

A COMPOSITE MATERIAL FOR REDUCING TEMPERATURE GAIN AND/OR INCREASING ATMOSPHERIC CONDENSATION ON A SURFACE OF A SUBSTRATE

Field of Invention

The invention relates to a composite material for reducing temperature gain and/or for increasing
5 atmospheric condensation on a surface of a substrate. The composite material may be used for passive cooling when exposed to the sky and/or is suitable for increasing atmospheric condensation on a surface of a substrate. In particular, the composite material when applied to a substrate (such as in the form of a single- or multi-layered coating) may be suitable for atmospheric water harvesting (AWH).

Background of the Invention

10 The stable, sustainable supply of clean water is one of this century's most significant global challenges. While desalination can supplement water consumption during prolonged draught, it is energy-intensive and requires a high capital investment, and is only suited to coastal locations. Identifying a new sustainable source of water will help alleviate water shortages in the future.

Harvesting water from humid ambient air or atmospheric water harvesting (AWH) offers an alternative
15 to the conventional means of obtaining water. Water can be harvested from the air using various methods. AWH technology, if successfully exploited on a large scale, could potentially have enormous, sustainable economic and environmental consequences by supporting livelihoods and farming, especially those in remote regions. It could provide drinking water for people, for farm animals and for wild animals, and have the potential to increase water use efficiency for irrigation in green houses and
20 other horticultural settings and for delicate water-sensitive crops such as seedlings.

The most common AWH methods presently known in the art are (i) active condensation, i.e., cooling the air below its dew point or (ii) absorption via desiccants. However, these methods generally require an external source of energy either to provide active cooling in the case of the condensation technique or to drive captured water from the desiccants for harvesting.

25 Despite a variety of scientific efforts to realise AWH on a scale that can have societal impact, two outstanding scientific challenges limit its use: (1) water condenses only on cold surfaces, which require a continuous supply of energy; and (2) in order to collect large volumes of water, the collecting devices need to cover a large area (i.e. several m² and above).

Accordingly, there is a need for developing materials for AWH that may provide passive cooling to surfaces and that may be suitable for fabricating large scale collection areas in a cost effective manner. These materials should also provide increased or improved atmospheric water collection on surfaces. There is also a need for developing surfaces that facilitate the condensation of water in other
5 applications, such as for example in a desalination plant. There is also a need for developing surfaces that may use active cooling obtained through the use of solar cells that provide additional cooling power to the surface and therefore increased water collection yield.

In addition, there is a need to cool structures in hot climates in order to reduce the heat island effect, due to re-emission of heat from hot roofs; for buildings in which the roof is not insulated, such as sheds
10 or warehouses, there is a need to cool buildings with the use of reduced energy, and/or to increase the efficiency of the cooling of a structure, by using functional coatings.

It is well known that (especially solar) radiation provides a significant source of heat to exposed surfaces that, over time, typically deteriorate as a result. For instance, surface coatings and materials may become brittle when exposed to (especially solar) radiation leading to costly replacement cycles. Part of
15 that deterioration may be due to UV radiation chemically modifying the surface coatings and materials, part of that deterioration may be due to thermal expansion/contraction associated with heat gain and loss, and part of that deterioration may be due to the available heat accelerating the rate of decomposition of the surface coatings and materials by providing sufficient activation energy for degradative processes.

20 When an exterior surface is exposed to airborne particles the surface may become dirty over time, as undesired contaminating particles accumulate on the surface. This accumulation of undesired contaminating particles on the surface is not aesthetically pleasing, may damage the surface, and/or reduce the performance of a surface where it is functional. While that surface may be manually cleaned on a regular basis, doing so can be difficult and/or costly, particularly where access is challenging. As
25 such it might be considered that a self-cleaning coating on a surface could be provided to facilitate the removal of undesired contaminating particles from the surface. A self-cleaning coating may increase the lifespan of surfaces by: reducing undesired contaminating particle accumulation and corrosion; provide an environmental benefit by reducing the water required for cleaning along with chemical compounds such as surfactants to aid in cleaning; and/or reduce maintenance costs. Such a self-cleaning coating
30 would be highly desirable. It is an object of the invention to address and/or ameliorate at least one of the above problems.

Alternatively, or in addition, it is an object to provide a material that provides passive cooling.

Alternatively, or in addition, it is an object to provide a system for reducing the (rate and/or degree of) deterioration of a surface coating or material exposed to (especially solar) radiation.

Alternatively, or in addition, it is an object to provide a material that helps to facilitate atmospheric
5 water capture (AWH).

Alternatively, or in addition, it is an object to provide a material that is self-cleaning.

Alternatively, it is an object of the invention to at least provide the public with a useful choice.

Summary of the Invention

The present disclosure describes a composite material (that may be used as at least part of a coating
10 system) to reduce the increase in temperature due to (especially solar) radiation of a substrate to which
it is applied, particularly when compared with the increase in temperature of the substrate due to
(especially solar) radiation when the composite material is not applied. The reduction in increase in
temperature is believed to be due to the composite material having a high reflectivity, particularly when
compared with the reflectivity of the substrate itself, or the reflectivity of other materials that may be
15 applied to the substrate.

As used herein a “composite material” refers to a type of material that is produced from two or more
component materials having different physical or chemical properties. Two examples of composite
materials are: a mixture of particles of one material within a binder matrix of a different material; and
the combination of two or more layers of material – at least two of the layers being different physically
20 or chemically. In numerous embodiments, the composite materials of the invention can be provided as
surface coatings. Such coatings may consist of one or more layers of material.

The present disclosure describes a composite material (that may be used as at least part of a coating
system) to emit energy derived from (especially solar) radiation to space. Typically the amount of energy
emitted to space is greater than would be emitted from a substrate to which the composite material is
25 applied. For example, where the composite material is provided as a coating on an exterior surface such
as the roof of a building, the amount of energy emitted to space by the exterior surface coated in the
composite material is greater than would be emitted from the exterior surface without the composite
material coating.

In a first aspect the invention provides a composite material including:

- a water dispersible binder;
- particulate material having a critical pigment volume concentration (CPVC); and
- voids;

- 5 wherein the particulate material is bound by the binder, and the pigment volume concentration (PVC) of the particulate material is higher than the CPVC so as to provide a composite material having voids that form from 1% to 40% by volume of the composite material.

- As described in further detail below, the term “water dispersible binder” as used herein means that at some stage prior to being used in the composite material the binder may have been, or was capable of
10 being, dispersed in water. It is typically not possible to redisperse the binder in the composite material once it has been at least partially dried, such as when the composite material is solid.

- Examples of water dispersible binders of the present invention include those that include hydrophilic moieties that have assisted in dispersal of the binder in an aqueous carrier prior to at least partially drying. Examples of hydrophilic moieties are polar functional groups such as hydroxyl, carbonyl,
15 carboxyl, amino, phosphate, amido, ester, and ether. Examples of polar functional groups include those provided in acrylate groups, acetate groups and silicone groups. Polymers that may be used as water dispersible binders include an acrylic polymer; a polyvinylidene fluoride (PVDF)-acrylic copolymer; styrene-acrylic copolymer; polyvinyl acetate copolymer; vinyl-acrylic copolymer; and a silicone (co)polymer.

- 20 Preferably the ratio of volume of particulate material to volume of binder is from 1:1 to 10:1.

In a second aspect the invention provides a composite material including:

- a water dispersible binder;
- particulate material; and
- voids;

- 25 wherein particulate material is bound by the binder, and the ratio of volume of particulate material to volume of binder is from 1:1 to 10:1, and the voids form from 1% to 40% by volume of the composite material.

In a third aspect the invention provides a dispersion including:

- an aqueous carrier;
- a water dispersible binder;
- particulate material;

5 wherein the binder is selected from: an acrylic polymer; a polyvinylidene fluoride (PVDF)-acrylic copolymer; styrene-acrylic copolymer; polyvinyl acetate copolymer; vinyl-acrylic copolymer; and a silicone (co)polymer;

and wherein the particulate material is selected from: calcium carbonate; barium sulphate; talcum powder; kaolin clay; huntite; wollastonite; boron nitride; silica; zinc oxide; zinc phosphate and titanium
10 dioxide; or a combination thereof.

In a further aspect the invention provides a dispersion for use in preparing a composite material according to the first aspect or the second aspect.

In a fourth aspect the invention provides a method of forming a composite material, the method including the steps of spreading onto a substrate a dispersion including:

- 15
- an aqueous carrier;
 - a water dispersible binder;
 - particulate material;

so as to form a composite material including:

- 20
- the water dispersible binder;
 - the particulate material having a critical pigment volume concentration (CPVC); and
 - voids;

wherein the particulate material is bound by the binder, and the pigment volume concentration (PVC) of the particulate material is higher than the CPVC so as to provide a composite material having voids that form from 1% to 40% by volume of the composite material.

25 The method of the fourth aspect will typically also include a step of allowing the dispersion spread on the substrate to harden by drying or curing so as to form a composite material. Such hardening by drying or curing may occur by such that the composite material is substantially free of low boiling point

carriers (such as those having a boiling point below about 180 °C). Preferably the composite material will be hardened so that it is substantially free of at least 90%, such as at least 95%, such as at least 99% of the water used as a carrier in the dispersion.

In a fifth aspect the invention provides a method of forming a composite material, the method including
5 the steps of spreading onto a substrate a dispersion including:

- an aqueous carrier;
- a water dispersible binder;
- particulate material;

so as to form a composite material including:

- 10
- the water dispersible binder;
 - the particulate material having a critical pigment volume concentration (CPVC); and
 - voids;

wherein particulate material is bound by the binder, and the ratio of volume of particulate material to volume of binder is from 1:1 to 10:1, and the voids form from 1% to 40% by volume of the
15 composite material.

The method of the fifth aspect will typically also include a step of allowing the dispersion spread on the substrate to harden by drying or curing so as to form a composite material.

It has now been found that the use of a composite material of the invention (including that of the first, second, and ninth aspects of the invention) provides one or more significant advantages, including:

- 20
- by being water dispersible, a substantially aqueous carrier may be used to spread a mixture of the binder and particulate material over a substrate with a reduced amount of volatile organic compounds (VOCs), compared with (organic) solvent-borne binders, if any at all. In turn, the spreadable mixture is available at a lower cost; is more user friendly; and/or is more environmentally friendly;
- 25
- when applied to a surface exposed to (especially solar) radiation, the composite material is significantly cooler than would otherwise be expected using either a traditional paint covering, for example, or even no covering on the surface. As referred to herein this property may be referred to as “reducing temperature gain” on a surface of a substrate. In some cases, the

temperature difference may be 3-6 °C less than the atmospheric temperature, and at least 30 °C less than a traditional black paint covering during daytime as well as night-time. Without wishing to be bound by theory, this effect is believed to be the result of the surface absorbing less (especially solar) radiation (if at all) and/or emitting heat at a wavelength that is transferred to the coldness of space. More specifically, the composite material of the invention typically provides a radiative cooling function provided by the action of:

- reflecting the majority of incident (especially solar) radiation (preferably having a reflectance of over 92% (more preferably over 93%, such as over 95%) in the wavelength range of 0.3-2.5 μm); and/or
- emitting strongly in the wavelengths where earth's atmosphere is transparent (preferably having an emissivity of over 95% in the wavelength range of 8-13 μm , known as the atmospheric window).

One advantage in minimising the temperature of a surface exposed to (especially solar) radiation is to provide energy savings by reducing the need to cool infrastructure and/or reduce damage to surfaces caused by elevated temperature and/or (especially solar) radiation; and/or

- under suitable environmental conditions of temperature, humidity, wind, and (especially solar) irradiation, the composite material can become cooler than the dewpoint temperature, and then start to condense atmospheric water in the form of droplets (dew collection). If the droplets are collected in collection tanks, a new source of water can be obtained. This process may be referred to as Atmospheric Water Harvesting (AWH) and is especially advantageous in providing a decentralized, clean water supply.

Where the composite material is applied to a surface, particularly for AWH, it may be advantageous to enhance the properties of the material by providing the composite material with a surface coating to provide one or more of the following function(s):

- providing chemical and/or mechanical resistance towards erosion sources including airborne contaminants, dirt, physical impacts, rain, coastal wind carrying high concentrations of salt, etc;
- be compatible with condensation of water from moisture in the air;
- promote roll-off of condensed water droplets;
- seal the porosity on the surface of the composite material;
- provide self-cleaning properties; and/or
- radiate heat in the atmospheric window with high emissivity.

Any such surface coating ideally does not substantially modify the structure of the composite material defined herein, such as by filling/infusing a substantial (or any) number of the voids of the composite material. Nonetheless, the surface coating may provide a smoother surface (than that of the composite material) for contact with any water that condenses on the surface coating.

5 Accordingly in a sixth aspect the invention provides a coating system for coating at least part of a substrate, including:

- a composite material of the invention applied to a substrate; and
- a surface coating applied to the composite material.

For the avoidance of doubt, the composite material will typically be interposed between the surface
10 coating and the substrate in such a system.

While the surface coating may be applied initially as a solid material which is placed over the composite material (such as a sheet of suitable material), it is typically applied (such as spread) as a liquid to the composite material so that it may then harden by drying or curing, for example.

Accordingly, in a seventh aspect the invention provides a method of applying the coating system of the
15 sixth aspect, the method including the steps of performing the method of the fourth or fifth aspect of the invention so as to provide a composite material of the invention prior to performing the additional step of applying a liquid to the surface of the composite material, such that the liquid becomes the surface coating.

As used herein the substrate may refer to any surface upon which the coating material is to be applied,
20 and includes metal (such as aluminium, iron (including galvanised)); wood; tiles (including ceramic tiles); masonry; concrete; polymer membranes (such as those used as tents; umbrellas; fabric; nets; any material that can be rolled away for storage and transport); tubing and pipes; asphalt; glass; and combinations thereof. Typically the substrate will be substantially incapable of facilitating the movement of gases and/or liquids through itself. Typically the substrate will be solid, so that when
25 applied to the substrate the composite material does not act as a membrane through which gases and/or liquids may travel from one side of the composite material to the other side of the substrate. In some cases it may be beneficial to provide the substrate with a surface that promotes adhesion of the composite material to it. Such a surface may be provided by a primer, such as a commercially available primer. A primer may perform numerous functions including: sealing the underlying material, especially

in the case of porous materials such as wood; provide a more uniform/smooth surface to which the composite material (or a precursor dispersion) may be applied.

In numerous embodiments, the present invention may provide:

- a material that provides passive cooling;
- 5 • a system for reducing the (rate and/or degree of) deterioration of a surface coating or material exposed to (especially solar) radiation;
- a material that helps to facilitate atmospheric water harvesting (AWH);
- when provided at a sufficient angle to the horizontal, the low roll-off angle of the surface coating provides a self-cleaning material.

- 10 In an eighth aspect the invention provides a method for increasing atmospheric condensation on a surface coating, the method including the steps of:

- i) applying the coating system of the sixth aspect to a substrate so as to provide a substrate coated in the composite material and the surface coating;
- ii) exposing the composite material on the substrate to solar radiation so that water condenses on
15 the surface coating.

The method of the eighth aspect may be performed under atmospheric conditions having a relative humidity of about 30% or more, such as about 50% or more, but more preferably 70% or more.

- The method of the eighth aspect may also include the step of collecting at least some of the water that condenses on the surface coating. Such collected water may be transported to one or more collection
20 vessels.

