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(57) **Abrégé/Abstract:**

This can be a method of making a high strength composite reinforcing fiber using flat GO flakes coated on a conventional reinforcing fiber. This maintains some the flexibility of the fiber and aligns the flat graphene flakes along the surface of the fiber; this dramatically increases the strength of the fiber. It also allows bonding between overlapping flakes, in contrast to flakes being uniformly dispersed in a host material that is being reinforced and dramatically increases the strength of the host material.

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(54) Title: GRAPHITE OXIDE REINFORCED FIBER IN HOSTS SUCH AS CONCRETE OR ASPHALT

(57) Abstract: This can be a method of making a high strength composite reinforcing fiber using flat GO flakes coated on a conventional reinforcing fiber. This maintains some the flexibility of the fiber and aligns the flat graphene flakes along the surface of the fiber; this dramatically increases the strength of the fiber. It also allows bonding between overlapping flakes, in contrast to flakes being uniformly dispersed in a host material that is being reinforced and dramatically increases the strength of the host material.



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GRAPHITE OXIDE REINFORCED FIBER IN HOSTS SUCH AS CONCRETE OR ASPHALT

TECHNICAL FIELD OF THE INVENTION

The present invention relates in general to the field of high electrical conductivity nanocomposites, and more particularly, graphite oxide reinforced fiber in hosts such as
5 concrete or asphalt.

BACKGROUND OF THE INVENTION

Without limiting the scope of the invention, its background is described in connection with composite materials.

10 Graphene is one of the strongest materials ever tested. Various research institutes have loaded hosts with carbon allotropes such as carbon nanotubes (CNT), graphene flakes (GF), graphene oxide (GO), and graphite oxide and have seen up to a 200 % increase in tensile strength in the loaded host, but with inconsistent results. Measurements have shown that graphene has a breaking strength 200 times greater than steel, with a tensile modulus
15 (stiffness) of 1 TPa (150,000,000 psi). An atomic Force Microscope (AFM) has been used to measure the mechanical properties of a suspended graphene sheet. Graphene sheets held together by Van der Waals forces were suspended over SiO₂ cavities where an AFM tip was probed to test its mechanical properties. Its spring constant was in the range 1–5 N/m and the Young's modulus was 0.5 TPa (500GPa) thereby demonstrating that graphene can be
20 mechanically very strong and rigid.

Carbon nanotubes (CNTs) depending on whether they are single walled CNTs (SWCNTs) or multi-walled CNTs (MWCNTs), generally have the diameter of 1-3 nm or 5-50 nm, respectively. The length of CNTs can be up to centimeters, which gives an aspect ratio exceeding 1000. CNTs also exhibit extraordinary strength with moduli of elasticity on the
25 order of TPa and tensile strength in the range of GPa. With the concurrent benefits of high aspect ratio and excellent mechanical performance, CNTs have been found to improve the physical properties of cementitious or asphalt materials. Not only are CNTs extremely expensive, but also poor dispersion of CNTs is generally the reason for not achieving the desired enhancement of the physical properties of the composite. CNTs and graphene are
30 often difficult to disperse due to the strong Van der Waal's attractive forces between particles and the interaction of the particles in the host material. CNTs and graphene materials tend to

form agglomerates or self-attraction/assembly similar to that seen in carbon black creating defect sites in the composites. Without the use of a dispersing agent carbon based cement composites have worse mechanical properties than the plain cement paste. Non-uniform distribution/dispersion of CNTs and graphene bundles are responsible for the deterioration of the mechanical properties.

Some classic engineered structures such as reinforced concrete may not be recognized as a composite. The fact is that cement/concrete with rebar (short for reinforcing bar) qualifies as a composite. The rebar, having specific physical properties that significantly exceed those of the surrounding matrix is placed into a pattern to optimize the strength of the composite.

