution and the impregnation of the fibers. It has been found that it can also reduce the surface energy of the resin, thereby improving the wettability of the fibers, and increase the interfacial bonding between the resin and the fiber, thereby improving the resin distribution at the fiber.

It was also found that the addition of micronized biochar can lead to improved mechanical damping and energy recovery after dynamic deformation of the prepreg. The resulting higher elasticity and dynamics of the composite material are particularly beneficial for sports equipment subjected to elastic deformation, such as for example snowboards and/or skis but also, e.g., airplane wings, or rotor blades of wind turbines.

The combination of the resin, filler material and the fiber (the "elements") can occur simultaneously, meaning that the elements are combined at the same time, or the combination can occur at different points of time. For example, two of the elements can be combined prior to their combination with the third one. Also, the elements can be combined with some of the above-mentioned additives, solvents, binders, filler materials, etc. before or during being combined with the other element(s). Some combination examples are the processes of suspending, mixing, sonicating, agitation, sheer-mixing, dissolving, impregnating, wetting, dipping, sprinkling, coating, depositing, and/or their combinations. The at least one fiber combined with the resin and the filler material is optionally pre-dried.

In one embodiment, the combination of the fiber, resin and the filler material can be achieved by impregnating the fiber with the resin according to a process step comprising, in a first preferred variant, pre-mixing the resin and the micronized biochar to form a resin-biochar mixture and impregnating the fiber material with the resin-biochar mixture. To achieve a particularly homogeneous distribution of the biochar particles in the resin system, pre-mixing includes agitation, sonication and/or shear mixing.

In a second advantageous variant, which can be used as a supplement or alternative to the first variant, the combination of the fiber with the resin and the particulate filler material comprises the following steps:

(i) providing the at least one, preferably more than one, fiber or fiber mat pre-impregnated with the resin,

(ii) providing a suspension of the micronized biochar and a liquid, in particular highly volatile liquid, and

(iii) applying the suspension on the outer surface of the at least one, preferably more than one, fiber or fiber mat to obtain a prepreg having a biochar-containing coating on the outer surface.

In this particular embodiment, the micronized biochar is suspended in a preferably highly volatile liquid, such as ethanol or methyl ethyl ketone (MEK). The suspension is applied to the outer surface of the at least one, preferably more than one, fiber or fiber mat pre-impregnated with the resin, for example by flooding, spinning, dipping, brushing, pressurizing in an autoclave, and/or spraying. After evaporation of the suspension liquid, a biochar-containing coating remains on the outer surface of the fiber(s).

In order to obtain high-quality prepregs with an equal coating distribution, it is advantageous and important to remove the resin excess from the surface of the pre-impregnated fiber(s).

Another factor playing a role in the quality of prepregs is the gas contained in the resin which is coating the fiber(s). In a preferred embodiment, the resin does not contain any gas bubbles. The latter can be removed prior to the combination of the at least one fiber with the resin and the filler material, or after the fiber has been combined with the resin.

The partial curing of the combined fiber(s), the resin and the filler material is defined as a partial polymerization, optionally occurring quickly at elevated temperatures, and is an optional process step which can be performed for example to reduce the volatile content of the resin and impart better handling characteristics. For example, in cases where no volatile solvents are used, the step of partial curing can but does not have to be performed. Optionally, the filler material comprising or consisting of micronized biochar leads to a more homogenous and controlled temperature distribution during the partial curing.

The partially cured prepreg(s) must be stored in a deep-frozen state. The deep-frozen state describes a state in which the resin polymerization is greatly slowed. Accordingly, the deep-frozen state is achieved at a temperature, at which the resin polymerization is slowed down to a large extent, e.g., at or below the freezing point of the resin. The storage can occur for example at or below 0°C, or at or below –18°C or below –20°C, for example in a freezer.

In another embodiment of the inventive method, which can be combined with any other embodiment(s) unless in contradiction,

- the resin and the particles of the filler material comprising or consisting of micronized biochar, are combined prior to their combination with the at least one fiber, and/or
- the at least one fiber is combined with the particles of the filler material comprising or consisting of micronized biochar, prior to their combination with the resin, and/or
- the at least one fiber is combined with the resin prior to their combination with the particles of the filler material comprising or consisting of micronized biochar.

In another embodiment of the inventive method, which can be combined with any other embodiment(s) unless in contradiction, the method comprises an additional step of generating the micronized biochar from a granular biochar feedstock having an average particle size of 50µm and/or more than 50µm, by separating the micronized biochar having a particle size below and/or equal 50µm from the granular biochar feedstock.

The step of generating micronized biochar from a granular feedstock can be conducted at any point during the process. However, generating the micronized biochar before its combination with the fiber and/or the resin should be guaranteed.

The biochar feedstock from which the micronized biochar is separated, is described as granular, meaning that it is composed of many micro- and/or macroscopic particles. In this sense, the biochar feedstock is not limited to particles having a granular or grain form. The particles can be of any shape.