- As used herein, the step of exposing any object (composite material, system, etc) of the invention to solar radiation will generally involve exposing the object to an unobstructed view of the sky, including under the sun. It will be appreciated that the advantages of the invention will generally be most noticeable when the object of the invention is exposed to heightened solar radiation, such as during
25 daylight, when the solar radiation from the sun is substantially unobstructed from being incident on the object – such as when there are few if any clouds present between the object and the sun.

As used herein the feature “so that water condenses on the surface coating” may be contemporaneous with the exposure of the object (composite material, system, etc) of the invention to solar radiation or may not be contemporaneous with the exposure of the object to solar radiation. In some embodiments, the maximal rate of water condensation may occur some hours after (such as 1 or more hours after, such as 2 or more hours after, such as 4 or more hours after, such as 8 or more hours after) the exposure to solar radiation. For instance, the object may be exposed to the solar radiation during daylight hours, and the maximal rate of water condensation may not occur until during the ensuing night-time. Nonetheless, it will be appreciated that it is the exposure to the sky, followed by emission of heat, that will generally lead to a temperature reduction that may lead to water condensing when the temperature of the object reaches the dewpoint, or falls below the dewpoint.

In a ninth aspect the invention provides a composite material including:

- a UV-Vis reflective sub-layer, including boron nitride; and
- a Vis-Near IR reflective sub-layer, including titanium dioxide.

The composite material of the ninth aspect may be considered as including a plurality of sub-layers. In this context plurality means two or more.

Conventional cool roof paints typically reflect no more than about 70% of overall light in the UV, Visible, and IR regions of the spectrum (0.3-2.5 μm wavelengths). Modern high performance coatings rarely (if ever) exceed 90% total reflectance across these wavelengths.

The solar spectrum could be further broken down to contributions from the various regions of the spectrum as follows: UV (~3.5%), Visible (~42%), and IR (~54.5%). As can be seen, the greatest contribution to solar gain is in the Visible and IR regions.

Advantageously the Vis-NIR reflective sub-layer of the present invention is exceptionally good at reflecting solar radiation in the Visible region – reflecting as much (or more) as 90% (such as at least 95%, such as at least 97%) of that incident radiation. As such, it is not particularly crucial in materials, systems, etc that incorporate a Vis-NIR reflective sub-layer for the UV-Vis reflective sub-layer to be highly reflective in visible range, as long as it is not absorbing. In the context of the present invention it has been found that the UV-Vis reflective sub-layer should reflect at least 30% of incident solar radiation in the UV region of the spectrum, such as at least 40%, such as at least 50%, such as at least 60%, such as at least 70%, such as at least 80%, such as at least 90%. Because of the relative contribution of the UV

region to total solar gain, this level of reflectivity may provide only about 1% extra solar reflectance compared to those systems lacking the UV-Vis reflective sub-layer and yet that contribution is still beneficial, and the contribution may be up to 3% for example.

Advantageously the Vis-NIR reflective sub-layer of the present invention may reflect as much as 80% of the incident solar radiation in the Vis-NIR region of the spectrum, such as at least 85%, such as at least 90%, such as at least 92%. When considering the relative reflectivity of the Vis-NIR reflective sub-layer of the present invention, optimally the sub-layer reflects at least 90% (such as at least 95%, such as at least 97%) of the incident radiation in the Visible region. When considering the relative reflectivity of the Vis-NIR reflective sub-layer of the present invention, optimally the sub-layer reflects at least 70% (such as at least 80%, such as at least 90%) of the incident radiation in the IR region (such as in the NIR region).

The boron nitride in the UV-Vis reflective sub-layer will typically be bound by a water dispersible binder.

The titanium dioxide in the Vis-Near IR reflective sub-layer will typically be bound by a water dispersible binder.

The composite material of the ninth aspect will generally be provided on a substrate. The UV-Vis reflective sub-layer may preferably be applied over the Vis-Near IR reflective sub-layer, such that the UV-Vis reflective sub-layer lies between a source of radiation and the Vis-Near IR reflective sub-layer.

In a tenth aspect the invention provides a multi-layered system including an optional primer layer; a layer of a composite material according to the ninth aspect; and a surface coating layer, wherein the order of the layers and sub-layers in the system is: primer layer where present; Vis-Near IR reflective sub-layer; UV-Vis reflective sub-layer; surface coating layer.

Each sub-layer of the composite material of the ninth aspect may be provided by applying a dispersion of the third aspect to a substrate (respectively including boron nitride as the particulate material for the UV-Vis reflective sub-layer; and including titanium dioxide as the particulate material for the Vis-Near IR reflective sub-layer) and allowing the dispersion to harden by drying or curing.

As such, in an eleventh aspect the invention provides a method of providing a composite material on a substrate, the method including the steps of:

- i) providing a substrate and spreading onto the substrate a first dispersion including:

- an aqueous carrier;
 - a water dispersible binder;
 - titanium dioxide;
- 5 ii) allowing the first dispersion applied to the substrate to harden, so as to provide a Vis-Near IR reflective sub-layer, including titanium dioxide;
- iii) spreading onto the Vis-Near IR reflective sub-layer a second dispersion including:
- an aqueous carrier;
 - a water dispersible binder;
 - boron nitride;
- 10 iv) allowing the second dispersion applied to the Vis-Near IR reflective sub-layer to harden, so as to provide a UV-Vis reflective sub-layer, including boron nitride.

In a twelfth aspect the invention provides a composite material applied on a substrate as provided by the method of the eleventh aspect.

- 15 In a thirteenth aspect the invention provides a method for increasing atmospheric condensation on a surface coating, the method including the steps of:

- i) applying the multi-layered system of the tenth aspect to a substrate so as to provide a substrate coated in the composite material and the surface coating;
- ii) exposing the composite material on the substrate to solar radiation so that water condenses on the surface coating.
- 20 The method of the thirteenth aspect may be performed under atmospheric conditions having a relative humidity of about 30% or more, such as about 50% or more, but more preferably 70% or more.

The method of the thirteenth aspect may also include the step of collecting at least some of the water that condenses on the surface coating. Such collected water may be transported to one or more collection vessels.

In a fourteenth aspect the invention provides a method for reducing temperature gain on a surface of a substrate due to solar radiation, the method including the step of interposing a composite material or a system according to the invention between the surface of the substrate and the solar radiation.

Typically the method of the fourteenth aspect will involve providing the composite material or system as
5 at least part of a coating on the surface of the substrate.

Advantageously the first dispersion of the invention may be applied directly to a range of substrates without those substrates needing to be primed. Such a dispersion may be considered self-priming. Self-priming dispersions are particularly beneficial since it reduces both labour and material costs. The Vis-Near IR reflective sub-layer of the invention may be particularly well-suited to being self-priming, as
10 described in more detail below.

While many of the advantages of the present invention are disclosed in relation to the use of a combination of a UV-Vis reflective sub-layer and a Vis-Near IR reflective sub-layer, it should be appreciated that the user may elect to use either layer in the absence of the other layer. For example, the user may elect to use the Vis-Near IR layer alone or as a layer in combination with one or more other
15 types of material. Similarly, the user may elect to use the UV-Vis reflective sub-layer alone or as a layer in combination with one or more other types of material

Further aspects of the invention, which should be considered in all its novel aspects, will become apparent to those skilled in the art upon reading of the following description which provides at least one example of a practical application of the invention.

20 **Brief Description of the Drawings**

One or more embodiments of the invention will be described below by way of example only, and without intending to be limiting, with reference to the following drawings, in which:

Figure 1 shows examples of shapes of particulate materials that may be used in the present invention;

Figure 2 shows a schematic cross section of a composite material of the invention, showing the location
25 of particulate material, binder, and voids;

Figure 3 shows scanning electron microscopy (SEM) micrographs visually demonstrating the relationship between film porosity and pigment volume concentrations (PVC);

Figure 4 shows how the total solar reflectivity changes versus film porosity for two examples of a composite material of the invention, where the films have been prepared using a Doctor Blade applicator wherein the gap size of the applicator is 200 μm (L2 200 μm) and 500 μm (L2 500 μm) thus providing wet film thicknesses of about 60-75% of those gap sizes;

- 5 Figure 5 shows the pore size distribution of three formulations, having PVC values of: 0.7 (figure 5(a)); 0.65 (figure 5(b)); and 0.6 (figure 5(c));

Figure 6 shows the measured spectral reflectivity across two spectral bands of different ranges (Figure 6(a) and 6(b)) of sub layers and a complete system of the invention;

- 10 Figure 7 shows Atomic Force Microscopy (AFM) micrographs for two repeats of an exemplary surface coating of the present invention demonstrating very low surface roughness (< 1 nm);

Figure 8 shows two scanning electron microscopy (SEM) micrographs demonstrating the cross-sectional structures of a Vis-Near IR reflective sub-layer of the composite material;

Figure 9 shows dispersed hexagonal platelet boron nitride and nano-scale hard shell polymer hollow sphere, in the presence of pores induced by the deficient polymer binder matrix;

- 15 Figure 10 shows micro-scale flexible shell expandable polymer hollow sphere, embedded in a deficient polymer binder matrix;

Figure 11 shows two SEM micrographs of hexagonal boron nitride (H-BN) nanoparticles (50 nm thick, diameter 500 nm) that may be included in the composite material to afford UV reflectance;

- 20 Figure 12 shows the individual HBN particles that have been dispersed and are now stabilised into minimal size particles;

Figure 13 shows emissivity of a system of the invention (primer, composite material, and surface coating system) of example 1 compared with a commercial black paint and a commercial white paint (Astec);

Figure 14 shows the subcooling measurement setup used to measure the performance of the invention;

- 25 Figure 15 shows the difference in temperature (left y-axis) of two surfaces (black commercial paint; and a 3-layered system of the present invention including primer, composite material, surface coating –

labelled as the “Dewpoint surface”) over two whole days, compared to the dew point temperature; the right y-axis shows the solar irradiance over the same two days.

Figure 16 shows the difference in temperature of two surfaces (black commercial paint; and a 3-layered system of the present invention including primer, composite material, surface coating – labelled as the
5 “Dewpoint surface”) compared to the ambient air (shade) temperature;

Figure 17 shows preliminary measurements of volume of dew collected on the Dewpoint surface on the morning of the 21st of February 2023 from a surface of area 40 cm²;

Figure 18 shows a dew collecting measurement setup;

Figure 19 shows preliminary cooling power measurements of the Dewpoint surface versus time over
10 two days of peak summer, together with the solar irradiation;

Figure 20 shows the impact of the use of a silicone material on the system of the invention;

Figure 21 shows the temperature (left y-axis) of two surfaces (black commercial paint; and a 3-layered system of Example 1 of the present invention including primer, composite material, surface coating – labelled as the “Dewpoint Formulation”) over two whole days, compared to the dew point temperature,
15 on a winter day in Sydney, Australia; the right y-axis shows the solar irradiance as shaded regions over the same two days;

Figure 22 shows the difference in temperature of two surfaces (black commercial paint; and a 3-layered system of Example 1 of the present invention including primer, composite material, surface coating – labelled as the “Dewpoint Formulation”) compared to the ambient air (shade) temperature;

20 Figure 23 shows preliminary measurements of volume of dew collected on the Dewpoint Formulation (3-layered system of Example 1) surface on the mornings of the 25th and 26th of July 2023;

Figure 24 shows a histogram of advancing and receding contact angle of a 3-layered system of Example 1 according to the invention;

Figure 25 shows the particle size distribution of sub-micron sized particulate material dispersion capable
25 of being used in the present invention;

Figure 26 shows the dynamic light scattering results for a binder that may be used in the invention;

Figure 27 shows a comparison of spectral reflectivity between Dewpoint 3-layer system prepared according to Example 1, and Dewpoint L2A single layer system within the solar wavelength range;

Figure 28 shows the temperature (left y-axis) of two surfaces (black commercial paint; and a Dewpoint L2A single layer system labelled as the "L2A") over two whole summer days in Sydney Australia,
5 compared to the dew point temperature; the right y-axis shows the solar irradiance as shaded regions over the same two days;

Figure 29 shows the difference in temperature of two surfaces (black commercial paint; and a Dewpoint L2A single layer system labelled as the "L2A") compared to the ambient air (shade) temperature over two summer days;

10 Figure 30 shows the total solar reflectivity of a 3-layered system according to example 1 of the invention (Dewpoint 3 layers); a composite material described in the scientific literature (OPUR), and two commercial composite paints (Astec and Acratex) over a period of 16 weeks. Advantageously the Dewpoint 3 layers coating exhibits a constant high solar reflectance throughout the period of study;

Figure 31 shows the emissivity of a 3-layered system according to example 1 of the invention (Dewpoint
15 3 layers; a composite material described in the scientific literature (OPUR); and two commercial composite paints (Astec and Acratex) over a period of 16 weeks. Beneficially the Dewpoint 3 layers coating retains a constant emissivity throughout the period of study;

Figure 32 shows the measured spectral reflectivity of a 3-layered system according to the invention as described in Example 1; a single layer system (Dewpoint L2A); and a dual layered system of sub layers
20 L2A-1 and L2B-1;

Figure 33 shows that the contact angle hysteresis of the 3-layer system of Example 1 is similar or lower than that OPUR and the commercial paints, Astec and Acratex. Moreover, the roll-off angle of the 3-layer system is lower than those of OPUR, Astec and Acratex;

Figure 34 shows the profile of a 50 μ L water droplet on the surfaces of a 3-layered system of Example 1
25 (Dewpoint 3 layers), a Vis-Near IR reflective single sub-layer of the composite material according to the present invention (Dewpoint L2A), and two commercial composite paints, Astec and Acratex;

Figure 35 shows the ability of the Vis-Near IR reflective single sub-layer Dewpoint L2A to resist soiling (dirt pick-up test) in comparison with the commercial roof paints Astec and Acratex;

Figure 36 shows the contribution to reflectivity from this dispersion as a function of thickness of the UV-Vis reflective sub-layer (Dewpoint L2B) at a composition for 20 % w/w of h-BN. Based on this data, a film thickness of 50 μm is sufficient to achieve maximum reflectivity across the range tested.

Detailed Description of the Invention

5 Composite Material

Particulate Material

The particulate material typically has a maximum dimension in the nanometre or micrometre scale, such as from 1 nm to less than 1 mm. Generally the particulate material has a maximum dimension from 100 nm to 80 μm . The particulate material may also be characterised with reference to the maximum or
10 minimum size of a nominal or actual mesh at which a fraction of the particles will fall. For example, a D98 value of more than 100 nm refers to 98% of the particulate material being more than 100 nm (such as by a mesh equivalent). Similarly, a D98 value of less than 80 μm refers to 98% of the particulate material being less than 80 μm (such as by a mesh equivalent). As used herein, the particle sizing may be
15 with reference to the maximum dimension of any particle in the bulk mixture of particulate material, or may refer to the D98 value. In a relatively uniform mixture of particles, the maximum dimension and D98 values will be approximately and substantially the same. To that end, it will be understood that the particulate material of the invention may include material of a range of particle sizes, and such a range may be referred to in the art as a particle size distribution. As used herein the particle size distribution may be described with reference to its polydispersity which may range from narrow to broad. The
20 particle size distribution may have a single mode, or be polymodal, such as bimodal. Without wishing to be bound by theory, it is believed that using a polymodal particle size distribution helps to facilitate optimal packing of the particulate material so as to provide voids of a desired dimension; and/or to provide optimal reflectivity for the composite material. To that end, it has been found that voids having a size of:

- 25
- at least 50 nm in largest dimension are particularly beneficial; or
 - at least 100 nm in largest dimension are particularly beneficial; or
 - at least 150 nm in largest dimension are particularly beneficial.