Other composite engineered structures such as fiber-reinforced plastics cement and asphalt are generally recognized as composites. Such structures are often engineered to create the best combination of lowest weight and increased strength.

SUMMARY OF THE INVENTION

This invention relates to a novel method of making an engineered composite structure using flat flakes of at least one of graphene, reduced graphene oxide and graphene oxide, and coating the flakes on the surface of fibers, such that the flake reinforced fibers can be used to reinforce other materials. These can have the potential to be used to reinforce a large number of host materials (e.g. concrete, glass, or plastic) because graphene is one of the strongest materials ever tested.

One embodiment relates to a method of making a composite reinforcing fiber comprising: providing flat graphene oxide (GO) flakes; providing a reinforcing fiber; providing a host material; coating the GO flakes on the reinforcing fiber; wherein 95% of the GO flakes have a surface area to thickness ratio greater than 300 Angstroms and a thickness of less than 160 Angstroms, and wherein the GO flakes have no physical surface distortions and no epoxy functionalization, and wherein surfaces of the GO flakes have the same hydrophobicity as the host material. In one aspect, the GO flakes have an oxidation level greater than 1.5% by mass. In another aspect, the GO flakes have an oxidation level less than 1.5% by mass. In another aspect, 95% of the GO flakes are greater than 0.8 and less than 16 nanometers in thickness. In another aspect, the maximum dimension of the GO flakes is between 220 Angstroms and 100 microns. In another aspect, the GO flakes have edge oxidation. In another aspect, the method further includes the step of mechanochemically exfoliating

graphite into graphene flakes and/or the GO flakes with a stirred media mill, wherein the stirred media mill is an attrition mill or ball mill. In another aspect, the composite reinforcing fiber is used to make a structure, air drying the coated reinforcing fiber; incorporating the air dried coated reinforcing fiber into the host material; forming the host material with the incorporated air dried coated reinforcing fiber into a structure; and adding water to react the host material with one or more materials that form concrete to form a concrete composite when cured. In another aspect, the step of mixing the GO flakes in the host material for at least 30 minutes in a sonic mixing system. In another aspect, the method includes adding Bitumen or other non-polar material to react with the host material. In another aspect, the GO flakes have a mass greater than 0.00005% of the mass of the host material.

In one embodiment the present invention includes a method of making a high strength composite reinforcing fiber comprising: providing graphene oxide (GO) flakes; providing a conventional reinforcing fiber; and coating said GO flakes on said conventional reinforcing fiber. In one aspect, the GO flakes are substantially flat. In another aspect, the substantially flat GO flakes with a surface area to thickness ratio greater than 300 Angstroms, and thickness of less than 160 Angstroms, wherein the graphene flakes have no significant physical surface distortions, having no significant epoxy functionalization and has an oxidation level greater than 1.5% by mass. In another aspect, the GO flakes have a surface area to thickness ratio greater than 300 Angstroms, and thickness of less than 160 Angstroms, and wherein the graphene flakes have no significant physical surface distortions, having no significant epoxy functionalization and has an oxidation level less than 1.5% by mass. In another aspect, 95% of the GO flakes are from about 0.8 to 16 nanometers in thickness. In another aspect, 95% of the GO flakes have a surface area to thickness ratio of a minimum of

300 Angstroms. In another aspect, the maximum dimension of the GO flakes between 220 Angstroms and 100 microns. In another aspect, the GO flakes have primarily edge oxidation. In another aspect, the method further comprises the step of mechanochemical exfoliating graphite into graphene/graphite oxide flakes is done in a stirred media mill, and the stirred
5 media mill is an attrition mill or ball mill.