The granular biochar feedstock refers to pyrolyzed and comminuted biomass and/or products of organic or fossil origin or any other carbonaceous mass, wherein the mass can first be pyrolyzed and then comminuted, or it can be first comminuted and then pyrolyzed. By using biomass, the carbon footprint of the prepreg product can be reduced. The comminution can be reached, for example, by dry or wet grinding, with or without grinding media (e.g., in a ball mill), and/or by using ultrasonication. Particles remaining after comminution having a particle size of more than 50µm are separated from the micronized biochar, or the micronized biochar is separated from the particles having a particle size of more than 50µm, for example by sieving, filtering, centrifuging, and/or screening. However, also other suitable separation methods known by those skilled in the art can be applied.

Preferably, particle size fractions of the micronized biochar are produced, either by separating the micronized biochar from the granular biochar feedstock, or by separating the granular biochar feedstock from the micronized biochar, wherein the micronized biochar has a particle size below and/or equal 50µm.

In another embodiment of the inventive method, which can be combined with any other embodiment(s) unless in contradiction, the particles of the filler material and/or the particles of the micronized biochar have a particle size below 50µm, in particular below 30µm or below 10µm, further in particular below 1µm.

Without being bound by theory, biochar particles of suitable size can effectively be injected between the fibers and cause a bonding between them. This can improve the compressive and transverse tensile strength of the cured prepreg. Due to the porous surface of the biochar particles, the resin can penetrate the pores of the biochar particles, which contributes to the formation of a strong interfacial bond between the filler material and the resin, leading to improved strength and force/energy transmission. It affects the flexural and tensile strength as well as the hardness of the fiber-reinforced composite material after curing of the resin.

In another embodiment of the inventive method, which can be combined with any other embodiment(s) unless in contradiction, the micronized biochar is obtained by pyrolysis of a biomass and/or products of organic or fossil origin, or gasification of a biomass or products of organic or fossil origin.

In another embodiment of the inventive method, which can be combined with any other embodiment(s) unless in contradiction, the biomass is selected from the group consisting of wood, parts of plants, organic waste, packaging material, sewage sludge, and a combination thereof.

In another embodiment of the inventive method, which can be combined with any other embodiment(s) unless in contradiction, the pyrolysis is performed at a temperature above 650°C, in particular at a temperature between 651°C and 1500°C, further in particular between 700°C and 900°C.

Preferably, the micronized biochar used as the filler material should mainly consist of clusters of several aromatic carbon rings, in particular of clusters of several aromatic carbon rings having more than seven aromatic rings.

Most preferred, the micronized biochar does not contain significant amounts of aliphatic carbon compounds, and/or small clusters of aromatic carbon rings (1-4 rings). The latter can for example originate from pyrolytic gases and precipitate as pyrolytic condensates on the biochar surfaces.

The concentration of such pyrolytic condensates is preferably less than 3wt%, more preferably less than 1wt%, based on the total weight of the micronized biochar material. If the biochar contains more than 3wt% of such pyrolytic condensates, this may degrade its bond with the resin system. It has been found that almost condensate-free biochar surfaces show the optimal bonding to the resin and can allow the resin to partly enter the porous interiors of the biochar and can thus contribute to the improved force transmission between the fiber(s), the resin, and the biochar.

An advantageous electrical conductor effect is achieved when the electrical conductivity of the solid biochar is 100 mS/cm or more, measured at a pressure of 5t, according to the analytical methods of the European Biochar Certificate (EBC).

In another embodiment of the inventive method, which can be combined with any other embodiment(s) unless in contradiction, the resin comprises and/or consists of a thermosetting resin.

In another embodiment of the inventive method, which can be combined with any other embodiment(s) unless in contradiction, the thermosetting resin is selected from the group consisting of an epoxy, a polyester, a vinyl ester, a polyurethane, and a mixture thereof.

In another embodiment of the inventive method, which can be combined with any other embodiment(s) unless in contradiction, the resin further comprises a catalyst and/or a curing agent.

The objective of the present invention is further solved by a method to produce a body comprising or consisting of at least two, preferably more than two, prepregs, as described in claim 28.

The inventive fiber-reinforced composite body, further referred to as the "body" is produced using prepregs according to the invention. Hence, the prepregs used to form the body each have at least one fiber that is embedded in a polymer matrix obtained by (partially) curing a resin. The polymer matrix contains a filler material, optionally a filler material in the form of micronized biochar, as described above.

The method for producing a body comprising or consisting of at least two, preferably more than two, prepregs, comprises the following steps in the given order:

- providing at least two, preferably more than two, prepregs, wherein the prepreg comprises a plurality of fibers forming a unidirectional or woven fabric, a mat, a felt, a foil, or a stripe;
- laminating the at least two, preferably more than two, prepregs to form a pre-body;
- heat and pressure treatment of the pre-body to obtain the body.