It has also been found that voids having a size of:

- at most 800 nm in largest dimension are particularly beneficial; or
- at most 600 nm in largest dimension are particularly beneficial; or
- at most 400 nm in largest dimension are particularly beneficial.

To that end, it has been found that voids having a size of approximately 150-400 nm in largest dimension is particularly beneficial. Voids having a size of approximately 150-400 nm in largest dimension may be provided using a bimodal particle size distribution wherein the two modes are centred around 600 nm and 20 μm , such as centred from 1 μm up to 20 μm .

The particulate material of the present invention is not particularly limited by shape. Examples of shapes of particulate materials that may be used in the present invention are shown in Figure 1, and include granular (Figure 1(a)), planar (Figure 1(b)), or acicular (Figure 1(c)) shape, for example. Any particle of the particulate material may have an aspect ratio (ratio of its major dimension and minor dimension) ranging from, for example, 1:1 to 1:30.

The selection of the shape of particulate material contributes to the spatial packing of particulate material and/or the flow properties of any liquid dispersion used to form the composite material. Advantageously, particulate material having one or more of the properties described herein may be used to apply a single coat of a liquid composition which may subsequently harden to form the composite material of the present invention.

Examples of materials that can be used as the particulate material of the present invention include natural, precipitated or modified sources of: calcium carbonate; barium sulphate; talcum powder; kaolin clay; huntite; wollastonite; boron nitride; silica; zinc oxide; zinc phosphate; and titanium dioxide; or a combination thereof. In addition to particulate materials made of these pure materials (and combinations thereof), the present invention also contemplates the use of modified variants of these pure materials as particulate materials of the invention. All such modified variants are contemplated herein. For instance, it is known that silica particles (which are normally hydrophilic) may be surface modified with hydrophobic groups so as to form hydrophobic silica. Fuming silica also provides distinct properties to the silica particles. Again, all such variants are contemplated.

In some embodiments the particulate material may be a hollow particulate material, such as hollow spheres (such as those made from a synthetic polymer) which encapsulate a gas, such as air. The hollow particulate material may encapsulate a void of size from around 150 nm to 30 μm in largest dimension, which in the case of a sphere is the diameter.

The particulate material of the present invention ideally demonstrates selective spectral properties. For instance, the particulate material is ideally:

- non absorptive within the solar radiation spectrum (0.3 - 2.5 μm), otherwise known as the UV-Vis region of the electromagnetic spectrum; and/or
- 5 • is emissive (>90%) in the atmospheric window (8 - 13 μm), otherwise known as the Vis-Near IR region of the electromagnetic spectrum.

It will be appreciated that some particulate materials (such as titanium dioxide, zinc oxide, and zinc phosphate) possess one of the above desired spectral properties, but not the other desired spectral property. Nonetheless, such materials may be used in the composite material of the present invention, particularly where the composite material is partitioned into discrete sub-layers. For example, despite
10 titanium dioxide (TiO_2) absorbing strongly at wavelengths <380 nm, it may still be used in the composite material of the invention, particularly where an intervening layer is placed between the titanium dioxide and the source of (especially solar) radiation so as to screen the titanium dioxide. By adopting this configuration, it is possible to make use of the beneficial properties of TiO_2 which include its high
15 refractive index, which provides superior scattering of visible and near IR wavelengths.

In some embodiments a plurality (two or more) of distinguishable particulate materials may be included in the composite material. For example, the composite material may include titanium dioxide and boron nitride. The composite material may include multiple grades of particulate material, or crystalline or amorphous forms of particulate material. All such combinations are contemplated by the present
20 invention.

Boron nitride (BN) is a thermally and chemically resistant refractory compound. In the present invention, hexagonal BN (H-BN, or h-BN) is preferably used. H-BN particles are hydrophobic, with a high tendency to agglomerate. For some of the applications of the present invention, since particle agglomerates reduce light scattering efficiency, it is desirable to breakdown H-BN agglomerates. While H-BN can be
25 dispersed in organic carriers, the use of such organic carriers, such as organic solvents, is disfavoured in the present invention which preferably uses an aqueous carrier. However very few approaches to dispersing H-BN have used aqueous carriers (such as water) without the use of surface active agents (surfactants). Previous approaches to creating dispersions of BN in aqueous carriers have involved chemically functionalising the BN to increase its hydrophilicity, such as by incorporating hydroxyl groups
30 on the BN. As used herein, such a form of BN is called functionalised BN. Such functionalisation is time

consuming, costly, and may adversely modify the spectral functionality of the BN for use in the present invention by reducing the ability to substantially reflect UV-Vis. On the other hand, the present inventors have identified systems for dispersing *unfunctionalized* H-BN in aqueous carriers which may use a dispersant to ideally stabilise the H-BN as primary particles (i.e. single platelets). For instance, selecting, optimising, and utilising a special polymeric additive (i.e. dispersant) in the formulation can help achieve optimal light scattering efficiency. Through this combination of features, the present invention may advantageously: i) retain the benefits of H-BN (over functionalised BN and the associated costs of producing that functionalised BN); and ii) is provided in an aqueous carrier thereby having a reduced amount of organic compounds, such as volatile organic compounds (VOCs), compared with (organic) solvent-borne systems, if any at all - in turn being provided at a lower cost; being more user friendly; and/or being more environmentally friendly.

Water Dispersible Binder

As used herein the expression "water dispersible" in relation to the binder is intended to refer to a binder polymer that is not substantially (if at all) soluble in water to any extent. In general terms, such binders are made in a separate process and supplied in a liquid form – namely of the binder dispersed in an aqueous carrier. The binder dispersion may be prepared through an emulsion polymerisation process. It is generally not readily possible (if at all) to convert a solid binder into a usable dispersion once dry. Accordingly, as used herein the expression "water dispersible binder" means that at some stage prior to being used in the composite material the binder was dispersed in water. Typically once included in the composite material the binder is not re-dispersible in water.

In general, the dispersed binder is dispersed more or less throughout the aqueous carrier such that no recognizable binder is recoverable from the aqueous carrier upon filtration (such as filtration with a filter pore size of 1 mm, such as 50 µm, such as 5 µm, for example).

A co-solvent may also be used to aid in the dispersion of the binder in the water, including providing a function such as: 1. Modulating (such as retarding) the evaporation of water to manipulate the drying time; 2. Suppressing the freeze point temperature (such as to below 0 °C) of the paint mixture to enable paint storage and/or application in cold climate; 3. Plasticising the binder after water dries out therefore assisting the film formation by binder coalescing. As such, where used any such cosolvent will typically be water-miscible. Examples of such water-miscible cosolvents includes alcohols, ketones, glycol ethers, esters and the like. Accordingly, as used herein the expression "aqueous carrier" contemplates the use

of: water alone as the carrier; and also mixtures of water and at least one cosolvent. Nonetheless, one of the numerous advantages provided by the present invention is that the binder is water dispersible meaning that the dispersion used to form the composite material may be provided with a low VOC (volatile organic compound) content if any at all. Preferably the VOC content in the dispersion is less than 100 g/L, preferably <5 g/L. To that end, a VOC content below 5 g/L can be called Zero VOC.

It is intended for this terminology to include conditions where the binder is dissolved to form a true solution as well as those where the binder is dispersed within the aqueous carrier. Typically at least some of the binder will not be dissolved, but will merely be dispersed in the aqueous carrier. More typically, most of the binder will not be dissolved, but will merely be dispersed in the aqueous carrier.

In some embodiments the binder will be a polymeric material that is not dissolved to any significant degree, and instead the polymer material is solely dispersed in the aqueous carrier. Without wishing to be bound by theory, such dispersed polymeric material may exist as a dispersion of particles of the binder in the aqueous carrier. It will be understood that the binder is typically a polydisperse polymeric material, and hence it is possible for the binder to provide a soluble fraction and a dispersed fraction when placed in an aqueous carrier.

Preferably the water dispersible binder is a film-forming polymeric material. For example, the binder may be selected from: an acrylic polymer; a polyvinylidene fluoride (PVDF)-acrylic copolymer; styrene-acrylic copolymer; polyvinyl acetate copolymer; vinyl-acrylic copolymer; and a silicone (co)polymer.

It will be appreciated that the binder may provide a binding function through any of a number of different mechanisms. For example, where the water dispersible binder is a polymeric material, the film forming function may be provided through entanglement of the polymeric chains. Such entanglement is caused, or accelerated during the drying or curing phase. In some embodiments the water dispersible binder may undergo a chemical transformation such as crosslinking during the drying or curing phase.

Typically the binder will demonstrate selective spectral properties. For instance, the binder will typically:

- be either non-absorptive or have minimal absorptivity (less than 5%, such as less than 2%) within the solar radiation spectrum (0.3 - 2.5 μm), otherwise known as the UV-Vis region of the electromagnetic spectrum; and/or

- be highly emissive (over 90% when present as a layer of pure binder at a thickness of 30 μm or above) in the atmospheric window (8 - 13 μm), otherwise known as the Vis-Near IR region of the electromagnetic spectrum

For some materials, and without limitation, the particulate material may have a refractive index contrast with the water dispersible binder of at least 0.1. Without wishing to be bound by theory, refractive index contrast results in incident (especially solar) radiation being bent when encountering an interface of particulate material and binder, which collectively contributes to the overall diffusive reflection of (especially solar) radiation by the composite material of the invention.

At the relatively low binder concentrations used in the present invention, it has been identified by the inventors that it is preferable for the binder to have good elasticity properties to accommodate potential stress from thermal expansion or other mechanical stimuli, while balancing those elastic properties with a tendency to attract and retain contaminants. Such elasticity helps the voids to maintain size/shape, and in turn provide substantially consistent reflectivity over time. It has been identified by the inventors that binders exhibiting a glass transition temperature (T_g) between -20 $^{\circ}\text{C}$ and 10 $^{\circ}\text{C}$ (such as around 0 $^{\circ}\text{C}$) are particularly well suited to providing the desired elasticity.

The binder will typically be provided as particles of a film-forming polymeric material. Such particles may preferably have a modal/peak size between 200 nm and 300 nm and a maximum dimension (or D98 value) of no larger than 5 μm . In such embodiments, the relatively small size of the binder assists in the formation of a substantially homogeneous mixture of binder and particulate material. Thus, the particulate material of high refractive index contrast may be spaced out by the binder in an advantageous manner.

Voids

The present inventors have realized that the combination of water dispersible binder, particulate material, and voids provides particular reflectivity and emissivity properties. In part, this effect is due to the presence of voids which provide the composite material with porosity. Without wishing to be bound by theory it is believed that reflectance is provided by the high refractive index contrast (preferably >0.5) between the gas (typically air) provided in the voids, and the particulate material and/or binder.

A schematic of that structure is provided in Figure 2 where the particulate material (2) is bound by a relatively small amount of binder (4) so as to generate voids (6).

In some embodiments of the composite material of the invention the particulate material is bound by the binder, however the binder is provided at a concentration that limits the ability of the binder to entirely coat the particulate material. In providing a limited concentration of binder, the composite material of some embodiments of the invention is provided with voids. The precise ratio of binder to particulate material so as to achieve the desired amount of voids will depend on a number of factors including the particulate material size distribution. For example, the so-called pigment volume concentration (PVC) of the particulate material may be higher than the critical PVC (CPVC) so as to provide a composite material having voids that form from 1% to 40% by volume of the composite material. By way of a further example, the ratio of volume of particulate material to volume of binder is from 1:1 to 10:1 (such as from 1:2 to 4:1), so as to provide a composite material having voids that form from 1% to 40% by volume of the composite material.

The skilled person will be familiar with calculating the CPVC of a material. For instance, The CPVC for a particulate material can be calculated from the oil absorption (OA) provided that the OA value is based on a non-flocculated dispersion. OA is expressed as grams of linseed oil per 100 grams of particulate material.

$$CPVC = \frac{1}{1 + (OA)(p)/93.5}$$

where p is the density of the particulate material, and 93.5 is 100 times the density of linseed oil (EU).

Figure 3 shows SEM micrographs visually demonstrating the relationship between film porosity and pigment volume concentrations (PVC). Figure 3(a) is a SEM micrograph of dry powders (nano hollow sphere and calcite) including no binder, and thus having a PVC value of 1. Figure 3(b) is a SEM micrograph of powders (nano hollow sphere and calcite) including some binder, such that the PVC has a value of 0.66. Figure 3(c) is a SEM micrograph of powders (nano hollow sphere and calcite) including some binder, such that the PVC has a value of 0.51. As shown, as the PVC decreases from 1 to 0.5, the amount of binder increases which results in less exposed pigment particle surfaces and consequently less open pores in the composite material, which may be a dried paint film.

When the composite material of the invention is provided by applying a dispersion of the invention on a substrate, such that the dispersion is laid down on the substrate as a wet film (such as a paint) having a

thickness, it has been possible to measure the effect of wet film thickness, and porosity on overall solar reflectivity, particularly after the film has hardened (by drying or curing, for instance). In two such examples of a composite material of the invention which are represented in Figure 4, where the films have been prepared using a Doctor Blade applicator wherein the gap size of the applicator is 200 μm (L2 200 μm) and 500 μm (L2 500 μm) thus providing wet film thicknesses of about 60-75% of those gap sizes, a positive correlation was seen between degree of porosity and solar reflectance. The porosity value is determined as a function of pigment volume concentration (PVC) and the results confirm that air pores due to the deficient binder matrix promotes scattering of light and therefore increase solar reflectivity.

10 Some of the inventors' further investigations into the role that pore size may play in affecting the functionality of the composite material of the invention centred on pore size distribution. Figure 5 shows the pore size distribution of three formulations, having PVC values of: 0.7 (figure 5(a)); 0.65 (figure 5(b)); and 0.6 (figure 5(c)). The porosity in the microscale is 50, 40 and 30%, respectively, whereas the nano pore volume fractions are 1%, 0.4% and 0.3%, as shown on the graphs.

15 *Sub-layers within the composite material*

In the course of developing the present invention, the inventors identified that the functionality of the composite material may be enhanced by providing the composite material with a plurality of sub-layers, such as two sub-layers, such that the sub-layers together form, typically, the whole of the composite material. In this context a sub-layer may be considered to be a layer that forms part of a composite material. The sub-layer may be internal within the composite material, or may partially or completely form an external surface of the composite material as context allows. In particular, the inventors identified that performance of the composite material can be maximised and/or cost of the composite material can be minimised, by providing the composite material as a combination of:

- 25 • a UV-Vis reflective sub-layer. Such a sub-layer may be configured to provide maximum reflectivity in the UV-Vis, such as at a wavelength of from 295 nm to 700 nm, for example. Such a sub-layer may incorporate: boron nitride; optionally in combination with calcite; and/or barium sulphate; and
- 30 • a Vis-Near IR reflective sub-layer. Such a sub-layer may be configured to provide maximum reflectivity in the visible and Near-IR. Advantageously, such a sub-layer may be configured to include particulate material that may, for example, absorb UV yet strongly yet reflect in visible

and Near-IR. Such a sub-layer may incorporate: titanium dioxide; optionally in combination with zinc oxide; and/or calcite.

Advantageously, in some embodiments the UV-Vis reflective sub-layer may be applied over the Vis-Near IR reflective sub-layer (such that the UV-Vis reflective sub-layer lies between the source of the
5 (especially solar) radiation and the Vis-Near IR reflective sub-layer) since it has been identified that the UV portion of the incident (especially solar) radiation may be filtered prior to reaching the UV absorptive components of the composite material.

The performance of such a system including sub-layers was shown to be advantageous for a number of reasons as discussed below.