In another embodiment the present invention includes a method of making a high strength structure: comprising: providing GO flakes; providing a conventional reinforcing fiber; providing the structure's host material; coating said GO flakes on said conventional reinforcing fiber; air drying said coated fiber; incorporating said coated fiber into the
10 structure's host material; and forming into the structure's host material with the incorporated said coated fiber into a structure. In one aspect, the GO flakes are substantially flat. In another aspect, the flakes with a surface area to thickness ratio greater than 300 Angstroms, and thickness of less than 160 Angstroms, wherein the GO flakes have no significant physical surface distortions, having no significant epoxy functionalization and has an oxidation level
15 greater than 1.5% by mass, and are combined with Ordinary Portland Cement and other dry powders. In another aspect, the method further comprises the step of mixing the GO flakes in the host material for at least 30 minutes in a sonic mixing system. In another aspect, the method further comprises the step of adding water to react the powders with one or more materials that form concrete to form a concrete composite when cured. In another aspect, the
20 GO flakes with a surface area to thickness ratio greater than 300 Angstroms, and thickness of less than 160 Angstroms, wherein the GO flakes have no significant physical surface distortions, having no significant epoxy functionalization and has an oxidation level less than 1.5% by mass, and said flakes are combined with sand and other dry powders. In another aspect, the method further comprises the steps of mixing the GO and the host material for at
25 least 30 minutes in a sonic mixing system, and adding Bitumen or other non-polar material to react the powders to form a composite when cured. In another aspect, the GO flakes have a mass greater than 0.00005% than the mass of the dry powder material. In another aspect, 95% of the GO flakes are from about 0.8 to 16 nanometers in thickness. In another aspect, 95% of the GO flakes have a surface area to thickness ratio of a minimum of 300 Angstroms.
30 In another aspect, the maximum dimension of the GO flakes between 220 Angstroms and 100 microns. In another aspect, the GO flakes have primarily edge oxidation. In another aspect, the GO flake surfaces have the same hydrophobicity as the other powders. In another aspect, the method further comprises the step of mechanochemical exfoliating graphite into

graphene/graphite oxide flakes in a stirred media mill, and the stirred media mill is an attrition mill or ball mill.

DETAILED DESCRIPTION OF THE INVENTION

5 While the making and using of various embodiments of the present invention are discussed in detail below, it should be appreciated that the present invention provides many applicable inventive concepts that can be embodied in a wide variety of specific contexts. The specific embodiments discussed herein are illustrative of ways to make and use the invention and do not delimit the scope of the invention.

10 To facilitate the understanding of this invention, a number of terms are defined below. Terms defined herein have meanings as commonly understood by a person of ordinary skill in the areas relevant to the present invention. Terms such as “a”, “an” and “the” are not intended to refer to only a singular entity, but include the general class of which a specific example may be used for illustration. The terminology herein is used to describe specific embodiments of the invention, but their usage does not delimit the invention, except as outlined in the claims.

15 As used herein, the term “graphene” refers to a polycyclic hexagonal lattice with carbon atoms covalently bonded to each other. The covalently bonded carbon atoms can form a six-member ring as a repeating unit, and may also include at least one of a five-member ring and a seven-member ring. Multiple graphene layers are referred to in the art as graphite. Thus, graphene may be a single layer, or also may comprise multiple layers of graphene that are
20 stacked on other layers of graphene yielding graphene oxide. Generally, graphene oxide can have a maximum thickness of about 100 nanometers (nm), specifically about 0.5 nm to about 90 nm.

As used herein, the term “graphene oxide flake” refers to a crystalline or “flake” form of graphene oxide that has been oxidized and includes many graphene sheets oxidized and
25 stacked together and can have oxidation levels ranging from 0.01% to 25% by weight in ultra pure water. The flakes are preferably substantially flat.

This can be a method of making a high strength composite reinforcing fiber using flat GO flakes coated onto a conventional, e.g. plastic or glass, reinforcing fiber. This coating maintains some the flexibility of the fiber and aligns the flat graphene flakes along the
30 surface of the fiber; this dramatically increases the strength of the fiber. It can also allow some bonding between partially overlapping flakes, in contrast to flakes being uniformly widely dispersed in a host material that is being reinforced.

