Claims

1. A composite material in the form of a bead, comprising:

a polyethyleneimine;

graphene oxide; and

zeolite nanoparticles, wherein:

the bead has a hollow core and a layered shell structure comprising a plurality of layers of graphene oxide and a plurality of layers of polyethyleneimine, where any two layers of graphene oxide are separated by a layer of polyethyleneimine and the zeolite nanoparticles are intercalated between the plurality of graphene oxide layers;

the polyethyleneimine is crosslinked by a negatively charged crosslinking agent, the negatively charged crosslinking agent is hyaluronic acid; and

the polyethyleneimine is a branched polyethyleneimine.

2. A composite material in the form of a bead, comprising:

a polyethyleneimine; and

graphene oxide, wherein:

the bead has a hollow core and a layered shell structure comprising a plurality of layers of graphene oxide and a plurality of layers of polyethyleneimine, where any two layers of graphene oxide are separated by a layer of polyethyleneimine;

covalent bonds are formed between the polyethyleneimine and the graphene oxide to crosslink the polyethyleneimine to the graphene oxide; and

the polyethyleneimine is a branched polyethyleneimine.

3. The composite material according to Claim 1, wherein the weight to weight ratio of the graphene oxide to the zeolite nanoparticles is from 1:1 to 1.4:1, such as about 1.33:1.

4. The composite material according to any one of the preceding claims, wherein the weight to weight ratio of the polyethyleneimine to graphene oxide is from 1:1 to 1.4:1, such as about 1.36:1.

5. The composite material according to any one of Claim 1, Claim 3 and Claim 4, as dependent upon Claim 1, wherein the zeta potential of the composite material is from +19 to +28 mV.

6. The composite material according to any one of Claim 1, Claim 3 and Claims 4 to 5 as dependent upon Claim 1, wherein the composite material has an ammonia adsorption capacity of from 7 to 19 mg/g, such as about 8.24 mg/g.

7. The composite material according to Claim 2 and Claim 4 as dependent upon Claim 2, wherein the zeta potential of the composite material is from +27 to +39 mV.

8. Use of a composite material according to any one of Claims 1 to 7 in aquaculture.

9. A method of aquaculture comprising the steps of:
(a) providing an aquaculture medium; and
(b) placing a plurality of beads of a composite material according to any one of Claims 1 to 7 into the aquaculture medium.

10. A method of manufacturing a composite material according to Claim 1 and Claims 3 to 6, as dependent upon Claim 1, wherein the method comprises the steps of:
(i) providing a mixture comprising a suspension of graphene oxide and zeolite nanoparticles in a liquid;
(ii) adding a plurality of droplets of branched polyethyleneimine to the mixture to provide beads comprising graphene oxide, zeolite nanoparticles and branched polyethyleneimine; and
(iii) ionically crosslinking the branched polyethyleneimine in the beads with a negatively charged crosslinking agent to provide the composite material,
wherein the negatively charged crosslinking agent is hyaluronic acid.

11. The method according to Claim 10, wherein the weight to weight ratio of graphene oxide to zeolite nanoparticles in the liquid is from 1:2 to 2:1, such as 1:1.

12. A method of manufacturing a composite material according to Claim 2 and Claims 4 and 7, as dependent upon Claim 2, wherein the method comprises the steps of:
(i) providing a mixture comprising a suspension of graphene oxide in a liquid;
(ii) adding a plurality of droplets of branched polyethyleneimine to the mixture to provide beads comprising graphene oxide and branched polyethyleneimine; and
(iii) covalently crosslinking the branched polyethyleneimine in the beads to the graphene oxide with a crosslinking agent to provide the composite material.

13. The method according to any one of Claims 10 to 12, wherein the weight to weight ratio of the graphene oxide to polyethyleneimine is from 2:1 to 1:2, such as about 1.19:1.

14. The method according to Claim 12 or Claim 13, as dependent upon Claim 12, wherein the crosslinking agent is a carbodiimide (e.g. 1-ethyl-3-(3-dimethylaminopropyl)carbodiimide).