10 That said, the composite material of the present invention does not always consist of multiple layers. In some embodiments, the composite material of the present invention may consist of a single layer. For example, the composite material the Vis-Near IR reflective sub-layer may be applied as a single layer. Advantageously, the Vis-Near IR reflective sub-layer has been identified as being self-priming – namely the Vis-Near IR reflective sub-layer can be applied directly to a substrate without the prior use of a
15 primer.

Figure 6 shows the measured spectral reflectivity across two spectral bands of different ranges (Figure 6(a) and 6(b)) of:

- a Vis-Near IR reflective sub-layer (containing titanium dioxide) – L2A;
- the UV-Vis reflective sub-layer (containing boron nitride) – L2B; and
- 20 • a complete system including a primer, composite material, and a surface coating – which may be referred to as having “3 layers”, although the composite material layer may include sub-layers as discussed below.

In these embodiments, the Vis-Near IR reflective sub-layer (L2A) is a 200 µm wet thickness film of the formulation described in Example 1 and the UV-Vis reflective sub-layer (L2B) is a 200 µm wet film
25 thickness of the formulation described in Example 1.

A complete system tested, the results of which are shown in Figure 6, consists of:

- a primer layer (L1);

- Sub-layer L2A – Example 1; having an exemplary dry film thickness around 80-100 micron (although without limitation it is believed that a dry film thickness of: at least about 50 micron such as at least about 60 micron; to a dry film thickness of about 500 micron, such as to about 200 micron; such as from about 50-500 micron, such as about 60-200 micron is useful);
- 5 • Sub-layer L2B – Example 1; having an exemplary dry film thickness around 80-100 micron (although without limitation it is believed that a dry film thickness of: at least about 20 micron such as at least about 60 micron, to a dry film thickness of about 200 micron; such as to about 100 micron, such as from about 20-200 micron, such as about 20-100 is useful); and
- 10 • Surface coating – Example 1 layers; having an exemplary dry film thickness about 30-40 micron (although without limitation it is believed that a dry film thickness of at least about 10 micron such as at least about 20 micron, to a dry film thickness of about 100 micron, from about 10-100 micron is useful).

In this example, a primer layer is provided on the test substrate prior to addition of sub-layer L2A of the composite layer, to facilitate/enhance adhesion of the composite layer to the substrate (although as
15 discussed above a primer is not always needed). Where a primer layer is used, the optical properties of the primer layer may be masked by the composite material so that its reflectivity does not affect the complete system to any significant degree (if at all).

Without wishing to be bound by theory it is believed that the most effective reflectivity wavelength of a composite layer is approximately double the maximum dimension of the particulate material used in the
20 composite layer. Hence, the Vis-Near IR reflective sub-layer (L2A) demonstrates high reflectivity in the visible and near IR region resulting from micron size particles of titanium dioxide and calcite pigments.

Because titanium dioxide has a strong absorption in UV wavelengths below 430 nm, in that region of the electromagnetic spectrum the reflectance of the L2A sub-layer diminishes to practically zero. This region consists of 5% of total solar energy which in summer days forms approximately 50 W/m² of solar energy
25 (1/3 of theoretical upper limit of the black body radiation emitted at room temperature).

The UV-Vis reflective sub-layer, containing boron nitride with sub-micron and nano-size size particles, is added as with the intention of reflecting this UV region and prevents the heating of the UV-Vis reflective sub-layer. The UV-Vis reflective sub-layer has some reflectivity in the near IR region but this is not detrimental because the drop in the reflectivity is minor.

30 This novel combination of:

- a Vis-Near IR reflective sub-layer (which may contain titanium dioxide, for example); and
- a UV-Vis reflective sub-layer (which may contain boron nitride, for example)

provides the combined advantages of maintaining reflectivity of the composite material in the UV wavelength (which would otherwise not be possible with the use of titanium dioxide throughout the composite material) without requiring the use of excessive amounts of boron nitride (preferably
5 hexagonal boron nitride, H-BN; especially unfunctionalized H-BN).

Some reduction of reflectivity is seen after coating the composite material with a surface coating, due to some absorption from the components in that coating. In this case, that loss in functionality is offset by the surface coating acts as durable layer to protect the paint from weathering as well as serving self-
10 cleaning properties.

In some embodiments, increasing the thickness of layers in the complete system may help with maintaining performance when exposed to environmental conditions; and/or increasing the reflectivity of the layer(s).

Further additives in the Composite Material

- 15 The properties of the composite material may be modified by the inclusion of further additives:
- For example, the present inventors have identified that the void structure of the composite material may be further fortified against any liquid ingressing/infusing into the voids to any substantial degree (if at all) when a liquid is applied to its surface, such as when a liquid formulation is applied with the intention of it forming a surface coating. It is preferable for such
20 a liquid formulation to be applied as a water-borne dispersion. To retard the ingress/infusion of any water-borne dispersion, it has been found to be preferable to include an agent for increasing the hydrophobic nature of the composite material in its matrix, herein referred to as a **hydrophobising agent**. Four examples of hydrophobising agents that may be used individually or in combination are the following:
- A silicone (co)polymer binder, which may optionally be fluorinated. The silicone (co)polymer binder may be provided at a weight ratio of 20-50% of the total binder
25 content in the composite material; and

- A siloxane based additive, which may optionally be fluorinated. Such an additive may be included at a weight ratio of 1-3% of the dispersion which may be used to form the composite material;
- A micronized wax, although this is thought to be less preferred than the above two examples due to possible reduced exterior surface stability.
- A modified colloidal silica dispersion, although this is thought to be less preferred than the above three examples.
- By way of further example, a **dispersant** may be incorporated in the composite material as an artefact of the dispersant being used to disperse the particulate material in the aqueous carrier of the dispersion of the invention. It has been identified that some particulate materials suitable for use in the invention have a strong tendency to agglomerate in the aqueous carrier, in part due to the small particle size, high surface area, and/or hydrophobic nature of the materials. Boron nitride in particular exhibits these problems. In turn, intermolecular forces between the particles may induce non-Newtonian rheology properties making it difficult to spread the dispersion, such as paint the dispersion on a substrate. To address, or even overcome, these problems a dispersant, such as a wetting agent, surfactant, and/or amphiphilic polymer may be used. In some embodiments a short chain amphiphilic polymer having a portion showing affinity for the binder, together with bulky side chains may be used with the intention of wetting the surface of the particulate material. In some embodiments, the dispersant may be premixed in an aqueous carrier prior to addition to the particulate material so as to promote optimal coverage. The dispersant may be used at any suitable ratio to the particulate material, including at from 2% to 200% by weight. It will be recognised that the skilled person, equipped with the above disclosure will be able to select an appropriate quantity of dispersant based on knowledge of the particle size, geometry, and surface area to weight ratio of the particulate material. Examples of dispersants that may be used in the present invention include: ethoxylated alcohol oligomer; and copolymers with pigment affinity groups (such as water-soluble and/or modified styrene-maleic acid copolymer, a copolymer with pigment-affinic group, a copolymer with pigment-affinic group, a blend of ethoxylated alcohols (e.g. C₁₄-C₁₅, C₉-C₁₁) and acetylene diol, an alkylol ammonium salt of a higher molecular weight acidic polymer).
- By way of further example, a **stabiliser** may be incorporated in the composite material as an artefact of the stabiliser being used to modify the characteristics of the dispersion of the invention. For instance, a layered synthetic silicate clay platelet (which may have an average diameter of 25 nm and thickness of 1 nm) may be included in the dispersion so as to modify the

characteristics by gelling the aqueous carrier by an electrostatic interaction. In turn the dispersion is provided with a pseudoplastic flow character, thus preventing the particulate material (especially) from settling after the dispersion is spread on a substrate, for example. An example of a rheology modifier is synthetic phyllosilicate. By way of a further example, a water softener (such as sodium hexametaphosphate) may be included in the dispersion to reduce unintended consequences of using water of variable quality. By way of further example, a preservative (such as isothiazolinone) may be included in the dispersion to prevent fouling and bacterial growth.

- Further additives may be included in the dispersion of the invention, and hence may be found as an artefact in the composite material of the invention. Such additives may be used to provide a flat, uniform, and/or defect-free surface of the composite material after drying of the dispersion. Such additives may affect the surface tension, flow behaviour (i.e. rheology), and/or the film formation (i.e. coalescence) process, and include hydroxyethyl cellulose, attapulgite clay, modified urethane ethoxylate, modified polydimethylsiloxane, and glycol ether.

15 Aqueous Carrier

Advantageously, in some embodiments the composite material of the present invention may be applied as a dispersion including an aqueous carrier. The term "aqueous" takes its standard meaning and includes any carrier including at least some water (such as at least 30%, such as at least 50%, such as at least 60%, such as at least 70%, such as at least 80%, such as at least 90%). In some embodiments the carrier will be mostly water (by weight, for example). It is envisaged that the aqueous carrier could be 100% water, although in some embodiments the aqueous carrier will include one or more non-water carriers, such that the, some, or each of the non-water carriers are of themselves water miscible. Examples of non-water carriers include alcohols, ketones, glycol ethers (such as dipropylene glycol n-butyl ether, ethylene glycol n-butyl ether, dipropylene glycol methyl ether, diethylene glycol ethyl ether, diethylene glycol n-butyl ether, dipropylene glycol dimethyl ether, propylene glycol phenyl ether), esters (for example 2,2,4-trimethyl-1,3-pentanediol monoisobutyrate) and the like. One or more components of the aqueous carrier may function to solubilise one or more other components of the dispersion of the invention, and hence may be referred to as a co-solvent.

Method of Manufacturing Dispersion

The particulate material may be provided in a dry powdered form which is added to the aqueous carrier under shear, such as by a vortex created by a high-speed disperser. A high-speed disperser equipped with a blade with a diameter that is between 40% to 70% of the diameter of the mixing vessel is one particularly preferred form, although it will be understood that numerous other pieces of equipment
5 may be used for that purpose. The sequence of addition of the powder may be based on the specific surface area of the particles (m^2 per g). For instance, higher surface area powder may be introduced into the carrier before lower surface area powder is introduced. The particulate material, where supplied in an agglomerated form, may be crushed to smaller sizes close to their primary particle size during the dispersing process by the shear, created by the vortex for example. Where used, the dispersant is
10 believed to wet the particle surface and replace air trapped between primary particles, which facilitates the dispersing process. In some embodiments, the dispersing process may take between 15 minutes to 60 minutes, depending on the particulate material selected. Following that stage, the binder may be added as a dispersion under shear, such as by a vortex.

Method of Applying Dispersion

15 Where used, the dispersion of the invention may be applied to a substrate by any conventional means, including by brush, roller, conventional spray, and airless spray. In some cases it may be beneficial to provide the substrate with a surface that promotes adhesion of the dispersion of the material (and hence composite material) to it. As disclosed herein, such a surface may be provided by a primer, such as a commercially available primer. A primer may perform numerous functions including: sealing the
20 underlying material, especially in the case of porous materials such as wood; and/or provide a more uniform/smooth surface to which the composite material (or a precursor dispersion) may be applied. Prior to application of the dispersion, or primer, it may be beneficial to physically modify the surface of the substrate by sanding, grinding, etc so as to minimise surface roughness.

The composite material of the present invention may be built up on a substrate by spreading layers of
25 the dispersion of the invention on it. Each such layer may, for example, have a wet thickness of from 100 μm to 500 μm . Layers of such wet thickness may each provide a dried layer from 50 μm to 300 μm in thickness. The present inventors have identified that the total solar reflectivity of the composite material is dependent, in part, on the coating thickness. However it has been identified that the solar reflectivity of the composite layer essentially saturates, or plateaus, at a thickness of around 300-500
30 μm wherefrom any further increase in thickness provides marginal benefit. As such, even a single layer of the dispersion may be sufficient to achieve substantially all of the benefit of the present invention. In

other embodiments a plurality of (sub)layers of the dispersion may be applied, such as to achieve a desired thickness. Preferably the composite material of the invention is no greater than 1 mm thick, such as no greater than 800 μm thick, such as no greater than 600 μm thick, such as no greater than 500 μm thick. Preferably the composite material of the invention is at least 25 μm thick, such as at least 50 μm thick.

Surface Coating

Where the composite material is applied to a substrate, particularly for AWH, it may be advantageous to enhance the properties of the composite material by providing a surface coating (such that the composite material will typically be interposed between the surface coating and the substrate) to provide the following function(s):

- providing chemical and/or mechanical resistance towards erosion sources including airborne contaminants, dirt, physical impacts, rain, coastal wind carrying high concentrations of salt, etc;
- be compatible with condensation of water from moisture in the air;
- promote roll-off of condensed water droplets;
- seal the porosity on the surface of the composite material;
- provide self-cleaning properties; and/or
- radiate heat in the atmospheric window with high emissivity.

In some embodiments, the use of a very high PVC formulation of over 0.8 for the composite material may cause the composite material to exhibit poor water resistance, mudcracking, and poor mechanical strength. Some or all of these potential issues may be addressed through the use of a surface coating.

Any such surface coating ideally does not substantially modify the structure of the composite material defined herein, such as by infusing/ingressing into a substantial (or any) number of the voids of the composite material.

While in some limited cases a commercially available top coat paint may address some of these potential issues to a limited degree, such top coats would be considered to substantially modify the structure of the composite material defined herein, such as by infusing/ingressing into a substantial (or any) number of the voids of the composite material and/or significantly reduce reflectivity by 20% or more which is undesirable.

On the other hand, the present inventors have realised that a surface coating may be used that provides high transmissivity in the solar spectrum – such as greater than 85%, such as greater than 90%, such as greater than 95%. For example the surface coating may include polymeric film forming material formed of materials that are substantially a blend of: an acrylic-polyol copolymer; acrylic-fluoro copolymer; polyester -polyol; silicone copolymer; and hexamethylene diisocyanate (HDI) based cross-linking agent. Such a surface coating provides chemical and physical resistance. The resistance of the surface coating may be enhanced by the inclusion of micro particles. Such micro particles may have a Mohr hardness of at least 6 so as to improve toughness and mechanical resistance. Micro particles which may be used include ground, crystalline quartz silica, or feldspar mineral. Where used, the micro particles may have a refractive index similar to the polymer used to form the surface coating, so that the surface coating maintains a high transmissivity in the solar spectrum – such as greater than 85%, such as greater than 90%, such as greater than 95%. In some embodiments, hexagonal boron nitride can be included so as to modulate transmissivity.

The surface coating, including any polymer and/or other components included in the surface coating (such as micro particles), should be highly emissive (such as greater than 85%, such as greater than 90%, such as greater than 95%) within the atmospheric window.

For application of a liquid containing the polymer (and any other components) for formation of the surface coating, a suitable polymer solvent may be used. The solvent may be a high boiling point, water miscible solvent, examples of which include: glycol ethers (commercially available as Dowanol DPnB, Dowanol DPM, Dowanol DPh, and Butyl CARBITOL, for example); N-methyl-2-pyrrolidone (NMP); and ester alcohols (commercially available as Eastman Texanol, for example); and combinations thereof. The solvent (including solvent combinations) may be chosen based on Hansen Solubility Parameters assessment based on the polymer intended for use in the surface coating.

The surface coating may optionally be used in combination with a surface active agent (such as a siloxane based additive) so as to modify the surface energy of a liquid containing the polymer (and any other components) for formation of the surface coating. Without wishing to be bound by theory, the use of such a surface active agent may assist in reducing/preventing ingress/infusion of a liquid used to form the surface coating into the void structure of the composite material to which the liquid is applied.

