CLAIMS

1. A composite material comprising:

a structural matrix; and

a plurality of delignified, cellulose-based macrofibers disposed within the structural matrix, each cellulose-based macrofiber having been chemically-extracted intact from a matrix of lignin and hemicellulose that joined microfibrils of one or more macrofibers to parenchyma cells in a microstructure of a respective piece of natural bamboo,

wherein a content of lignin in each cellulose-based macrofiber is less than or equal to 4 wt%,

each cellulose-based macrofiber is separate and distinct from any other cellulose-based macrofiber extracted from the natural bamboo,

each cellulose-based macrofiber has a moisture content less than or equal to 10 wt%,

each cellulose-based macrofiber has a length of at least 5 cm, a diameter of at least 100 μm, and a density of at least 1 g/cm^3, and

each cellulose-based macrofiber exhibits a tensile strength of at least 1 GPa.

2. The material of claim 1, wherein the structural matrix comprises a polymer or concrete.

3. A composite material comprising:

a plurality of delignified, cellulose-based macrofibers, each cellulose-based macrofiber having been chemically-extracted intact from a matrix of lignin and hemicellulose that joined microfibrils of one or more macrofibers to parenchyma cells in a microstructure of a respective piece of natural bamboo; and

a polymer infiltrating each cellulose-based fiber,

wherein a content of lignin in each cellulose-based macrofiber is less than or equal to 4 wt%,

each cellulose-based macrofiber is separate and distinct from any other cellulose-based macrofiber extracted from the natural bamboo,

each cellulose-based macrofiber has a moisture content less than or equal to 10 wt%,

each cellulose-based macrofiber has a length of at least 5 cm, a diameter of at least 100 μm, and a density of at least 1 g/cm^3, and

each cellulose-based macrofiber exhibits a tensile strength of at least 1 GPa.

4. An engineered plant material comprising:

one or more delignified, cellulose-based macrofibers that have been chemically-extracted intact from a matrix of lignin and hemicellulose that joined microfibrils of one or more macrofibers to parenchyma cells in a microstructure of a respective piece of natural bamboo,

wherein a content of lignin in each cellulose-based macrofiber is less than or equal to 4 wt%,

each cellulose-based macrofiber is separate and distinct from any other cellulose-based macrofiber extracted from the natural bamboo,

each cellulose-based macrofiber has a moisture content less than or equal to 10 wt%,

each cellulose-based macrofiber has a length of at least 5 cm, a diameter of at least 100 μm, and a density of at least 1 g/cm^3, and

each cellulose-based macrofiber exhibits a tensile strength of at least 1 GPa.

5. The material of any one of claims 2 and 3, wherein the polymer comprises epoxy resin, polyvinyl alcohol (PVA), polyethylene glycol (PEO), polyamide (PA), polyethylene terephthalate (PET), polybutylene terephthalate (PBT), polytrimethylene terephthalate (PTT), polyacrylonitrile (PAN), polycaprolactam (PA6), poly(m-phenylene isophthalamide) (PMIA), poly-p-phenylene terephthalamide (PPTA), polyurethane (PU), polycarbonate (PC), polypropylene (PP), high-density polyethylene (HDPE), polystyrene (PS), polycaprolactone (PCL), polybutylene succinate (PBS), polybutylene adipate terephthalate (PBAT), poly(butylene succinate-co-butylene adipate) (PBSA), polyhydroxybutyrate (PHB), poly(3-hydroxybutyrate-co-3-hydroxyvalerate) (PHBV), poly(glycolic acid) (PGA), polypyrrole (PPy), polythiophene

(PTh), polyvinylidene fluoride (PVDF), polyvinyl fluoride (PVF), ethylene vinyl alcohol (EVOH), poly(vinylidene chloride) (PVDC), polyxylylene adipamide (MXD6), polyethylene (PE), polyvinyl chloride (PVC), poly(methyl methacrylate) (PMMA), acrylonitrile butadiene styrene (ABS), polyimide (PI), polyethylenimine (PEI), polylactic acid (PLA), octadecyltrichlorosilane (OTS), polyoctahedral silsesquioxane (POSS), paramethylstyrene (PMS), polydimethylsiloxane (PDMS), poly(ethylene naphthalate (PEN), a graft copolymer of acrylonitrile-butadiene-styrene-methylmethacrylate (ABSM), dodecyltrimethoxysilane (DTMS), rosin, chitin, chitosan, protain, plant oil, carboxymethyl cellulose, cellulose acetate, starch, agar, alginic acid, or any combination of the foregoing.