In a particularly preferred method pre-conditioned prepregs, meaning fibers having a biochar-containing coating and being before the curing, optionally after the curing, are used as prepregs. The at least two pre-conditioned prepregs, in particular prepreg plies, are laminated to form a pre-body of a fiber-reinforced composite material. The pre-body is further processed to form the body of fiber-reinforced composite material by applying heat and/or pressure. In one embodiment, the biochar particles are pressed into and distributed in the resin under pressure, optionally under high pressure, for example, by means of a press or vacuum and preferably in an autoclave. At the same time, the resin hardens so that the body of fiber-reinforced composite material is obtained.

The present objective of the invention is further solved by a body according to claim 29, which comprises or consists of at least two, preferably more than two, prepregs and that is obtainable by a method comprising the following steps:

- providing at least two, preferably more than two, prepregs, wherein the prepreg comprises a plurality of fibers forming a unidirectional or woven fabric, a mat, a felt, a foil, or a stripe;
- laminating the at least two, preferably more than two, prepregs to form a pre-body;
- heat and pressure treatment of the pre-body to obtain the body.

The objective of the present invention is moreover solved by a use of the above body according to claim 30, to produce sports equipment and/or its parts, in particular skis, snowboards, surfboards, hydrofoils and/or sails.

The fiber-reinforced composite body according to the invention is advantageously applicable for the use in sports equipment and/or its parts and/or the production of sports equipment and/or its parts, in particular skis, snowboards, surfboards, hydrofoils and/or sails. Of course, also other types of sports equipment fall within the scope of the inventive use. The inventive body can particularly be used in the form of semi-finished products, such as for example films, webs, and/or laminates.

In another embodiment of the present invention, the above body can be used to produce a vehicle and/or its parts, in particular a boat, an airplane, a car, a spaceship, a motorbike, and/or a bicycle.

The fiber-reinforced composite body according to the invention is advantageously applicable for the use in vehicles and/or their parts and/or the production of vehicles and/or their parts, in particular a boat, an airplane, a car, a spaceship, a motorbike, and/or a bicycle. Of course, also other types of vehicles fall within the scope of the inventive use.

In another embodiment of the present invention, the above body can be used to produce a rotor blade for wind power plants, furniture and/or its parts, films, sheets, or laminates for electronic circuits.

The fiber-reinforced composite body according to the invention is advantageously applicable for the use in and/or the production of rotor blades for wind power plants, furniture and/or its parts, films, sheets, or laminates for electronic circuits. In this context also other parts of electronic circuits fall within the scope of the inventive use.

In another embodiment of the present invention, the prepreg comprising a plurality of fibers forming a unidirectional or woven fabric, a mat, a felt, a foil, or a stripe, is used in the production of light-weight constructions.

The prepreg meant herein has the form of one single ply. The physical and mechanical properties of this type of prepreg are especially advantageous for a use in constructions that require a lightweight, such as for example cars, planes, or spacecraft.

The objective of the present invention is moreover solved by a use of the biochar, optionally the micronized biochar (5) in the production of the prepreg and/or in the production of the body to reduce the carbon footprint of the prepreg and/or of the body, according to claim 34.

The use of biochar in prepregs has the effect of reducing the carbon footprint of the prepregs, and consequently, of the objects formed thereof. For example, sports equipment, or a vehicle comprising prepregs which contain biochar, are more environmentally friendly than the analogous objects comprising the state-of-the-art prepregs without biochar. Consequently, the use of biochar in prepregs, as well as the fusion of the prepreg and the biochar technology, have a great potential and are a valuable contribution both for the protection of the environment and for the industries.

The invention shall now be further exemplified with the help of figures. The figures schematically show:

Fig. 1a	an exemplary fiber, which can be used according to the invention;
Fig. 1b	a plurality of fibers, which can be used according to the invention;
Fig. 1c	a plurality of fibers, which can be used according to the invention;
Fig. 1d	a plurality of fibers, which can be used according to the invention;
Fig. 2a	an exemplary combination sequence of the fiber, the resin, and the filler material according to the invention;
Fig. 2b	an exemplary combination sequence of the fiber, the resin, and the filler material according to the invention;
Fig. 2c	an exemplary combination sequence of the fiber, the resin, and the filler material according to the invention.
Fig. 3	a graph illustrating damping measurement results of a snowboard containing nano-carbon and a snowboard without nano-carbon.

Figure 1a shows a single fiber (1), which can be applied in one of the embodiments of the inventive prepreg and/or in the method for producing the inventive prepreg. The single fiber can have any diameter in the range of 0.5µm to 20µm, in particular in the range of 0.5µm to 10µm, further in particular in the range of 5µm to 10µm and any length. The fiber can also be composed of smaller fibers arranged in a way to form a bigger fiber, such as for example the fiber 1. In the Figure, the boarders of the fiber are straight, however, also unevenly cut, and/or curved fibers can be used according to the invention.

Figure 1b shows a plurality of fibers (2) formed by single fibers (1) arranged to a fiber textile. The single fibers can be connected, for example woven, or loose. Also, the angle in which the fibers stand to each other can differ from the depicted 90° and 180°.

Figure 1c shows another embodiment of the plurality of fibers (2) depicted in Figure 1b having different diameters of the single fibers (1).