Where used, the surface coating is ideally substantially smooth at the nanometre scale on its surface. Without wishing to be bound by theory, it is believed that the low surface roughness and the uniform

chemical composition of the surface coating helps to facilitate droplets of water rolling off the surface, which is particularly useful in AWH applications. The present inventors have been able to determine that water droplets of volume between 50 and 70 μL roll-off the surface coating at a tilt angle of the surface to the horizontal of 30 degrees or even less. The facile roll-off of water droplets at such a small droplet
5 volume provides a more efficient rate of water capture from the atmosphere when used for that AWH purpose and also provide self-cleaning properties, as the rolling droplets can take dirt away from the surface.

Preferably the root mean square (RMS) roughness of the surface coating is less than 100 nm, such as less than 10 nm, such as less than 5 nm, such as less than 2 nm, such as less than 1 nm.

10 Figure 7 shows Atomic Force Microscopy (AFM) micrographs for two repeats of an exemplary surface coating of the present invention demonstrating very low surface roughness (< 1 nm) which is advantageous to ensure easy shedding of condensed water droplets off the surface, for collection. Figure 7(a) shows an RMS roughness R_q of 0.74 nm (R_q = root mean square roughness of surface); Figure 7(b) shows an RMS roughness of R_q of 0.76 nm.

15 Examples

Example 1

The composite material of the invention may be applied to a surface by forming a dispersion which is then allowed to harden. That dispersion may be applied as part of a system including three coating layers (referred to herein as the 3-layer or 3-layered, system) – a primer; the composite material (which
20 itself may be provided as a composite of a plurality of sub-layers); and a surface coating. The system may provide a durable coating, being made of materials suited to the exterior environment for protection purposes (i.e. roofing). When used as a roof coating, the main properties expected are: waterproofing; anti-mould/mildew; self-cleaning and insulation, which can bring heat reduction.

An example of a commercial product that may be used as a comparator with the composite material,
25 and system, of the present invention is Astec Energy Star Wallmaster IR Reflective Exterior Paint (referred to herein as Astec) which is specified to include “colour infused nano ceramics that reflect heat by selective reflection of infrared light”. The comparative properties of the commercial system and the system of the invention are detailed below.

The system of the invention may include the following layers (which have been listed in one order in which the layers may be provided/applied from a solid substrate up to the top layer, which may form the exterior surface of such a multi-layered system) - primer; Vis-Near IR reflective sub-layer; UV-Vis reflective sub-layer of the composite material; surface coating:

5 *Primer*

A primer may be used to assist with adhesion of the composite material to the substrate. One such primer is a commercial primer such as British Paint Prep 4 in 1 Primer White. The choice of primer is not especially important, although preferably the primer is a water-borne primer that may include acrylic polymer particles. In some embodiments the primer may include titania.

10 *Vis-Near IR reflective sub-layer of the composite material*

A dispersion may be prepared by a high-speed disperser with commercially available raw materials through the following exemplary procedures. Further details of the individual materials are provided in the table immediately below.

1. Fill the mixing vessel (500 mL capacity) with water (55.4 g, 9.71% w/w)
- 15 2. Immerse the blade in water with a diameter of 50-70% of the diameter of the vessel and start mixing at 400 RPM.
3. Whilst mixing, sprinkle in a high surface area synthetic phyllosilicate clay (0.5 g, 0.09% w/w – example Laponite RDS). Mix for 20 minutes until no visible particles can be seen in water.
- 20 4. Add sodium hexametaphosphate (0.3g, 0.06% w/w – example Calgon), Disperbyk 199 (8.5g, 1.49% w/w), Cabowet GA100 (1.2g, 0.21% w/w), an aqueous blend of 1,6-dihydroxy-2,5-dioxahexane, 5-chloro-2-methyl-3(2h)-isothiazolone and 2-methyl-3(2h)-isothiazolone (0.9g, 0.15% w/w – example Mergal K14) and BYK-022 (0.7g, 0.12% w/w) to the mixture in sequence. Increase the mixing speed to 800 RPM.
- 25 5. Add a surface treated (Alumina, silica and organic treatment), chloride processed, rutile titanium dioxide pigment with a mean primary particle size between 200 – 300 nm (66.3g, 11.6% w/w – example Tiona RCL 3) to the vortex of the mixture slowly. Ensure the pigment is mixed in the

mixture and no dry powder is sitting on the surface of the liquid during the addition. Increase the mixing speed to 1500 RPM.

- 5 6. Add an ultra-fine, grounded natural calcium carbonate pigment with a mean primary particle size between 0.8-1.0 μm (77.5g, 13.58% w/w – example Omyacoat 855) and an Ultra-fine hydroxyapatite modified natural calcium carbonate, platelet geometry, mean particle diameter 2.5 μm (77.5g, 13.58% w/w – example Omyabrite X1300) to the vortex of the mixture slowly. Ensure the pigment is mixed in the mixture and no dry powder is sitting on the surface of the liquid during the addition. Add water (51.2g, 8.96% w/w) gradually whenever the mixture becomes too viscous and dry powder starts to sit on the liquid surface. Raise the level of the
10 blade accordingly to maintain a vortex.
7. Continue mixing at 1500 RPM for further 30 minutes after last addition of material.
8. Reduce mixing speed to 800 RPM, and then add Neocryl A6093 (104.0g, 18.21% w/w), Silres BS45 (52.0g, 9.11% w/w), Silres BS1360 (5.0g 0.88% w/w), a polystyrene copolymer based polymeric hollow sphere, 30% by weight dispersion in water (50.0g, 8.75% w/w – example
15 Innotion 10) and an expanded hollow thermoplastic proprietary copolymer microsphere, mean particle size 40 μm , blown by isobutane (10.0g, 1.75% w/w – example Expancel 921 WE 40 D24) in sequence. Adjust the level of the blade accordingly to blend in the material being added.
9. Add Propylene Glycol (5.0g, 0.88% w/w), Dowanol DPnB (4.0g, 0.70% w/w) and BYK-025 (1.0g, 0.18% w/w) and mix for further 15 minutes.
- 20 10. Stop the mixer and transfer the mixture to a storage container.

This dispersion formulation is referred to herein as L2A-1.

Another exemplary dispersion according to the present invention can be prepared as follows:

1. Fill the mixing vessel (500 mL capacity) with water (122.6 g, 19.97% w/w)
2. Immerse the blade in water with a diameter of 50-70% of the diameter of the vessel and start
25 mixing at 400 RPM.
3. Whilst mixing, sprinkle in hydrophobically modified hydroxyethylcellulose (2.18 g, 0.36% w/w – example Natrosol Plus). Mix for 5 minutes until no visible lumps can be seen in water.

4. Add sodium hexametaphosphate (0.44g, 0.07% w/w – example Calgon), Disperbyk 199 (6.08g, 0.99% w/w), Cabowet GA100 (2.22g, 0.36% w/w), an aqueous blend of 1,6-dihydroxy-2,5-dioxahexane, 5-chloro-2-methyl-3(2h)-isothiazolone and 2-methyl-3(2h)-isothiazolone (0.9g, 0.15% w/w – example Mergal K14), 28% Aqueous Ammonia (1.0g, 0.16% w/w) and BYK-022 (0.9g, 0.15% w/w) to the mixture in sequence. Increase the mixing speed to 800 RPM.
5. Add titanium dioxide (123.9g, 20.19% w/w – example TiO₂ BLR895) to the vortex of the mixture slowly. Ensure the pigment is mixed in the mixture and no dry powder is sitting on the surface of the liquid during the addition. Increase the mixing speed to 1500 RPM.
6. Add an ultra-fine, grounded natural calcium carbonate pigment with a mean primary particle size between 0.8-1.0 µm (19.42, 19.42% w/w – example Omyacoat 855) and calcium carbonate (47.0g, 7.66% w/w – example Omyacarb 5) to the vortex of the mixture slowly. Ensure the pigment is mixed in the mixture and no dry powder is sitting on the surface of the liquid during the addition. Add water (15.4g, 2.51% w/w) gradually whenever the mixture becomes too viscous and dry powder starts to sit on the liquid surface. Raise the level of the blade accordingly to maintain a vortex.
7. Continue mixing at 1500 RPM for further 30 minutes after last addition of material.
8. Reduce mixing speed to 800 RPM, and then add Silres BS45 (33.4, 5.44% w/w), Silres BS1360 (3.65g 0.59% w/w), and Neocryl XK99 (101.7, 16.57% w/w), in sequence. Adjust the level of the blade accordingly to blend in the material being added.
9. Premix an expanded hollow thermoplastic proprietary copolymer microsphere, mean particle size 40 µm, blown by isobutane (3.4g, 0.55% w/w - example Expancel 921 WE40 D24) with water (6.8g, 1.1% w/w) manually into a slurry, add directly to the pot.
10. Add Propylene Glycol (5.0g, 0.88% w/w), Dowanol DPnB (4.0g, 0.70% w/w) and BYK-025 (1.0g, 0.18% w/w) and mix for further 15 minutes.
11. Stop the mixer and transfer the mixture to a storage container.

This dispersion formulation is referred to herein as L2A-2.

The table below summarises the function of each component.

Chemical nature (function – appearing in parentheses)	Purpose in formulation	Commercial Name (Source)
Water (carrier)	Carrier (May be present between 1 and 50% w/w).	N/A
Sodium Hexametaphosphate (Other)	Stabiliser. A water softener. Removes excessive free ions in tap water by complexation, reducing the risk of unforeseen side reactions in the formulation. (May be present between 0 and 0.5% w/w).	Calgon (Redox)
Hydrophobically modified hydroxyethylcellulose	Stabiliser. A rheology modifier – a thickener. Functions through hydrogen-bonding and chain entanglement and hydrophobic interactions. (May be present between 0 and 5% w/w).	Natrosol Plus
Aqueous ammonia solution	Dispersant. Ammonia helps to disperse the pigments evenly throughout the paint, thereby providing an excellent consistency and color uniformity. (May be present between 0 and 5% w/w).	28% Liquor Ammonia (Redox)
Synthetic phyllosilicate (Other, optional)	Stabiliser. A rheology modifier. Focuses on low shear condition (i.e. storage stability). Thickens mixture up by establishing electrostatic interaction between polar nanoplatelets. Does not absorb in the solar spectrum. May be present between 0 and 0.5% w/w).	Laponite RDS (BYK)
Aqueous blend of 1,6-dihydroxy-2,5-dioxahexane, 5-chloro-2-methyl-3(2h)-isothiazolone and 2-methyl-3(2h)-isothiazolone (Other)	Stabiliser. In-can preservative. Biocide that prevents fouling and bacteria growth in paint formulation during storage.	
Water soluble styrene-maleic acid copolymer (Other)	Stabiliser and cooling function. A dispersant additive. An amphiphilic polymer with pigment affinity groups that wet pigment surfaces and assist the breakdown of particle agglomerates. After the dispersing stage, it stabilises primary particles of pigment in suspension. (May be present between 0 and 5% w/w).	Disperbyk 199 (BYK)

Ethoxylated alcohol oligomer (Other)	Stabiliser. A wetting additive. With a special gemini structure it has a low foaming tendency compared to commodity wetting agents. (May be present between 0 and 1% w/w).	Cabowet GA100 (Evonik)
Isothiazolinone mixture (Other)	Stabiliser. In-can preservative. Biocide that prevents fouling and bacteria growth in paint formulation during storage. (May be present between 0 and 1% w/w).	Mergal K14 (Arxada)
Compound of modified polysiloxanes, polyether and hydrophobic particles (Other)	Film Integrity. A defoamer. Molecules have a tendency to migrate to air-water interface and destroy any stabilized air by surfactant (i.e. foam). Foam is a common cause of film defects when the paint is applied. (May be present between 0 and 1% w/w).	BYK-022 (BYK)
Titanium dioxide, such as surface treated (alumina, silica, organic), chloride processed, rutile titanium dioxide pigment, particle size 200 – 300 nm (Particulate material)	Cooling function. A pigment. Rutile titanium dioxide is known as a white pigment in the paint industry because of its high refractive index and high efficiency in reflecting visible light. The specific surface treatment ensures good weathering stability, ease for dispersing (May be present between >0 and 40% w/w).	Tiona RCL3 (Tronox) TiO ₂ BLR895 (Iomon Billions)
Ultra-fine natural calcium carbonate, particle size 0.8 – 1 µm (Particulate material)	Cooling function. A pigment/extender. Use to fill up volume in dried paint to optimise cost/performance balance. Space up titanium dioxide particle for best effectiveness in light scattering and avoid the over-crowding of pigment. (May be present between 0 and 50% w/w).	Omyacoat 855 (OMYA) Omyacarb 5 (OMYA)
Hydroxyapatite modified natural calcium carbonate, platelet geometry, mean particle diameter 2.5 µm (Particulate material)	Cooling function. A pigment/extender. This treated grade of calcite maximises the surface area to volume ratio of the pigment hence making dry paint film more porous. (May be present between 0 and 30% w/w).	Omyabrite 1300 X (OMYA)
Acrylic elastomeric copolymer (optionally provided as an aqueous emulsion) (Binder)	Cooling function and film integrity. Good elasticity, no absorption in the solar spectrum, high emission in the atmospheric window wavelength. Tg approximately 0 °C. (May be present between 0 and 30% w/w).	Neocryl A6093 (Covestro)

Silicone copolymer (optionally provided as an aqueous emulsion) (Binder, optional)	Cooling function and film integrity. Hydrophobise surfaces of dry film. Creates water beading effect as a result of rendering open pores non-wettable by water. (May be present between 0 and 20% w/w).	Silres BS45 (Wacker)
Polysiloxane emulsion (Other, optional)	Cooling function and film integrity. Hydrophobise surfaces of dry film. Creates water beading effect as a result of rendering open pores non-wettable by water. Whereas Silres BS45 takes time to develop, Silres 1346 and 1360 provides a sacrificial early water resistance. (May be present between 0 and 5% w/w).	Silres 1346 and 1360 (Wacker)
Expanded hollow thermoplastic copolymer microsphere, mean particle size 40 μm, blown by isobutane (Particulate material, optional)	Cooling function. Fill up the volume of dry film to optimise cost/performance balance. Elastic shell ensures good flexibility of film against thermal expansion whereas the encapsulated micron scale pores provides Near-IR reflectivity (May be present between 0 and 5% w/w).	Expancel 921 WE 40 d24 (Nuoryon)
Polymeric hollow sphere (optionally provided as an aqueous dispersion) (Particulate material, optional)	Cooling function. Hard shell polymeric hollow sphere to fill up volume and incorporate closed nanopores for cost/performance balance. The quantity used is optimised to balance open pores vs. closed pores. (May be present between 0 and 20% w/w).	Innotion 10 (Connell Brothers)
Polystyrene copolymer based polymeric hollow sphere, 30% by weight dispersion in water (Particulate material, optional)	Cooling function. Hard shell polymeric hollow sphere to fill up volume and incorporate closed nanopores for cost/performance balance. The quantity used is optimised to balance open pores vs. closed pores.	
Polyacrylate resin dispersion	Film integrity. It provides excellent water resistance and very good blocking & alkali resistance. (May be present between 0 and 30% w/w).	NeoCryl XK-99 (Covestro)
Propylene glycol (Carrier)	Stabiliser and film integrity. Retards surface drying time of painted film by slowing down evaporation of surface water. Ensures a more uniform through drying therefore reduces chance of surface defects especially when a thick wet film is applied. Also lowers the freeze point	Propylene Glycol (Redox)

	of the paint. (May be present between 0 and 5% w/w).	
Dipropylene glycol n-butyl ether (Carrier)	Film integrity. Slow evaporating solvent for the acrylic polymer binder that serves the function as coalescing agent. Solvates polymer binder particle after water evaporates from the applied film and improves the film formation. (May be present between 0 and 5% w/w).	Dowanol DPnB (Dow)
Solution of polysiloxanes in dipropylene glycol monomethyl ether (Other)	Film integrity. A compatible grade defoamer. Useful for defoaming at a later stage of manufacturing where high shear mixing not applicable. (May be present between 0 and 5% w/w).	BYK-025 (BYK)

Figure 8 shows two scanning electron microscopy (SEM) micrographs demonstrating the cross-sectional structures of the Vis-Near IR reflective sub-layer of the composite material produced using the above described dispersion, before allowing to harden by drying and/or curing. Air voids are embedded in the film as a result of the specifically chosen low quantity of binder in the dispersion formulation. Also visible are granular titanium dioxide pigment particles added for high scattering efficiency, platelet calcite particles of size 2-5 μm added for spacing of the titanium dioxide and for some scattering, and granular calcite particles (size 0.6 – 2 μm). The size of the particles is selected for reflectance of different wavelengths of incident (especially solar) radiation.