This can also be a method of making a high strength structure using composite reinforcing fiber having flat GO flakes coated on a conventional reinforcing fiber. This maintains some the flexibility of the fiber during the combining of the host material with the composite reinforcing fiber.

5 Various research institutes have loaded hosts with carbon allotropes such as carbon nanotubes (CNT), graphene flakes (GF), and graphene oxide have seen up to a 200% increase in tensile strength in the loaded host. Measurements have shown that graphene has a breaking strength 200 times greater than steel, with a tensile strength of 130 GPa. An Atomic Force Microscope (AFM) has been used to measure the mechanical properties of a suspended
10 graphene sheet. A graphene sheet was suspended over a SiO₂ substrate with cavities and was probed with an AFM tip to test its mechanical properties. Its spring constant was in the range 1–5 N/m and the Young's modulus was 0.5-1 TPa, thereby demonstrating that graphene can be mechanically very strong and rigid. Despite these nano-scale mechanical properties, neither graphene nor graphene oxide has transitioned to commercial use in a macro-scale
15 mechanical structure due to price and dispersion related issues.

In the past, the process of producing a loaded host has not necessarily translated to a viable composite structure. The inability to translate the technology to a viable composite structure is a combination of technical issues, including uniform distribution/dispersion of the suspension in the host material, inadequate bonding of the reinforcing agent to the host
20 material, and cost factors. Traditionally, dispersion has been accomplished in a liquid host by a combination of sonication and stirring. In some cases the liquid or slurry of particles have been modified through functionalization of the particle or additive, or by modifying the host's viscosity, pH, or through the use of surfactants, as a means of improving dispersion and mechanical bonding. Interactions between the liquid host and particle, particle-to-
25 particle interaction/attraction and the settling of the particles have significantly and negatively impacted the uniformity of the dispersion which is deleterious to the strength of the resulting composite. In general, too highly concentrated graphene oxide/functionalized-graphite oxide (GO), GO or reduced oxide GO (rGO) additive in a host can result in the stacking or aggregation of the additive, resulting in thicker GO or rGO structures which
30 create point defects in the host. These thicker GO or rGO structures are stacked sheets held together by Van der Waals forces that can slip relative to each other, thereby creating point defects in the host. Such point defects will result in the composite having a lower mechanical

strength. Additive loadings greater than a few percent generally result in flocculation or loose agglomeration resulting in these point defects.

Graphene oxide, when uniformly dispersed in the host or in an engineered/ designed pattern, facilitates load transfer and mechanical support for greater structural strength. This technical approach offers the potential to replace the use of metallic reinforcements that corrode and lose mechanical integrity with a much more chemically stable additive.

Preferably using GO and rGO as mechanical enhancement additives, there is good interfacial bonding between the graphene/graphite oxide flake and the host's matrix. Improving the interfacial bonding generally has two important aspects. Preferably the flake surfaces are substantially planar, not distorted through the graphene/graphite oxide flake production process. Some production processes, e.g. the "Hummers" process, produce distorted flakes.

Preferably the chemistry of the flakes in addition allows full entrainment of the flakes into the host's matrix. Relative short, e.g. "chopped" fibers are preferred as they distribute the strengthening more evenly.