Figure 1d shows another embodiment of the plurality of fibers (2) depicted in the previous Figures, wherein the single fibers (1) are not only of different diameters, but also of different type, such as for example of a different chemical composition, or of different surface or physical properties.

Figure 2a schematically depicts an example of the combination of the fiber (1), or plurality of fibers (2), with the resin (3) and the filler material (4) according to the invention. The single fiber (1), or the plurality of fibers (2) can be first combined with the resin (3), wherein the resin (3) optionally comprises a catalyst and/or a curing agent. This combination can occur for example by deep coating, mixing, impregnation, layering, or wetting, but also any other types of combination by which the resin (3) is applied to the outer fiber surface, are possible. In the next step, which can be performed simultaneously to, or after the combination of the fiber (1), or plurality of fibers (2), and the resin (3), the filler material (4) is applied to the combined fiber (1), or plurality of fibers (2), and the resin (3). The filler material (4), comprising or consisting of micronized biochar, partially, optionally fully, penetrates the still viscous, optionally liquid, resin (3) on the outer surface of the fiber(s). However, some particles of the filler material (4) can also remain completely outside the resin (3), on the surface of the combined fiber(s) and resin (3).

Figure 2b schematically depicts an example of the combination of the fiber (1), or plurality of fibers (2), with the resin (3) and the filler material (4) according to the invention, wherein the fiber (1), or plurality of fibers (2) and the filler material (4) are combined prior their combination with the resin (3).

Figure 2c schematically shows an example of the combination of the fiber (1), or plurality of fibers (2), with the resin (3) and the filler material (4) according to the invention, wherein the filler material (4) and the resin (3) are combined prior their combination with the fiber (1), or the plurality of fibers (2).

Figure 3 shows a graph illustrating the damping measurement results obtained from an alpine snowboard containing a 3% (w/w) nano-carbon epoxy filler, also referred to as micronized biochar epoxy filler, (graph 11) and the control results obtained from a control snowboard where no nano-carbon was used. The normalized acceleration is plotted on the y-axis and the time [s] on the x-axis. It is shown that using the 3% (w/w) nano-carbon epoxy filler improved the snowboard damping by 11% in comparison to the control snowboard.

Reference signs

The following reference signs are not to be construed as limiting the extent of the matter protected by the claims.

Reference sign	Annotation
0	prepreg
1	(at least one) fiber
2	plurality of fibers
3	resin
4	filler material
5	micronized biochar

6	Biomass and/or products of organic or fossil origin
7	biochar feedstock
8	body
9	pre-body
10	graph illustrating a measurement result of the control snowboard
11	graph illustrating a measurement result of the snowboard containing 3% (w/w) nano-carbon epoxy filler

Examples

The invention is explained in more detail below with reference to embodiment examples. The latter are intended to provide a better understanding of the invention and should not limit its scope.

In one embodiment of the invention, the prepreg was produced using the following procedure:

Three layers of unidirectional (UD) fiber glass weighing 580 g/m^2 containing 40% (w/w) of a BFA diglycidyl-based epoxy resin were sprayed with 7 g/m^2 of micronized high-temperature biochar. The biochar was produced in a combined pyrolysis-gasification process from a woody feedstock at the highest treatment temperature of 965°C. The biochar was ball-milled to a particle size below 20µm and suspended in 45 ml ethanol per 1 m^2 of fabric.

Five additional layers of carbon biaxial 0/90 fabric, weighing 400 g/m^2 and containing 40% (w/w) of epoxy resin, were sprayed with 4.8 g/m^2 of micronized high-temperature biochar of the same quality, using the same procedure as above. The three impregnated UD fiberglass layers and the five carbon-fiber fabric layers were laminated alternately around a profiled hardwood core to produce the front wing of a hydrofoil. The front wing was vacuum sealed in a corresponding form and placed into an autoclave at 90°C and 5 bar for curing.

The above procedure example is e.g., used in the production of snowboards. Snowboards produced by this method have greatly improved damping, rebound and energy recovering properties if compared to state-of-the-art snowboards comprising additive reinforcement forms different from biochar-prepregs, for example non-biochar reinforced fiberglass prepregs. The resulting higher elasticity and dynamics of the obtained composite material is highly desirable in objects subjected to elastic deformation.

Moreover, the use of biochar brings a significant economic benefit to the producer(s) of composite materials, in particular prepregs. Using biochar for prepregs is more than 100 times cheaper than using conventional nanocarbons and results in composites having similar material qualities.

In this way, both the producer and the environment can benefit.

Exemplary production of biochar

Pyrolysis

Biomass in the form of wood chips was pyrolyzed in a Pyreg PX 1500 kiln at 650°C to 700°C with a residence time of 20min.

The amount of polycyclic aromatic hydrocarbons (PAHs) in the micronized biochar was determined to be less than 1µg 8EFSA PAHs per 1kg of biochar.

Crushing / Screening

To obtain micronized biochar, the biochar was mechanically crushed to particle sizes smaller than 50µm using a ball mill. The particles with a particle size above 50µm were removed by sieving.