10 UV-Vis reflective sub-layer of the composite material:

A dispersion may be prepared by a high-speed disperser with commercially available raw materials through the following procedure. Further details of the individual materials are provided in the table immediately below.

1. Fill the mixing vessel (500 mL capacity) with water (95.8g, 24.39% w/w)
- 15 2. Immerse the blade in water with a diameter of 50-70% of the diameter of the vessel and start mixing at 400 RPM.

3. Whilst mixing, sprinkle in a high surface area Synthetic Phyllosilicate Clay (0.49 g, 0.13% w/w; example - Laponite RDS). Mix for 20 minutes until no visible particles can be seen in water.
4. Add sodium hexametaphosphate (0.33g, 0.08% w/w; example - Calgon), Disperbyk 2014 (72.12g, 18.36% w/w), Cabowet GA100 (1.3g, 0.33% w/w), a aqueous blend of 1,6-dihydroxy-2,5-dioxahexane, 5-chloro-2-methyl-3(2h)-isothiazolone and 2-methyl-3(2h)-isothiazolone (0.65g, 0.17% w/w; example - Mergal K14) and BYK-022 (1.3g, 0.33% w/w) to the mixture in sequence. Increase the mixing speed to 800 RPM.
5. Add H-BN TW01 (76.83g, 19.56% w/w) to the vortex of the mixture slowly. Ensure the pigment is mixed in the mixture and no dry powder is sitting on the surface of the liquid during the addition. Increase the mixing speed to 1500 RPM.
6. Add water (6.5g, 1.65% w/w) gradually to assist the incorporation of dry H-BN powder. Continue mixing at 1500 RPM for further 30 minutes after last addition.
7. Reduce mixing speed to 800 RPM, and then add Neocryl A6093 (13.8g, 34.4% w/w). Adjust the level of the blade accordingly to blend in the material being added.
8. Add BYK-025 (1.0g, 0.18% w/w) and mix for further 15 minutes.
9. Stop the mixer and transfer the mixture to a storage container.

This dispersion formulation is referred to herein as L2B-1.

The table below summarises the function of each component.

Chemical nature	Purpose in formulation	Commercial Names (Source)
Water	Carrier (May be present between 0 and 50% w/w).	N/A
Sodium Hexametaphosphate (Other)	Stabiliser. A water softener. Removes excessive free ions in tap water by complexation, reducing the risk of unforeseen side reactions in the formulation. (May be present between 0 and 1% w/w).	Calgon (Redox)

Synthetic phyllosilicate clay (other, optional)	Stabiliser. A rheology modifier. Focuses on low shear condition (i.e. storage stability). Thickens mixture up by establishing electrostatic interaction between polar nanoplatelets. Does not absorb in the solar spectrum.	Laponite RDS (BYK)
Copolymer with pigment affinity groups	Stabiliser and cooling function. A dispersant additive with minimal absorption in the solar spectrum. (May be present between 0 and 30% w/w).	Disperbyk 2014 (BYK)
Ethoxylated alcohol oligomer	Stabiliser. A wetting additive. With a special gemini structure it has a low foaming tendency compared to commodity wetting agents. (May be present between 0 and 1% w/w).	Cabowet GA100 (Evonik)
Aqueous blend of 1,6-Dihydroxy-2,5-dioxahexane, 5-Chloro-2-methyl-3(2h)-isothiazolone and 2-Methyl-3(2h)-isothiazolone (Other)	Stabiliser. In-can preservative. Biocide that prevents fouling and bacteria growth in paint formulation during storage.	
Isothiazolinone mixture	Stabiliser. In-can preservative. Biocide that prevents fouling and bacteria growth in paint formulation during storage. (May be present between 0 and 1% w/w).	Mergal K14 (Arxada)
Compound of modified polysiloxanes, polyether and hydrophobic particles	Film integrity. A defoamer. Molecules have a tendency to migrate to air-water interface and destroy any stabilized air by surfactant (i.e. foam). Foam is a common cause of film defects when the paint is applied. (May be present between 0 and 1% w/w).	BYK-022 (BYK)
Hexagonal boron nitride platelet	Cooling function. Platelet shaped crystal in nanoscale size with high refractive index ($n = 2.1$) and no absorption in the solar spectrum. (May be present between >0 and 40% w/w).	H-BN TW01 (Jonze)
Acrylic elastomeric copolymer (aqueous emulsion)	Cooling function and film integrity. Good elasticity, no absorption in the solar spectrum, high emission in the atmospheric window wavelength. Tg approximately 0 °C. (May be present between 0 and 50% w/w).	Neocryl 6093 (Covestro)

Solution of polysiloxanes in dipropylene glycol monomethyl ether	Film integrity. A compatible grade defoamer. Useful for defoaming at a later stage of manufacturing where high shear mixing not applicable. (May be present between 0 and 1% w/w).	BYK-025 (BYK)
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Figures 9 and 10 show SEM micrographs demonstrating the cross-section structures of a UV-Vis reflective sub-layer of the composite material. Figure 9 shows: dispersed hexagonal platelet boron nitride and nano-scale hard shell polymer hollow sphere, in the presence of pores induced by the deficient polymer binder matrix. Figure 10 shows micro-scale flexible shell expandable polymer hollow sphere, embedded in a deficient polymer binder matrix. Open pores are present in the film, and significant volume is occupied by closed pores within the hollow sphere cavity. The hollow sphere porosity is added to reduce costs and to reduce penetration of the surface coating into the composite material.

Figure 11 shows two SEM micrographs of hexagonal boron nitride (H-BN) nanoparticles (50 nm thick, diameter 500 nm) that may be included in the composite material to afford UV reflectance, which is beneficial to prevent heating of the composite material, which is especially useful when it is applied as a paint film. H-BN particles are hydrophobic, with a high tendency to agglomerate, as seen in Figure 11. As particle agglomerates reduce the light scattering efficiency, the breakdown of H-BN agglomerates is desirable, which can be achieved by using a dispersant to stabilise them as primary particles (i.e. single platelets).

Figure 12 shows the HBN particles are dispersed using a dispersion of stabilised minimal size particles. This is achieved by selecting and optimising a special polymeric additive (i.e. dispersant) to the formulation.

20 *Surface Coating*

A dispersion may be prepared by a mixer (high shear not required) with commercially available raw materials through the following procedures. Further details of the individual materials are provided in the table immediately below:

1. Fill the mixing vessel (200 mL capacity) with Neocryl AF-10 (74.0g, 74.0% w/w)

2. Immerse the blade in liquid with a diameter of 50-70% of the diameter of the vessel and start mixing at 400 RPM.
3. Add Surfynol E104 (0.4g, 0.4% w/w) to the liquid while mixing.
4. Add Tafigel PUR65 (0.5g, 0.5% w/w) to the mixture while mixing. Mix for 5 minutes until mixture thickened. Increase mixing speed to 600 RPM.
5. Add Metolat ETC2 (1.0g, 1.0% w/w) to the mixture while mixing.
6. Add Bayhydur 3100 (24.5g, 24.5% w/w) to the mixture while mixing. Mix for 15 minutes until mixture is homogeneous. Leave for up to 1 hour until foam settles.

Ideally the application of paint should be completed within 4 hours of preparation (i.e. after reactive Bayhydur 3100 is mixed in).

Chemical nature	Purpose in formulation	Commercial Source
Water	Carrier	N/A
Hydrophillic aliphatic polyisocyanate based on hexamethylene diisocyanate	Chemical/physical durability and film integrity. Crosslink with hydroxyl functional group to form a strong, high molecular weight polymer structure	Bayhydur 3100 (Covestro)
Hydroxyl functional fluorinated acrylic polymer	Chemical/physical durability, water capture/roll-off, and film integrity. Crosslink with isocyanate functional group. Low surface energy polymer therefore good roll-off property and self-cleaning. Highly emissive in the atmospheric window.	Necoryl AF-10 (Covestro)
Tetramethyl decynediol, multifunctional surfactant	Film integrity. Low foaming gemini wetting agent that reduces surface tension and promotes wetting and levelling.	Surfynol E104 (Evonik)
Non-ionic polyurethane type rheology modifier with hydrophobic ends and hydrophilic backbone	Film integrity. Associative rheology modifier that assists in the application of paint.	Tafigel PUR65 (Munzing)

Solution of polysiloxanes in dipropylene glycol monomethyl ether	Film integrity. A compatible grade defoamer. Useful for defoaming at a later stage of manufacturing where high shear mixing not applicable.	BYK-025 (BYK)
Hydroxy functional and modified organo polysiloxane	Water capture/roll-off. Surface active siloxane polymer that anchors on the film surface through cross-linking via hydroxy group and promotes water roll-off.	Metolat ETC2 (Munzing)

Example 2

The system of Example 1 was applied stepwise to a substrate: first the primer (allowing to harden by drying); second the Vis-Near IR reflective sub-layer of the composite material (allowing to harden by drying); third the UV-Vis reflective sub-layer of the composite material (allowing to harden by drying); and fourth the surface coating (allowing to harden by drying). While in this example a single coat of each was applied, the reader will appreciate that one or more than one coats may be applied of each (sub)layer as desired.

Example 3

The emissivity of the primer, composite material, and surface coating system of example 1 (labelled in Figure 13 as Dewpoint 3 Layers) prepared with the preparations L2A-1 and L2B-1 was measured in the atmospheric window (8-13 μm) and compared with commercial white paint (Astec Energy Star Wallmaster Cooling Paint), and commercial black paint (British Paint Black Roof Paint). The results are presented in Figure 13. The thickness of 500 micron in the figure refers to the wet thickness of the various materials, providing a dry film thickness of approx. 180-200 μm .

The data shows that the system of the present invention, incorporating a water dispersible binder, provides comparable emissivity to the Astec product at wavelengths in the atmospheric window of 8-13 μm . Beyond that, however, the present system is advantageous over the Astec product in providing enhanced reflectivity, and may further be enhanced through a surface coating to provide advantageous roll-off.

Example 4**Method of measurement:**

- Measurements were taken on the roof of the Sydney Nanoscience Hub (-33.888373, 151.187168) on a subcooling measurement setup as shown in Figure 14. Temperatures are measured with K-type
- 5 thermocouples on the back of the surface embedded in insulating foam that was wrapped in reflective aluminium. The surfaces are positioned at a zenith angle of 0 degrees, facing the sky directly. Environmental variables are measured with the Campbell Scientific, ClimaVUE 50 weather station. One data point was measured every minute.

Example 4A – Temperature of the surface

- 10 Figure 15 shows (on the left y-axis) the temperature of Dewpoint Innovation coating, that of a reference black paint, the dewpoint temperature and (on the right axis) the solar irradiance measured on the 19th and 20th of February 2023. Over this period, the average temperature of the Dewpoint surface during the day was 12°C cooler than the black paint (26 °C versus 38 °C). Over this period, the average temperature in the night for the commercial black paint and the Dewpoint surface was the same (21 °C).
- 15 For dew to occur, the surface temperature needs not only to be cooler than the air, but also to drop below the dew point temperature, which occurs for the Dewpoint surface in the early hours of the morning of the second day. Surface temperatures increase during the day because of the increased amount of solar heat absorbed by the surface.

Method of measurement:

- 20 Measurements were taken on the roof of the Sydney Nanoscience Hub (-33.888373, 151.187168) on a subcooling measurement setup as shown in Figure 14. Temperatures were measured with K-type thermocouples on the back of the surface embedded in insulating foam that was wrapped in reflective aluminium. The surfaces were positioned at a zenith angle of 0 degrees, facing the sky directly. Environmental variables are measured with the Campbell Scientific, ClimaVUE 50 weather station. One
- 25 data point was measured every minute.

Example 4B – Subcooling

Figures 16 shows the difference in temperature of two surfaces (black commercial paint; and a 3-layered system of the present invention including primer, composite material, surface coating – labelled as the “Dewpoint surface”) compared to the ambient air (shade) temperature measured on the 19th and 20th of February 2023. For reference, a negative subcooling describes a surface of temperature below the ambient temperature, while a positive subcooling describes a surface of temperature above the ambient temperature.

The two surface temperatures are most different in the day when there is solar irradiance as the black commercial paint surface heats up more than the Dewpoint surface, due to the high reflectance of the Dewpoint surface.

The average difference in temperature between surface and the air during the daytime relative to atmospheric temperature of the commercial black paint was +12 °C (meaning that the black paint surface was on average 12 °C warmer than the air around it, with a peak of close to 35 °C warmer than the air around midday), and for the Dewpoint surface was -0.7 °C (meaning that the Dewpoint surface was on average 0.7°C cooler than the air, with a peak of close to -5°C cooler than the air at night). The average subcooling in the night for the commercial black paint and the Dewpoint surface for this period was the same (-2.5 °C).

Example 4C – Dew Collection

Figure 17 shows preliminary measurements of the volume of dew collected on the Dewpoint surface on the morning of the 21st of February 2023 (summer in Sydney, Australia) from a surface of area 40 ‘ 40 cm². Dew condenses directly from the atmosphere onto the cold Dewpoint surface and droplets roll off the inclined surface to be measured by a water gauge. The cumulative amount of dew increases over time from the early morning. Figure 18 shows schematically the dew collection device, and the photo shows a photo of the same device, on which a black paint reference surface was mounted. The dew collection gauge is contained inside the metal box under the device.

Method of measurement:

Measurements were taken from a surface 0.16 m² in size on the roof of the Sydney Nanoscience Hub (-33.888373, 151.187168) on a dew collecting measurement setup, as shown in Figure 18. Droplets that

roll off the surface were channelled into a precise water measurement device. The surface was embedded in insulating foam that was wrapped in reflective aluminium. The surface was positioned at a zenith angle of 30 degrees. Dew was measured on a Lambertech Rain(e) gauge. One data point was measured every minute.