Non-limiting examples of a "host" or "host material", which terms are used interchangeably, for use with the present invention include, e.g., ordinary Portland cement, polypropylene (PP), polyethylene (PE), Polycarbonate (PC), ceramic powders, ceramic powder is aluminum oxide, zirconium oxide, silica, silicon dioxide, or combination thereof, metal powders, metal powders of titanium, titanium hydride, tantalum, cobalt chrome, niobium, stainless steel, nickel, copper, aluminum, or combinations thereof, a polycrystalline material, polyvinylidene fluoride (PVF), or polyvinylidene difluoride (PVDF), polyurethane, poly(butylene terephthalate), nylon 11, poly(ethylene terephthalate), poly(ether ether ketone), poly(phenylene sulfide), polyolefin, an oxide, carbonate or silicate of an element of Groups 2a, 3a, 4a and 4b of the Periodic Table, poly(vinyl chloride) (PVC), poly(methylmethacrylate), polystyrene, polycarbonate/nylon alloy, polycarbonate/polyester alloy, ABS, ABS/nylon alloy, ABS/PVC alloy, acrylic copolymers, polysulfone, polysulfone/ABS alloy, polyetherimides, polyamide-imides, polyarylates, fluoropolymers, polyphenylene oxide/polystyrene blend, or poly(phenylene sulfide).

For example, graphene/graphite oxide flake chemistry may be changed by modifying the flake edge carboxylate group by thermal treatment or with chemical functionalization that can tailor the polarity and/or create a functional group that is compatible with the host's chemistry (e.g., polarity, hydrophobicity, etc.). Functionalizing the graphene/graphite oxide

additive with a similar chemistry to the host allows the graphene additive to be directly incorporated in the long or short range ordering or bonding. The host can include plastics, metals, cement, asphalt, ceramics, and glass materials.

5 Larger graphene surface area to thickness ratios better mitigate and distribute a mechanical load, giving the host enhanced mechanical properties, including but not limited to increased tensile, shear, and flexural strength. The ability to achieve substantial enhancement of the host's mechanical properties can be obtained with a flake with an area of 48400 \AA^2 and a thickness of 160 \AA to 200 \AA with a surface area to thickness ratio of about 200 \AA . A surface area to thickness ratio equal to or greater than 200 \AA can provide enhancement to the host's mechanical properties.

10 In preferred embodiments, the flake thicknesses are 16 nanometers or less, as too many layers significantly reduce the tensile strength (preferably, 95% of our flakes are from about 0.8 to 16 nanometers thick, and our surface area to thickness ratio is greater than 300 Angstroms). Preferably, the maximum dimension of the flake varies between 220 Angstroms and 100 microns in diameter; this requires precise process control or a process that allows separation of the graphene flakes by surface area and/or thickness.

15 In another embodiment, the GO flakes used in a method of making a composite reinforcing fiber have a surface area to thickness ratio greater than 300 Angstroms and a thickness of less than 160 Angstroms, and the GO flakes have no physical surface distortions and no epoxy functionalization.

20 Uniform distribution, dispersion and/or entrainment of graphene/graphite functionalized flakes within the host, e.g. cement or asphalt, can be achieved through several methods, including: use of an additional powder or multiple powder additives, mixing prior to reacting, casting or otherwise causing the powders to become ordered by thermal, chemical, electrical or other processes that induce order or bonding between the powders, e.g. solidified or gelled.

25 The functionalization can be an oxidation in the form of epoxied or carboxylic groups or other functionalization such as amine, fluorine, chlorine, or other chemicals that react with the host.

30 Chopped fibers can be used as an additive to enhance the mechanical performance of a composite. Chopped fibers have been used in composite hosts including: Plastics, cement, asphalt and other host materials used in composites. A wide number of fiber additives have been used for many years as a strength-enhancing additive in cement and asphalt they

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include: metal, plastic, glass, ceramic and CNT fibers to modify the physical characteristics. The fibers generally do not chemically react to the host material. The fibers provide mechanical enhancement by creating a tortuous threaded structure throughout the host on the millimeter/centimeter scale reinforcement. GO coated E-glass laminate has been shown to

have a large impact on the physical properties with only a 0.01 wt% GO before resin cure
1 200X increase in uniaxial flexural fatigue life 1-2 orders of magnitude better than SWNT
and MWNT 3 to 5X increase in tension fatigue life and 20-30% increased flexural strength.