Mixture of resin system and biochar - polymer matrix

Two components of BFA diglycidyl resin were purchased from CORES (Cores epoxy resin, LPL). The curing agent was a mixture of primary amines and DMP-30, which initiated a two-step polymerization process.

In the first polymerization step, the epoxy groups reacted with the amines at room temperature, resulting in a material with a low degree of polymerization and aromatic or aliphatic intermediate chain s. Thermal curing was then performed to complete the polymerization. During both steps, DMP-30 acted both as a catalyst and a co-curing agent, which promoted a more uniform polymerization process.

The biochar was dispersed in the epoxy monomer for 15min using an ultrasonic device (Sonics Vibra-cell).

Providing a fiber

The following carbon fiber(s)/fiber fabrics were used in some inventive embodiments: UD 0° glass fiber fabric 540 g/m^2, E-glass fiber woven 45°.

Impregnation of the fiber with resin and filler material(s)

In one embodiment of the inventive method, a carbon fiber fabric was impregnated with the BFA diglycidyl resin comprising micronized biochar in a weight percentage of 3wt%. The prepregs were treated to constant weight in an autoclave at temperatures in the range of 70°C to 90°C under vacuum. The volume fraction of the resin in this specific embodiment was 35%. The fiber volume fraction was thus 65%.

Claims

1. A prepreg (0) comprising at least one, preferably more than one, fiber (1) and a resin (3) comprising a filler material (4), wherein the filler material (4) comprises or consists of micronized biochar (5).

2. The prepreg according to claim 1, wherein the filler material (4) and/or the micronized biochar (5) have a particle size below 50µm, in particular below 30µm or below 10µm, further in particular below 1µm.

3. The prepreg according to any of claims 1 or 2 comprising a plurality of fibers (2) forming an unidirectional or woven fabric, a mat, a felt, a foil, or a stripe, in particular selected from the group consisting of a carbon fiber fabric, a carbon fiber mat, a carbon fiber stripe, a carbon fiber foil, a glass fiber fabric, a glass fiber mat, a glass fiber stripe, an aramid paper, an aramid fiber fabric, an aramid fiber mat, an aramid fiber stripe, a basalt fiber fabric, a basalt fiber mat, and a basalt fiber stripe.

4. The prepreg according to any of claims 1 to 3, wherein the resin (3) comprises or consists of a thermosetting resin.

5. The prepreg according to claim 4, wherein the thermosetting resin is selected from the group

consisting of an epoxy, a polyester, a vinyl ester, a polyurethane, and a mixture thereof.

6. The prepreg according to any of claims 1 to 5, wherein the resin (3) further comprises a catalyst and/or a curing agent.
7. The prepreg according to any of claims 1 to 6, wherein the weight percentage of the micronized biochar (5) with respect to the resin (3) is in the range of 0.1wt% to 99wt%, in particular in the range of 0.1wt% to 20wt%, further in particular in the range of 10wt% to 15wt% or 1wt% to 3wt%.

8. The prepreg according to any of claims 1 to 6, wherein the weight percentage of the combined filler material (4) and the micronized biochar (5) with respect to the resin (3) is in the range of 0.1wt% to 99wt%, in particular in the range of 0.1wt% to 20wt%, further in particular in the range of 10wt% to 15wt% or 1wt% to 3wt%.

9. The prepreg according to any of claims 1 to 8, wherein the at least one fiber (1) is selected from the group consisting of carbon fibers, glass fibers, basalt fibers, and aramid fibers.

10. The prepreg according to any of claims 1 to 9, wherein the micronized biochar (5) is obtained by pyrolysis of a biomass and/or products of organic or fossil origin (6).

11. The prepreg according to any of claims 1 to 9, wherein the micronized biochar is obtained by gasification of a biomass and/or products of organic or fossil origin (6).

12. The prepreg according to claim 10 or 11, wherein the biomass (6) is selected from the group consisting of wood, parts of plants, organic waste, packaging material, sewage sludge, and a combination thereof.

13. The prepreg according to any of claims 1 to 12, wherein the micronized biochar (5) comprises clusters of aromatic carbon rings, in particular polycyclic aromatic hydrocarbons (PAHs) having more than seven aromatic rings, and wherein the content of the clusters of aromatic carbon rings, in particular polycyclic aromatic hydrocarbons (PAHs) having more than seven aromatic carbon rings is in the range of 1wt% to 49wt%, and/or 50wt% to 75wt%, and/or 76wt% to 90wt% and/or 91wt% to 100wt%.

14. The prepreg according to any of claims 1 to 13, wherein the micronized biochar (5) comprises at least two, preferably more than two, of the following carbon allotropes: graphene, fullerene, carbon nanotubes, carbon nanobuds and graphene nanoribbons.

15. The prepreg according to any of claims 1 to 14, wherein the micronized biochar presents a high carbon content, in particular a carbon content of at least

50wt%, preferably at least 65wt%, and most preferred at least 80wt%.

16. The prepreg according to any of claims 1 to 15, wherein the micronized biochar (5) comprises or consists of at least two micronized biochar batches having different physical and/or chemical qualities, optionally of at least two micronized biochar batches being obtained at different temperatures.