5 Example 4D – Cooling power

Figure 19 shows preliminary cooling power measurements of the Dewpoint surface versus time over two days of peak summer, together with the solar irradiation. The first day shown (9th of February 2023) was a day with high cloud cover, while the second day (10th of February 2023) was a day with low cloud cover. On the 9th we can see that the surface maintains its cooling properties throughout the day due to the lack of solar heat deposited on the surface. On the 10th we can see that at solar irradiance levels above 600 W/m² the cooling effect is dominated by the high heat of the sun. The measured average cooling power on the Dewpoint surface over this period is:

- 9th February day: 66 W/m²
- 9th February night: 53 W/m²
- 15 • 10th February day: 28 W/m²
- 10th February night: 65 W/m²

Over total period: 52 W/m²

Maximum cooling power: 95 W/m²

Method of measurement:

20 These measurements were performed on a flat surface on the roof of the Sydney Nanoscience Hub (-33.888373, 151.187168) on a cooling power measurement setup. The surface was surrounded by insulation facing the sky at a zenith angle of 0 degrees. Three thermocouples and a programmable heating pad were placed underneath the surface, the surface temperature was measured against the ambient air temperature where a temperature difference was calculated, this difference was then fed
25 into a PID feedback loop dictating the magnitude of the power put into the system such that both measured temperatures stabilised. Data was recorded by LabVIEW software from a Graphtec data logger and a programmable power supply.

Example 5

The impact of the use of a silicone material is shown in Figure 20. Measured total solar reflectance of Vis-Near IR reflective sub-layer of the composite material (being the composite material sub-layer of the invention without boron nitride), containing silicone additive that reduces/prevents dispersion
5 infusion/ingressing into the top layer) vs. a control high PVC film, before and after applying a clear top coat.

This data demonstrates that the formulated Vis-Near IR reflective sub-layer of the composite material that includes the silicone material resists penetration of a layer applied on top of it. Any observed drop in reflectivity is due to loss of porosity due to penetration of the top layer. The reduction of total solar
10 reflectance for Vis-Near IR reflective sub-layer of the composite material is minimal (0.2%), while the reduction in reflectance for control film is significant (1.6%).

Example 5A – Temperature of the surface

Figure 21 shows (on the left y-axis) the temperature of the formulations (Dewpoint Formulation (3-layered system of Example 1) – solid black line; reference black paint – dashed black line) and the
15 dewpoint temperature (dotted black line) and (on the right axis) the solar irradiance (as shaded regions) measured on the 25th and 26th of July 2023. Over this winter period, the average temperature of the Dewpoint Formulation coating during the day was 8°C cooler than the black paint (13°C versus 21 °C).

For dew to occur, the surface temperature needs not only to be cooler than the air, but also to drop below the dew point temperature, which in this example occurred over many hours of the night and in
20 the early hours of the morning for the Dewpoint Formulation coating. The temperature of the Dewpoint Formulation coating is below the dewpoint temperature by more than the margin of error (0.3°C) for 20 hours of the 48-hour period for which this sample was taken. This is 42% of the time.

Example 5B – Subcooling

Figure 22 shows the difference in temperature of two surfaces (black commercial paint – dashed black
25 line; and a 3-layered system of Example 1 of the present invention including primer, composite material, surface coating – labelled as the “Dewpoint Formulation” (3-layered system of Example 1) – solid black line) compared to the ambient air (shade) temperature measured on the 25th and 26th of July 2023. For reference, a negative subcooling describes a surface of temperature below the ambient temperature, while a positive subcooling describes a surface of temperature above the ambient temperature.

The two surface temperatures are most different in the day when there is solar irradiance as the black commercial paint surface heats up more than the Dewpoint Formulation surface, due to the high reflectance of the Dewpoint Formulation surface.

- 5 During the daytime relative to atmospheric temperature the commercial black paint was on average 6 °C warmer than the air, while the Dewpoint Formulation surface was on average 2 °C below atmospheric temperature. The average subcooling in the night for the commercial black paint and the Dewpoint Formulation surface for this period was the same (-2°C). The Dewpoint Formulation surface was subcooling by more than the margin of error (0.3°C) for 99% of the time for which this measurement was taken.

10 **Example 5C – Dew Collection**

Figure 23 shows measurements of the volume of dew collected on the Dewpoint Formulation (3-layered system of Example 1) surface on the mornings of the 25th and 26th of July 2023. The surface collected a total of 576 mL/m² of dew over the two mornings.

Example 6

- 15 Figure 24 shows a histogram of advancing and receding contact angle of a 3-layered system according to Example 1 (primer; composite material (L2A-1 and L2B-1); surface coating) where the top layer formulation is the surface coating described in Example 1. Roll-off of a 50 µL water droplet initiated around 30° tilt on this system, which is an indication of self-cleaning and easy shedding surface properties.

20 **Example 7**

Figure 25 shows the particle size distribution of sub-micron sized particulate material dispersion (i.e. particle stabilised in aqueous carrier for the composite material formulation) capable of being used in the present invention and as analysed by Zetasizer through dynamic light scattering technique. The average diameter of all particles is of the order of 500 nm.

25 **Example 8**

Figure 26 shows the dynamic light scattering results for the binder (NeoCryl A6093) used in exemplary formulations of the invention as described above, showing particle size sample. The particle size by both volume and intensity average is 260 nm ± 60 nm.

Example 9

In some embodiments, the composite material of invention could be applied as a single Vis-Near IR reflective layer system, instead of the 3-layered system as demonstrated in Example 1. Without wishing to be bound by theory, such a single-layer system is believed to have somewhat reduced performance compared to the 3 layered system, namely lower solar reflectivity and lower ease of roll-off. However, a single-layer application provides a simplified approach that significantly saves material costs and labour costs and is believed to be a beneficial alternative for cost-sensitive markets.

Single Vis-Near IR reflective layer system as a solar reflective composite material

A dispersion may be prepared by a high-speed disperser with commercially available raw materials through the following exemplary procedures. Further details of the individual materials are provided in the table immediately below.

1. Fill the mixing vessel (500 mL capacity) with water (122.6 g, 19.97% w/w)
2. Immerse the blade in water with a diameter of 50-70% of the diameter of the vessel and start mixing at 400 RPM.
3. Whilst mixing, sprinkle in a hydrophobically modified hydroxyethyl cellulose polymer (2.18 g, 0.36% w/w). Mix for 5 minutes until no visible lumps can be seen in water.
4. Add sodium hexametaphosphate (0.44g, 0.07% w/w), Disperbyk 199 (6.08g, 0.99% w/w), Cabowet GA100 (2.22g, 0.36% w/w), an aqueous blend of 1,6-dihydroxy-2,5-dioxahexane, 5-chloro-2-methyl-3(2h)-isothiazolone and 2-methyl-3(2h)-isothiazolone (0.9g, 0.15% w/w), 28% aqueous ammonia (1.0g, 0.16% w/w) and BYK-022 (0.9g, 0.15% w/w) to the mixture in sequence. Increase the mixing speed to 800 RPM.
5. Add a surface treated (alumina, silica and organic treatment), chloride processed, rutile titanium dioxide pigment with a mean primary particle size between 200 – 300 nm (123.9g, 20.19% w/w) to the vortex of the mixture slowly. Ensure the pigment is mixed in the mixture and no dry powder is sitting on the surface of the liquid during the addition. Increase the mixing speed to 1500 RPM.

- 5
- 10
- 15
6. Add an ultra-fine, grounded natural calcium carbonate pigment with a mean primary particle size between 0.8-1.0 μm (19.42, 19.42% w/w) and a fine, grounded natural calcium carbonate pigment with a mean primary particles size between 2-10 μm (47.0g, 7.66% w/w) to the vortex of the mixture slowly. Ensure the pigment is mixed in the mixture and no dry powder is sitting on the surface of the liquid during the addition. Add water (15.4g, 2.51% w/w) gradually whenever the mixture becomes too viscous and dry powder starts to sit on the liquid surface. Raise the level of the blade accordingly to maintain a vortex.
7. Continue mixing at 1500 RPM for further 30 minutes after last addition of material.
8. Reduce mixing speed to 800 RPM, and then add Silres BS45 (33.4, 5.44% w/w), Silres BS1360 (3.65g 0.59% w/w), and Neocryl XK99 (101.7, 16.57% w/w), in sequence. Adjust the level of the blade accordingly to blend in the material being added.
9. Premix expanded hollow thermoplastic copolymer microspheres (3.4g, 0.55% w/w) with water (6.8g, 1.1% w/w) manually into a slurry, add directly to the pot.
10. Add propylene glycol (10.0g, 0.88% w/w), dipropylene glycol methyl ether (4.3g, 0.70% w/w), dipropylene glycol n-butyl ether (7.1g, 0.70% w/w), Tafigel PUR65 (0.8g, 0.13% w/w) and BYK-025 (0.8g, 0.13% w/w) and mix for further 15 minutes.
11. Stop the mixer and transfer the mixture to a storage container.

The table below summarises the function of each component.

Chemical nature (function in parentheses)	Purpose in formulation	Commercial Name (Source)
Water (carrier)	Carrier	N/A
Sodium Hexametaphosphate (Other)	Stabiliser. A water softener. Removes excessive free ions in tap water by complexation, reducing the risk of unforeseen side reactions in the formulation.	
Hydrophobically modified hydroxyethyl cellulose (Other)	Stabiliser. A rheology modifier that thickens the aqueous phase of the dispersion to build up viscosity hence retain solid particle in suspension	

Water soluble styrene-maleic acid copolymer (Other)	Stabiliser and cooling function. A dispersant additive. An amphiphilic polymer with pigment affinity groups that wet pigment surfaces and assist the breakdown of particle agglomerates. After the dispersing stage, it stabilises primary particles of pigment in suspension.	Disperbyk 199 (BYK)
Ethoxylated alcohol oligomer (Other)	Stabiliser. A wetting additive. With a special gemini structure it has a low foaming tendency compared to commodity wetting agents.	Cabowet GA100 (Evonik)
Aqueous blend of 1,6-Dihydroxy-2,5-dioxahexane, 5-Chloro-2-methyl-3(2h)-isothiazolone and 2-Methyl-3(2h)-isothiazolone (Other)	In-can preservative. Biocide that prevents fouling and bacteria growth in paint formulation during storage.	
28% Aqueous Ammonia (Other)	pH control. To raise the pH of dispersion to optimal level (8.0 – 9.0) for optimal stability of anionic species presented in the dispersion	28% Liquor Ammonia (Redox)
Compound of modified polysiloxanes, polyether and hydrophobic particles (Other)	Film Integrity. A defoamer. Molecules have a tendency to migrate to air-water interface and destroy any stabilized air by surfactant (i.e. foam). Foam is a common cause of film defects when the paint is applied.	BYK-022 (BYK)
Surface treated (alumina, silica, organic), chloride processed, rutile titanium dioxide pigment, particle size 200 – 300 nm (Particulate material)	Cooling function. A pigment. Rutile titanium dioxide is known as a white pigment in the paint industry because of its high refractive index and high efficiency in reflecting visible light. The specific surface treatment ensures good weathering stability, ease for dispersing, and	
Ultra-fine natural calcium carbonate, particle size 0.8 – 1 µm (Particulate material)	Cooling function. A pigment/extender. Use to fill up volume in dried paint to optimise cost/performance balance. Space up titanium dioxide particle for best effectiveness in light scattering and avoid the over-crowding of pigment.	
Fine natural calcium carbonate, particle size 2-10 µm	Cooling function. A pigment/extender. Use to fill up volume in dried paint to optimise cost/performance balance. Space up titanium dioxide particle for best effectiveness in light	

(Particulate material)	scattering and avoid the over-crowding of pigment.	
Silicone copolymer (optionally provided as an aqueous emulsion) (Binder, optional)	Cooling function and film integrity. Hydrophobise surfaces of dry film. Creates water beading effect as a result of rendering open pores non-wettable by water.	Silres BS 45 (Wacker)
Acrylic copolymer (optionally provided as an aqueous emulsion) (Binder)	Cooling function and film integrity. Minimal absorption in the solar spectrum, high emission in the atmospheric window wavelength.	Neocryl XK99 (Covestro)
Polysiloxane emulsion (Other, optional)	Cooling function and film integrity. Hydrophobise surfaces of dry film. Creates water beading effect as a result of rendering open pores non-wettable by water. Whereas Silres BS45 takes time to develop, Silres 1360 provides a sacrificial early water resistance.	Silres 1360 (Wacker)
Expanded hollow thermoplastic proprietary copolymer microsphere, mean particle size 40 μm , blown by Isobutane (Particulate material, optional)	Cooling function. Fill up the volume of dry film to optimise cost/performance balance. Elastic shell ensures good flexibility of film against thermal expansion whereas the encapsulated micron scale pores provides Near-IR reflectivity	
Polystyrene copolymer based polymeric hollow sphere, 30% by weight dispersion in water (Particulate material, optional)	Cooling function. Hard shell polymeric hollow sphere to fill up volume and incorporate closed nanopores for cost/performance balance. The quantity used is optimised to balance open pores vs. closed pores.	
Propylene glycol (Carrier)	Stabiliser and film integrity. Retards surface drying time of painted film by slowing down evaporation of surface water. Ensures a more uniform through drying therefore reduces chance of surface defects especially when a thick wet film is applied. Also lowers the freeze point of the paint.	Propylene Glycol (Redox)

Dipropylene Glycol Methyl Ether (Carrier)	Film integrity. Slow evaporating solvent for the acrylic polymer binder that serves the function as coalescing agent. Solvates polymer binder particle after water evaporates from the applied film and improves the film formation. Hydrophilic.	Dowanol DPM (Dow)
Dipropylene glycol n-butyl ether (Carrier)	Film integrity. Slow evaporating solvent for the acrylic polymer binder that serves the function as coalescing agent. Solvates polymer binder particle after water evaporates from the applied film and improves the film formation. Hydrophobic.	Dowanol DPnB (Dow)
Solution of Hydrophobically Ethoxylated Urethane Copolymer (Other, Optional)	Flow and levelling. A rheology modifier which associatively bridges polymer backbone of binder in film to enhance flow properties and achieve levelling. Considered as a high shear thickener.	Tafigel PUR65 (Munzing)
Solution of polysiloxanes in dipropylene glycol monomethyl ether (Other)	Film integrity. A compatible grade defoamer. Useful for defoaming at a later stage of manufacturing where high shear mixing not applicable.	BYK-025 (BYK)

Example 10 – Reflectivity and Emissivity

As shown in the Figure 27, the loss of reflectivity between the 3-layered system (Dewpoint 3 Layers; as described in Example 1), and the Vis-Near IR reflective single layer system (Dewpoint L2A; as described in Example 9), is about 3% over the whole solar spectrum.

The table immediately below shows the integrated total solar reflectance obtained on Dewpoint 3-layer system described in Example 1 and the single layer system described in Example 9 (Dewpoint L2A).

	Total Solar Reflectance (0.3 – 2.5 μm)	UV Reflectance (0.3 – 0.4 μm)	Visible Reflectance (0.4 – 0.7 μm)	Near-IR Reflectance (0.7 – 2.5 μm)
Dewpoint L2A	90.0	12.9	95.4	90.9
Dewpoint 3-layer	92.8	83.9	97.4	89.9

Both the multi-layered and single-layer systems provide a cooling ability below atmospheric temperature, as shown in Examples below.

Example 11 – Temperature of the surface

Figure 28 shows (on the left y-axis) the temperature of the single layer Dewpoint L2A coating, that of a reference black paint, the dewpoint temperature and (on the right axis as shaded regions) the solar irradiance measured on the 9th and 10th of March 2024 (the end of summer in Sydney, Australia). Over this period, the average temperature of the single layer Dewpoint L2A coating during the day was 12°C cooler than the black paint (25°C versus 27°C).

Example 12 – Subcooling

Figure 29 shows the difference in temperature of two surfaces (black commercial paint; and the single layer Dewpoint L2A coating) compared to the ambient air (shade) temperature measured on the 9th and 10th of March 2024 (end of summer in Sydney, Australia). For reference, a negative subcooling describes a surface of temperature below the ambient temperature, while a positive subcooling describes a surface of temperature above the ambient temperature.