6. The material of claim 2, wherein the concrete comprises Portland cement, agro-concrete, magnesium carbonate ($MgCO_3$), magnesium hydroxide ($Mg(OH)_2$), or any combination of the foregoing.

7. The material of any one of claims 1-3, wherein a content of the plurality of the cellulose-based macrofibers within the composite material is at least 0.1 wt%.

8. The material of any one of claims 1-4, wherein the length of each cellulose-based macrofiber is between 5 cm and 200 cm, inclusive.

9. The material of any one of claims 1-4, wherein each cellulose-based macrofiber has a crystallinity of at least 50%.

10. The material of any one of claims 1-4, wherein each cellulose-based macrofiber has a Young's modulus of at least 60 GPa.

11. The material of any one of claims 1-4, wherein each cellulose-based macrofiber has a cellulose content of at least 70 wt% and a hemicellulose content less than or equal to 10 wt%.

12. The material of any one of claims 1-4, wherein provided on or within each cellulose-base macrofiber is a conductive additive, a magnetic additive, a piezoelectric material, a stimuli-responsive material, a catalytic material, or any combination of the foregoing.

13. A method comprising:

(a) subjecting a piece of natural bamboo to one or more chemical treatments so as to remove lignin therefrom, at least one of the one or more chemical treatments comprising partial or full immersion in one or more chemical solutions, the natural bamboo having a microstructure with a plurality of cellulose-based macrofibers, parenchyma cells, and a matrix of lignin and hemicellulose that joins microfibrils of the cellulose-based macrofibers to the parenchyma cells, the one or more chemicals treatments being effective to dissolve the matrix and break down the parenchyma cells such that the cellulose-based macrofibers are released; (b) after (a), extracting from the chemically-treated piece the plurality of cellulose-based macrofibers as individual, intact cellulose-based macrofibers separate and distinct from each other; and

(c) after (b), drying the cellulose-based macrofibers such that evaporation of water from each cellulose-based macrofiber causes self-densification thereof,

wherein, after (c):

a content of lignin in each cellulose-based macrofiber is less than or equal to 4 wt%,

each cellulose-based macrofiber has a moisture content less than or equal to 10 wt%,

each cellulose-based macrofiber has a length of at least 5 cm, a diameter of at least 100 μm, and a density of at least 1 g/cm^3, and

each cellulose-based macrofiber exhibits a tensile strength of at least 1 GPa.

14. The method of claim 13, wherein (b) comprises agitating the chemically-treated piece in solution.

15. The method of claim 13, wherein the one or more chemical solutions comprise an alkaline solution.

16. The method of claim 13, wherein (a) comprises:

(a1) immersing at least a first portion of the piece of natural bamboo within a first solution to remove some of the lignin in the immersed first portion; and

(a2) after (a1), immersing at least the first portion within a second solution to remove remaining lignin in the immersed first portion.

17. The method of claim 16, wherein:

(i) the first solution comprises peroxyformic acid (CH_2O_3), and the second solution comprises sodium hydroxide (NaOH) or potassium hydroxide (KOH); or

(ii) the first solution comprises a mixture of potassium hydroxide (KOH) and sodium sulfite (Na_2SO_3), a mixture of potassium hydroxide (KOH) and sodium sulfide (Na_2S), a mixture of sodium hydroxide (NaOH) and sodium sulfite (Na_2SO_3), or a mixture of sodium hydroxide (NaOH) and sodium sulfide (Na_2S), and the second solution comprises a mixture of hydrogen peroxide (H_2O_2) and acetic acid ($C_2H_4O_2$), or a mixture of hydrogen peroxide (H_2O_2) and formic acid (CH_2O_2).

18. The method of claim 13, further comprising, after (c):

infiltrating a polymer into each cellulose-based macrofiber to form a composite material; or

embedding each cellulose-based macrofiber within a structural matrix to form a composite material, wherein the structural matrix comprises a polymer or concrete.

19. The method of claim 13, wherein, after (c), the length of each cellulose-based macrofiber is between 5 cm and 200 cm, inclusive.

20. The method of claim 13, wherein, after (b), the plurality of cellulose-based macrofibers remain attached to a base portion of the natural bamboo, and the method further comprises severing the cellulose-based macrofibers from the base portion.