17. A method for producing the prepreg according to any of claims 1 to 16, comprising the following steps:

- providing at least one, preferably more than one, fiber (1);
- providing a resin (3);
- providing particles of a filler material (4), which comprises or consists of micronized biochar (5);
- combining the at least one fiber (1) with the resin (3) and the filler material (4);
- optionally partially curing the at least one fiber (1) combined with the resin (3) and the filler material (4); and
- storing the at least one fiber (1) combined with the resin (3) and the filler material (4), optionally the partially cured at least one fiber (1) combined with the resin (3) and the filler material (4), in a deep-frozen state.

18. The method according to claim 17, wherein:

- the resin (3) and the particles of the filler material (4) comprising or consisting of micronized biochar (5), are combined prior to their combination with the at least one fiber (1), and/or

- the at least one fiber (1) is combined with the particles of the filler material (4) comprising or consisting of micronized biochar (5), prior to their combination with the resin (3), and/or

- the at least one fiber (1) is combined with the resin (3) prior to their combination with the particles of the filler material (4) comprising or consisting of micronized biochar (5).

19. The method according to any of claims 17 or 18 comprising an additional step of generating the micronized biochar (5) from a granular biochar feedstock (7) having an average particle size of 50µm and/or more than 50µm, by separating the micronized biochar (5) having a particle size below and/or equal 50µm from the granular biochar feedstock (7).

20. The method according to any of claims 17 to 19, wherein the particles of the filler material (4) and/or the particles of the micronized biochar (5) have a particle size below 50µm, in particular below 30µm or below 10µm, further in particular below 1µm.

21. The method according to any of claims 17 to 20, wherein the resin (3) comprises or consists of a thermosetting resin.

22. The method according to claim 21, wherein the thermosetting resin is selected from the group consisting of an epoxy, a polyester, a vinyl ester, a polyurethane, and a mixture thereof.

23. The method according to any of claims 17 to 22, wherein the resin (3) further comprises a catalyst, or a curing agent.

24. The method according to any of claims 17 to 23, wherein the micronized biochar (5) is obtained by pyrolysis of a biomass and/or products of organic or fossil origin (6).

25. The method according to any of claims 17 to 23, wherein the micronized biochar (5) is obtained by gasification of a biomass and/or products of organic or fossil origin (6).

26. The method according to claim 24 or 25, wherein the biomass (6) is selected from the group consisting of wood, parts of plants, organic waste, packaging material, sewage sludge, and a combination thereof.

27. The method according to claim 24 or 26, wherein the pyrolysis is performed at a temperature above 650°C, in particular at a temperature between 651°C

and 1500°C, further in particular between 700°C and 900°C.

28. A method to produce a body (8) comprising or consisting of at least two, preferably more than two, prepregs according to any of claims 1 to 16, comprising the following steps in the given order:

- providing at least two, preferably more than two, prepregs according to any of claims 1 to 16, wherein the prepreg comprises a plurality of fibers (2) forming an unidirectional or woven fabric, a mat, a felt, a foil, or a stripe;
- laminating the at least two, preferably more than two, prepregs to form a pre-body (9);
- heat and pressure treatment of the pre-body (9) to obtain the body (8).

29. A body (8) obtainable by the method according to claim 28.

30. A use of the body according to claim 29 to produce sports equipment and/or its parts, in particular skis, snowboards, surfboards, hydrofoils and/or sails.

31. A use of the body according to claim 29 to produce a vehicle and/or its parts, in particular a boat, an airplane, a car, a spaceship, a motorbike, and/or a bicycle.

32. A use of the body according to claim 29 to produce a rotor blade for wind power plants, furniture

and/or its parts, films, sheets or laminates for electronic circuits.

33. A use of the prepreg according to any of claims 1 to 16 in the production of light-weight constructions, wherein the prepreg comprises a plurality of fibers (2) forming a unidirectional or woven fabric, a mat, a felt, a foil, or a stripe.

34. A use of the biochar, optionally the micronized biochar (5) in the production of a prepreg, optionally in the production of the prepreg (0) according to any of claims 1 to 16, and/or in the production of the body (8) according to claim 29 to reduce the carbon footprint of a prepreg, optionally of the prepreg (0) and/or of the body (8).