5 While GO, rGO, CNTs and chopped fibers have been used separately and in some cases in
conjunction with each other to enhance the strength of the host. GO/rGO coated fibers have
never been used in cement and asphalt. Further, to date GO/rGO coated fibers have
apparently never been used as a strength-enhancing additive for any host.

The GO/rGO has a functionalization or decoration of COOH, epoxied or other functional
group that allows the GO_f/rGO_f to react with both the fiber and the host.

10 The functionalization is denoted by GO_f/rGO_f . Preferably the GO_f/rGO_f loading would be
greater than 0.01%(w) and preferably less than 1%(w) to the composite host material. The
 GO_f/rGO_f coated fibers react with the host creating a strength-enhanced region of the host
that when combined with other regions in the host have a macroscopic impact on the overall
physical properties.

15 In some embodiments, chopped fibers can be spray or dip coated with a GO_f/rGO_f
suspension. The suspension can have a concentration between 5% (w) and 0.0001%(w).
Thus the suspension is compatible with the fiber and has a reasonable vapor pressure to allow
ease of drying. Ethanol and acetone can be used as a suspension media. Utilizing a
compressor driven airbrush paint gun that produced droplets at 0.1mm droplet size at a rate of
20 1ml/min can be used to coat the chopped glass fiber. The chopped glass fiber is preferably
less than 6 cm in length and less than 0.5mm in diameter. The specific fiber length and
thickness can be chosen for the given final composite structure. The coated chopped fiber is
preferably air dried before incorporating into the cement or asphalt host. The cement or
asphalt host is then cured to optimize the strength. During the curing the GO_f/rGO_f material
25 can react with host material.

For cement, the epoxy and COOH groups chemically react with the calcium silica hydrate
(CSH) which is a nano scale gel in the cement. The GO_f/rGO_f material on the fiber catalyzes
CSH gel to grow into much larger crystal structures surrounding and extending the strength
around the fiber into three dimensions of the cement. The catalyzed CSH crystal structure
30 dramatically extends and improves the mechanical properties of the host cement. Similarly
the asphalt the GO_f/rGO_f material can react with thermal plastic (bitumen) within the asphalt,
dramatically extending and improving the mechanical properties of the host.

It is contemplated that any embodiment discussed in this specification can be implemented with respect to any method, kit, reagent, or composition of the invention, and vice versa. Furthermore, compositions of the invention can be used to achieve methods of the invention.

5 It will be understood that particular embodiments described herein are shown by way of illustration and not as limitations of the invention. The principal features of this invention can be employed in various embodiments without departing from the scope of the invention. Those skilled in the art will recognize, or be able to ascertain using no more than routine experimentation, numerous equivalents to the specific procedures described herein. Such equivalents are considered to be within the scope of this invention and are covered by the
10 claims.

The use of the word “a” or “an” when used in conjunction with the term “comprising” in the claims and/or the specification may mean “one,” but it is also consistent with the meaning of “one or more,” “at least one,” and “one or more than one.” The use of the term “or” in the
15 alternatives are mutually exclusive, although the disclosure supports a definition that refers to only alternatives and “and/or.” Throughout this application, the term “about” is used to indicate that a value includes the inherent variation of error for the device, the method being employed to determine the value, or the variation that exists among the study subjects.

As used in this specification and claim(s), the words “comprising” (and any form of
20 comprising, such as “comprise” and “comprises”), “having” (and any form of having, such as “have” and “has”), “including” (and any form of including, such as “includes” and “include”) or “containing” (and any form of containing, such as “contains” and “contain”) are inclusive or open-ended and do not exclude additional, unrecited elements or method steps. In embodiments of any of the compositions and methods provided herein, “comprising” may be
25 replaced with “consisting essentially of” or “consisting of”. As used herein, the phrase “consisting essentially of” requires the specified integer(s) or steps as well as those that do not materially affect the character or function of the claimed invention. As used herein, the term “consisting” is used to indicate the presence of the recited integer (e.g., a feature, an element, a characteristic, a property, a method/process step or a limitation) or group of
30 integers (e.g., feature(s), element(s), characteristic(s), propertie(s), method/process steps or limitation(s)) only.

