Claims

1. A microcapsule encapsulating a phase change material comprising:

a core encapsulated by a first shell and a second shell, where the first shell is sandwiched between the second shell and the core, wherein:

the core comprises a phase change material that undergoes a phase change at from 0ºC to 200ºC;

the first shell is an organic polymeric material;

the second shell is an inorganic material; and

the core further comprises carbon nanotubes.

2. The microcapsule of Claim 1, wherein the phase change material undergoes a phase change at from 5ºC to 150ºC.

3. The microcapsule of Claim 1 or Claim 2, wherein the phase change material is an organic material.

4. The microcapsule of Claim 3, wherein the organic material is a C_{14}-C_{45} paraffinic hydrocarbon.

5. The microcapsule of any one of the preceding claims, wherein the organic polymeric material comprises functional groups that are cationic in aqueous media, optionally wherein the functional groups are cationic in aqueous media at a pH of from 2.0 to 5.0, such as from 2.5 to 4.0, such as 3.0.

6. The microcapsule of Claim 5, wherein the organic polymeric material comprises a polyurea formed from a polyimine and an organic diisocyanate.

7. The microcapsule of Claim 6, wherein the organic polymeric material comprises a polyurea formed by the reaction between hexamethylene diisocyanate and polyethylenimine, optionally wherein the weight average molecular weight of the polyethylenimine is from 800 Daltons to 3,000 Daltons, such as from 1,000 Daltons to 2,000 Daltons, such as 1,300 Daltons.

8. The microcapsule of any one of the preceding claims, wherein the microcapsule has one or more of the following features:

(a) the inorganic material is silica;

(b) the microcapsule has an average size of from 50 µm to 500 µm, such as from 75 µm to 450 µm, 100 to 400 µm;

(c) the first shell has a thickness of from 75 to 250 nm;

(d) the second shell comprises spheres of the inorganic material having a diameter of from 100 to 500 nm; and

(e) the core material comprises from 60 to 85 wt% of the microcapsule.

9. A formulation comprising a microcapsule encapsulating a phase change material as defined in any one of Claims 1 to 8, wherein the formulation is a paint formulation, a cement formulation or a concrete formulation.

10. A process of making a microcapsule encapsulating a phase change material, comprising the steps of:

(a) providing an aqueous emulsion comprising a first organic material that is water-immiscible, a phase change material and a surfactant;

(b) adding a second organic material to the aqueous emulsion to form polymeric pre-microcapsules having a core comprising the phase change material and an organic polymeric shell, through the reaction of the first and second organic materials together in a polymerisation reaction; and

(c) adding an inorganic monomeric material to the polymeric pre-microcapsules to form an inorganic shell around each polymeric pre-microcapsule under conditions that cause polymerisation of the inorganic monomeric material to provide a microcapsule encapsulating a phase change material, wherein:

before step (a) the phase change material is pre-mixed with carbon nanotubes;

the conditions of step (c) cause self-assembly of the inorganic shell on the organic polymeric shell due to attractive electrostatic interactions between the organic polymeric shell and the inorganic monomeric material; and

the phase change material undergoes a phase change at from 0ºC to 200ºC.

11. The process of Claim 10, wherein:

(a) the surfactant is a non-ionic surfactant, optionally wherein the non-ionic surfactant is selected from one or more of the group consisting of arabic gum polyethylene oxide lauryl ether 30, sorbitan oleate, sorbitan 80, and polyoxyethylene sorbitol Yu monooleate 80 mixture; and/or

(b) the phase change material undergoes a phase change at from 5ºC to 150ºC.

12. The process of Claim 10 or Claim 11, wherein the phase change material is an organic material, optionally wherein the organic material is a C_{14}-C_{45} paraffinic hydrocarbon.

13. The process of any one of Claims 10 to 12, wherein the first and second organic materials, following reaction together, provide an organic polymeric material comprising functional groups that are cationic in aqueous media, optionally wherein the functional groups are cationic at a pH of from 2.0 to 5.0, such as from 2.5 to 4.0, such as 3.0.

14. The process of Claim 13, wherein the first organic material is an organic diisocyanate and the second organic material is a polyimine, optionally wherein the first organic material may be an hexamethylene diisocyanate and the second organic material may be a polyethylenimine.

15. The process of any one of Claims 10 to 14, wherein the microcapsule produced by the process has one or more of the following features:

(A) the inorganic monomeric material is a silica precursor;

(B) the microcapsule provided in step (c) of Claim 10 has an average size of from 50 to 500 µm, such as from 75 to 450 µm, 100 to 400 µm;

(C) the organic polymeric shell has a thickness of from 75 to 250 nm;

(D) the inorganic shell comprises spheres of the polymerised inorganic monomeric material having a diameter of from 100 to 500 nm; and

(E) the phase change material comprises from 60 to 85 wt% of the microcapsule.

16. The process of any one of Claims 10 to 15, wherein in step (a) of Claim 10, the aqueous emulsion comprising a first organic material that is water-immiscible, a phase change material and a surfactant is provided by:

(i) providing an aqueous solution of a surfactant under stirring at a stirring speed of from 200 to 4000 RPM; and

(ii) providing a mixture of the first organic material and the phase change material and adding it to the stirred aqueous solution of the surfactant.

17. The process of Claim 16, wherein step (ii) is conducted at a temperature of from 30 to 60 °C, such as 50 °C.

18. The process of any one of Claims 10 to 17, wherein:

(i) step (b) of Claim 10 is conducted at a temperature of from 30 to 60 °C, such as 50 °C; and/or

(ii) step (c) of Claim 10 is conducted at a pH of from 2.0 to 5.0, such as from 2.5 to 4.0, such as 3.0; and/or

(iii) step (b) of Claim 10 is conducted at a temperature of from 25 to 40 °C, such as 35 °C.