Figures

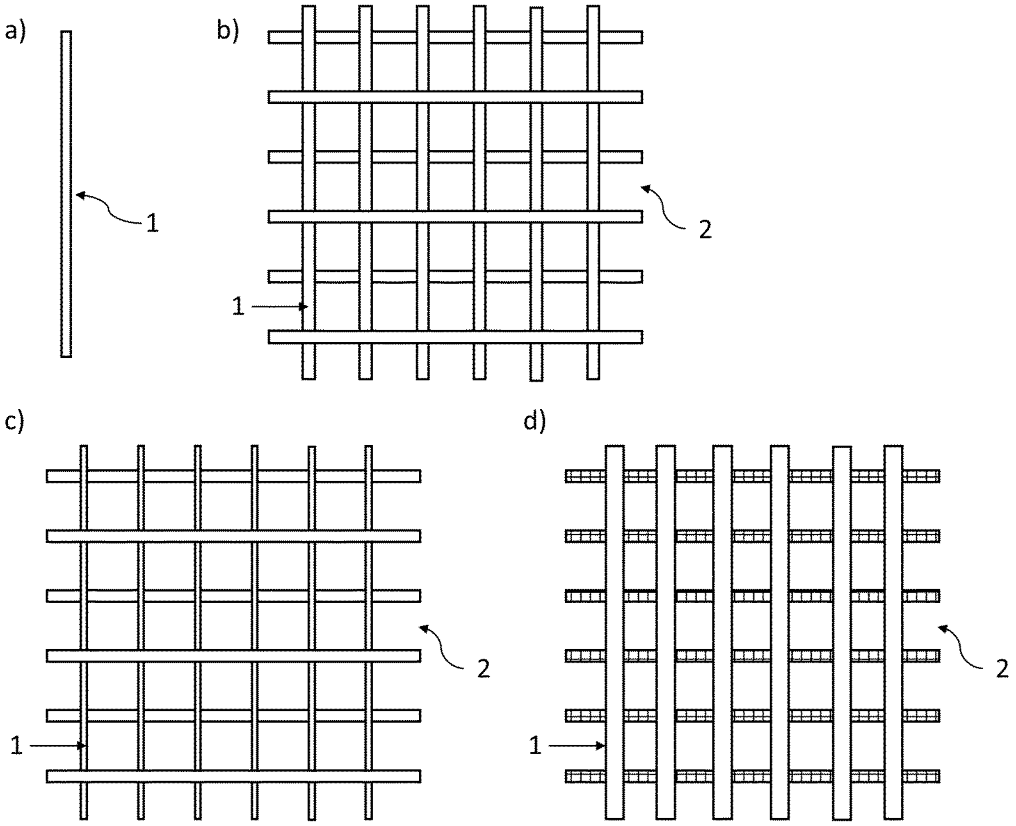


Fig. 1

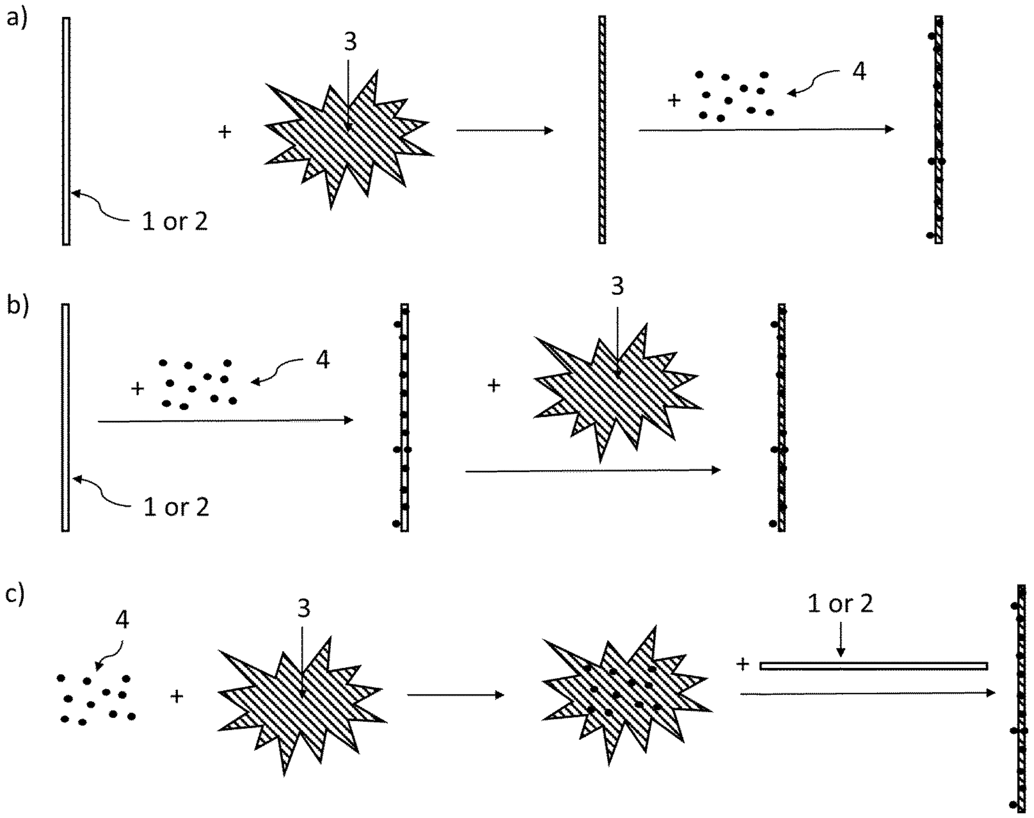
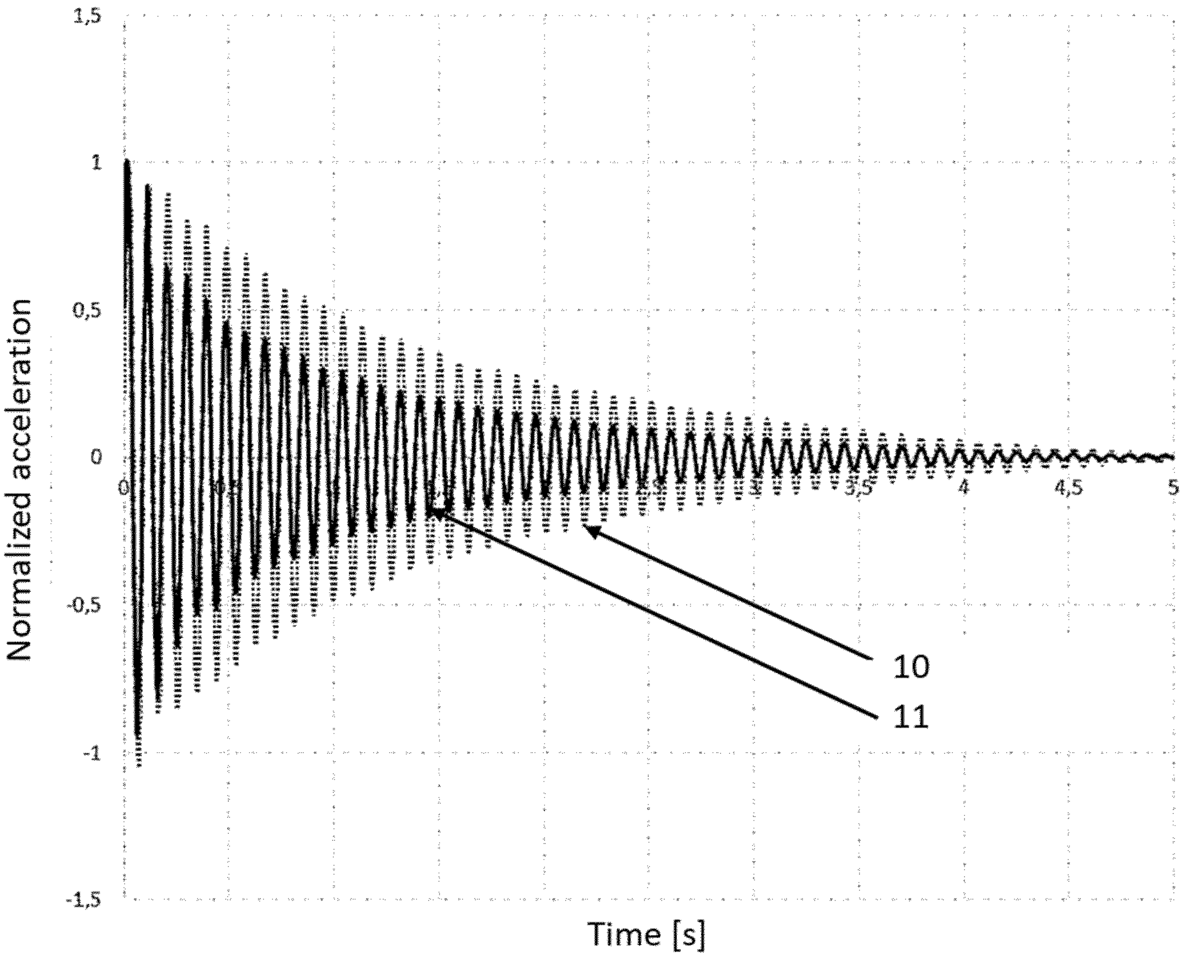


Fig. 2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0
-0,5
-1
-1,5
Normalized acceleration
0
0,5
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3
3,5
4
4,5
5
Time [s]
10
11

Fig. 3

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2023/083559

A. CLASSIFICATION OF SUBJECT MATTER
INV. C08J5/00 C08J5/04 C08J5/24
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C08J C08K C08L

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2022/195134 A1 (ODA AKIMICHI [JP] ET AL) 23 June 2022 (2022-06-23) paragraphs [0002] - [0004], [0017], [0049], [0060] -----	2,7-9, 13-16, 18-21, 23-28, 30-33
X	JP S55 80531 A (TOHO BESLON CO) 17 June 1980 (1980-06-17)	1,3-6, 10-12, 17,22, 29,34
Y	See explanations in the communication; paragraphs [0001], [0002]; claim 1 -----	2,7-9, 13-16, 18-21, 23-28, 30-33

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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Date of the actual completion of the international search 17 June 2024	Date of mailing of the international search report 27/06/2024
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Schweissguth, Martin

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2023/083559

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2022195134 A1	23-06-2022	EP 3957687 A1	23-02-2022
		JP 7189333 B2	13-12-2022
		JP WO2020213406 A1	23-12-2021
		TW 202104397 A	01-02-2021
		US 2022195134 A1	23-06-2022
		WO 2020213406 A1	22-10-2020
JP S5580531 A	17-06-1980	JP S5580531 A	17-06-1980
		JP S6234775 B2	29-07-1987