The term “or combinations thereof” as used herein refers to all permutations and combinations of the listed items preceding the term. For example, “A, B, C, or combinations thereof” is intended to include at least one of: A, B, C, AB, AC, BC, or ABC, and if order is important in a particular context, also BA, CA, CB, CBA, BCA, ACB, BAC, or CAB.

5 Continuing with this example, expressly included are combinations that contain repeats of one or more item or term, such as BB, AAA, AB, BBC, AAABCCCC, CBBAAA, CABABB, and so forth. The skilled artisan will understand that typically there is no limit on the number of items or terms in any combination, unless otherwise apparent from the context.

As used herein, words of approximation such as, without limitation, “about”, “substantial” or
10 “substantially” refers to a condition that when so modified is understood to not necessarily be absolute or perfect but would be considered close enough to those of ordinary skill in the art to warrant designating the condition as being present. The extent to which the description may vary will depend on how great a change can be instituted and still have one of ordinary skilled in the art recognize the modified feature as still having the required characteristics and
15 capabilities of the unmodified feature. In general, but subject to the preceding discussion, a numerical value herein that is modified by a word of approximation such as “about” may vary from the stated value by at least $\pm 1, 2, 3, 4, 5, 6, 7, 10, 12$ or 15%.

All of the compositions and/or methods disclosed and claimed herein can be made and executed without undue experimentation in light of the present disclosure. While the
20 compositions and methods of this invention have been described in terms of preferred embodiments, it will be apparent to those of skill in the art that variations may be applied to the compositions and/or methods and in the steps or in the sequence of steps of the method described herein without departing from the concept, spirit and scope of the invention. All such similar substitutes and modifications apparent to those skilled in the art are deemed to
25 be within the scope of the invention as defined by the appended claims.

CLAIMS

What is claimed is:

1. A method of making a composite reinforcing fiber comprising:
providing flat graphene oxide (GO) flakes;
5 providing a reinforcing fiber;
providing a host material; and
coating the GO flakes on the reinforcing fiber;
wherein 95% of the GO flakes have a surface area to thickness ratio greater than 300
Angstroms and a thickness of less than 160 Angstroms, and wherein the GO flakes have no
10 physical surface distortions and no epoxy functionalization, and wherein surfaces of the GO
flakes have the same hydrophobicity as the host material.
2. The method of claim 1, wherein the GO flakes have an oxidation level greater than
1.5% by mass.
3. The method of claim 1, wherein the GO flakes have an oxidation level less than 1.5%
15 by mass.
4. The method of claim 1, wherein 95% of the GO flakes are greater than 0.8 and less
than 16 nanometers in thickness.
5. The method of claim 1, wherein the maximum dimension of the GO flakes is between
220 Angstroms and 100 microns.
- 20 6. The method of claim 1, wherein the GO flakes have edge oxidation.
7. The method of claim 1, further comprising the step of mechanochemically exfoliating
graphite into the GO flakes with a stirred media mill, wherein the stirred media mill is an
attrition mill or ball mill.
8. The method of claim 1, wherein the composite reinforcing fiber is used to make a
25 structure, further comprising:
air drying the coated reinforcing fiber;
incorporating the air dried coated reinforcing fiber into the host material;
forming the host material with the incorporated air dried coated reinforcing fiber into a
structure; and

adding water to react the host material with one or more materials that form concrete to form a concrete composite when cured.

9. The method of claim 8, further comprising the step of mixing the coated reinforcing fiber in the host material for at least 30 minutes in a sonic mixing system.

5 10. The method of claim 8, further comprising adding Bitumen or other non-polar material to react with the host material.

11. The method of claim 8, wherein the GO flakes have a mass greater than 0.00005% of the mass of the host material.