During the daytime the commercial black paint was 11 °C warmer than atmospheric temperature while the single layer Dewpoint L2A coating was on average at atmospheric temperature (average subcooling 0°C). The average subcooling in the night for the commercial black paint and the single layer Dewpoint L2A coating for this period was the same (-2°C). The single layer Dewpoint L2A coating was subcooling by more than the margin of error (0.3°C) for 50% of the time for which this sample was taken.

Example 13

For most commercial paints designed to withstand exterior weathering, a primer needs to be used to aid proper bonding to the substrate. This is because usually there is a trade-off between the paint's adhesion properties and the chemical/physical resistance properties. The Vis-Near IR reflective sub-layer of the invention may be formulated to achieve a balance of good adhesion and resistance to natural weathering.

The Vis-Near IR reflective sub-layer coating itself may be "self-priming" i.e. does not require a separate primer coat to assist application. In the table below, we show that the Vis-Near IR reflective sub-layer referred to herein as Dewpoint L2A (or Dewpoint L2A-1), demonstrates self-priming properties on a) new Colourbond (a coated steel product, typically including a combination of aluminium, zinc, and silicon sometimes referred to as ZINCALUME) steel panel, b) weathered (20 years) and rusted Colourbond steel

panel, c) compressed fibre cement sheet, d) weathered terracotta tiles, e) weathered glazed terracotta tiles, f) weathered concrete tiles, and g) weathered polycarbonate sheet.

The weathered substrates were cleaned by water spray before coating, as common in the roofing sector. A comparison is made with Astec, a commercial cool roof paint, to demonstrate the difference in adhesion strength, assessed by the cross-hatch adhesion test, following Australian Standard method AS 1580.408.4.

The table below is an excerpt from Australian Standard method AS 1580.408.4 showing the grading classifications of the adhesion strength test.

Classification	Description	Appearance of surface of crosscut area from which flaking has occurred (example for six parallel cuts)
0	The edges of the cuts are completely smooth; none of the squares of the lattice is detached.	
1	Detachment of small flakes of the coating at the intersections of the cuts. A crosscut area not distinctly greater than 5 percent is affected.	
2	The coating has flaked along the edges, at the intersections of the cuts, or at both locations. A crosscut area distinctly greater than 5 percent, but not distinctly greater than 15 percent is affected.	
3	The coating has flaked along the edges of the cuts partly or wholly in large ribbons, it has flaked partly or wholly on different parts of the squares, or both have occurred. A crosscut area distinctly greater than 15 percent, but not distinctly greater than 35 percent is affected.	
4	The coating has flaked along the edges of the cuts in large ribbons, some squares have detached partly or wholly, or both have occurred. A crosscut area distinctly greater than 35 percent, but not distinctly greater than 65 percent is affected.	
5	Any degree of flaking greater than classification 4.	

The adhesion ratings from the cross-hatch adhesion tests conducted on Dewpoint L2A and competing products according AS 1580.408.4 on the substrates mentioned above are presented in the table immediately below.

Substrate	Vis-Near IR Reflective sub-layer, Dewpoint L2A	Astec Energy Star Wallmaster IR Reflective Exterior Paint

New Colourbond panel	0	0
Weathered Colourbond panel	0	1
Compressed Fibre Cement Sheet	0	5
Weathered Terracotta Tile	0	4
Weathered Glazed Tile	2	5
Weather Concrete Tile	1	1
Weather Polycarbonate Sheet	1	5

It is important to note that Astec specifically indicates that its product is not suitable for application to glazed tiles. This further shows the advantages provided by the present invention.

Example 14

- 5 The Dewpoint 3-layer system (Example 1), has a total solar reflectance of 92% and emissivity of 96%, as shown in Figures 30 and 31. This Dewpoint 3-layer system was compared alongside a composite material obtained from the scientific literature (OPUR), and two commercial composite paints (Astec and Acratex). OPUR is a stand-alone high reflectivity white low-density polyethylene (PE) foil, with 5% volume of TiO₂ microspheres (diameter 0.19 µm) and 2% volume of BaSO₄ microspheres (diameter 0.8 µm) embedded in
- 10 it that was adhered to an Aluminium panel. Acratex is a commercial roofing paint containing elastomeric acrylic polymer (i.e. binder) and titanium as pigment in a low PVC formulation. Astec and Acratex were applied to a primed aluminium substrate, resulting in a total film thickness similar to the Dewpoint 3-layer system (200 µm total dry film thickness). The prepared panels were left outdoors for natural weathering and soiling. The total solar reflectivity of the samples was assessed routinely over a period of 16 weeks
- 15 and are presented in Figure 30. The reflectivity of the Dewpoint 3-layer system is superior to all the materials studied, and remained stable over the first 16 weeks of exposure. Based on the literature, soiling and degradation of the initial reflectance is expected to happen within the first 1-2 months of exposure (Bretz, S. E.; Akbari, H., Long-term performance of high-albedo roof coatings. *Energy and Buildings* **1997**, 25 (2), 159-167). As shown in Figure 31, the emissivity of the Dewpoint 3 layer system remains constant
- 20 throughout the period of study as well.

Example 15

Comparative spectral reflectivity is shown in Figure 32 for a 3-layered system according to the invention as described in Example 1; a single layer system (Dewpoint L2A); and a dual layered system of sub layers L2A-1 and L2B-1.

- 5 The reflectivity of this 3-layered system according to the invention, is higher than the reflectivity of the corresponding 3-layer system shown in Figure 6.

Example 16

- Figure 33 shows that the contact angle hysteresis of the 3-layer system of Example 1 is similar or lower than that of the commercial paints, Astec and Acratex. Moreover, as shown in Figure 34, the roll-off angle of the 3-layer system is lower than those of Astec and Acratex. These findings indicate that the as-designed 3-layer system is particularly suited to collecting atmospheric water. The contact angle hysteresis and roll-off angle of the single layer Dewpoint L2A formulation is higher than the 3-layer system.
- 10

- Roll-off of a 50 μ L water droplet initiated around 22° tilt for the Dewpoint 3-layer system, which is an indication of self-cleaning and easy shedding surface properties. The profile of a 50 μ L water droplet on the surfaces of the Dewpoint 3-layer system, the single layer Dewpoint L2A, Astec and Acratex can be seen in Figure 34.
- 15

Example 17

- The single layer Dewpoint L2A system was tested for its ability to resist soiling (dirt pick-up test), relative to roof commercial paints, Astec and Acratex. The colour of the surface was assessed using a hand-held colour-meter used in the field. The samples were immersed in a suspension of iron oxide nanoparticles 20% by weight for 60 seconds, rinsed with running water for 15 seconds, dried with paper towel and allowed to dry for 24 hours (similar to the standard procedure for dirt pick-up UNI 10792). These samples are shown in Figure 35. The variation in colour was assessed based on change in the colour brightness parameter L before and after the immersion test as shown in the table below. The photographs of the resulting surfaces are shown in Figure 35, with the single layer L2A system shown on the left, Acratex in the centre, and Astec on the right. Based on this test, the single layer L2A system in the formulation (with $\Delta L=0.4$) resists soiling better than the two commercial comparison paints (ΔL close to 10 in both cases).
- 20
- 25

The dirt pickup is expressed through the following classification, based on the ΔL value measured:

Very low ≤ 3

Low from > 3 to ≤ 9

Medium from > 9 to ≤ 15

5 High > 15

The table immediately below shows the brightness values for the samples evaluated in the dirt-pick-up test.

Paint	ΔL
Single layer L2A system	0.4
Commercial A	10.3
Commercial B	9.0

Example 18

10 The function of the H-BN dispersion in the UV-Vis reflective sub-layer (either in a multi-layer system or single layer system) is to increase the reflectivity of the paint layer in the UV region. Figure 36 shows the contribution to reflectivity from this dispersion as a function of thickness of the UV-Vis reflective layer at a composition for 20 % w/w of H-BN. Based on this data, a film thickness of 50 μm is sufficient to achieve maximum reflectivity, with the effect apparently plateauing beyond that thickness.

15 Unless the context clearly requires otherwise, throughout the description and the claims, the words “comprise”, “comprising”, and the like, are to be construed in an inclusive sense as opposed to an exclusive or exhaustive sense, that is to say, in the sense of “including, but not limited to”.

The entire disclosures of all applications, patents and publications cited above and below, if any, are herein incorporated by reference.

20 Reference to any prior art in this specification is not, and should not be taken as, an acknowledgement or any form of suggestion that that prior art forms part of the common general knowledge in the field of endeavour in any country in the world.

The invention may also be said broadly to consist in the parts, elements and features referred to or indicated in the specification of the application, individually or collectively, in any or all combinations of two or more of said parts, elements or features.

Where in the foregoing description reference has been made to integers or components having known
5 equivalents thereof, those integers are herein incorporated as if individually set forth.

It should be noted that various changes and modifications to the presently preferred embodiments described herein will be apparent to those skilled in the art. Such changes and modifications may be made without departing from the spirit and scope of the invention and without diminishing its attendant advantages. It is therefore intended that such changes and modifications be included within
10 the present invention.

Claims

1. A composite material including a plurality of sub-layers, the composite material including:
 - a UV-Vis reflective sub-layer, including boron nitride; and
 - a Vis-Near IR reflective sub-layer, including titanium dioxide.
- 5 2. The composite material of claim 1 wherein the boron nitride in the UV-Vis reflective sub-layer is bound by a water dispersible binder.
3. The composite material of claim 1 or claim 2 wherein the titanium dioxide in the Vis-Near IR reflective sub-layer is bound by a water dispersible binder.
4. The composite material of claim 2 or claim 3 wherein the or each water dispersible binder
10 independently includes at least one functional group selected from hydroxyl, carbonyl, carboxyl, amino, phosphate, amido, ester, and ether.
5. The composite material of any one of claims 2 to 4 wherein the or each water dispersible binder independently includes a polymer including acrylate groups, acetate groups, and/or silicone groups.
6. The composite material of any one of claims 2 to 5 wherein the or each water dispersible binder
15 independently includes a polymer selected from: an acrylic polymer; a polyvinylidene fluoride (PVDF)-acrylic copolymer; styrene-acrylic copolymer; polyvinyl acetate copolymer; vinyl-acrylic copolymer; and a silicone (co)polymer.
7. The composite material according to any one of claims 1 to 6 wherein the boron nitride is hexagonal boron nitride.
- 20 8. The composite material according to any one claims 1 to 7 wherein the boron nitride is unfunctionalised hexagonal boron nitride.
9. The composite material according to claim 2 further including voids and wherein the pigment volume concentration (PVC) of the boron nitride is higher than the critical pigment volume concentration (CPVC) of the boron nitride so as to provide a composite material having voids that form
25 from 1% to 40% by volume of the UV-Vis reflective sub-layer.

10. The composite material according to claim 3 further including voids and wherein the pigment volume concentration (PVC) of the titanium dioxide is higher than the critical pigment volume concentration (CPVC) of the titanium dioxide so as to provide a composite material having voids that form from 1% to 40% by volume of the Vis-Near IR reflective sub-layer.
- 5 11. The composite material according to claim 2 further including voids and wherein the ratio of volume of boron nitride to volume of binder is from 1:1 to 10:1, and the voids form from 1% to 40% by volume of the UV-Vis reflective sub-layer.
12. The composite material according to claim 3 further including voids and wherein the ratio of volume of titanium dioxide to volume of binder is from 1:1 to 10:1, and the voids form from 1% to 40%
10 by volume of the Vis-Near IR reflective sub-layer.
13. A multi-layered system including an optional primer layer; a layer of a composite material according to any one of claims 1 to 12; and a surface coating layer, wherein the order of the layers and sub-layers in the system is: primer layer where present; Vis-Near IR reflective sub-layer; UV-Vis reflective sub-layer; surface coating layer.
- 15 14. The system according to claim 13 as applied to a substrate.
15. The system according to claim 14 wherein the substrate is selected from: steel coated in a combination of aluminium, zinc, and silicon; fibre cement; terracotta tiles; concrete tiles; and polycarbonate sheet.
16. A method of providing a composite material on a substrate, the method including the steps of:
- 20 i) providing a substrate and spreading onto the substrate a first dispersion including:
- an aqueous carrier;
 - a water dispersible binder;
 - titanium dioxide;
- ii) allowing the first dispersion applied to the substrate to at least partially harden, so as to provide
25 a Vis-Near IR reflective sub-layer, including titanium dioxide;
- iii) spreading onto the Vis-Near IR reflective sub-layer a second dispersion including:

- an aqueous carrier;
 - a water dispersible binder;
 - boron nitride;
- iv) allowing the second dispersion applied to the Vis-Near IR reflective sub-layer to at least partially
5 harden, so as to provide a UV-Vis reflective sub-layer, including boron nitride.
17. The method according to claim 16 wherein the aqueous carrier of the first dispersion and the aqueous carrier of the second dispersion are independently selected from water, alcohols, ketones, glycol ethers, esters, and combinations thereof.
18. The method according to claim 16 or claim 17 wherein the water dispersible binder of the first
10 dispersion and the water dispersible binder of the second dispersion each independently include at least one functional group selected from hydroxyl, carbonyl, carboxyl, amino, phosphate, amido, ester, and ether.
19. The method according to any one of claims 16 to 18 wherein the water dispersible binder of the first dispersion and the water dispersible binder of the second dispersion each independently include a
15 polymer including acrylate groups, acetate groups, and/or silicone groups.
20. The method according to any one of claims 16 to 19 wherein the water dispersible binder of the first dispersion and the water dispersible binder of the second dispersion each independently include a polymer selected from: an acrylic polymer; a polyvinylidene fluoride (PVDF)-acrylic copolymer; styrene-acrylic copolymer; polyvinyl acetate copolymer; vinyl-acrylic copolymer; and a silicone (co)polymer.
- 20 21. The method according to any one of claims 16 to 20 wherein the first dispersion is applied directly to the substrate.
22. The method according to any one of claims 16 to 21 wherein the substrate is selected from: steel coated in a combination of aluminium, zinc, and silicon; fibre cement; terracotta tiles; concrete tiles; and polycarbonate sheet.
- 25 23. A composite material produced by the method according to any one of claims 16 to 22.
24. A method for increasing atmospheric condensation on a surface coating, the method including the steps of:

- i) applying the multi-layered system according to claim 13 to a substrate;
- ii) exposing the multi-layered system on the substrate to solar radiation so that water condenses on the surface coating.

25. The method of claim 24 further including the step of collecting at least some of the water that
5 condenses on the surface coating.

26. A composite material including:

- a water dispersible binder;
- particulate material having a critical pigment volume concentration (CPVC); and
- voids;

10 wherein the particulate material is bound by the binder, and the pigment volume concentration (PVC) of the particulate material is higher than the CPVC so as to provide a composite material having voids that form from 1% to 40% by volume of the composite material.

27. A composite material including:

- a water dispersible binder;
- 15 • particulate material; and
- voids;

wherein particulate material is bound by the binder, and the ratio of volume of particulate material to volume of binder is from 1:1 to 10:1, and the voids form from 1% to 40% by volume of the composite material.

20 28. A dispersion including:

- an aqueous carrier;
- a water dispersible binder;
- particulate material;

25 wherein the binder is selected from: an acrylic polymer; a polyvinylidene fluoride (PVDF)-acrylic copolymer; styrene-acrylic copolymer; polyvinyl acetate copolymer; vinyl-acrylic copolymer; and a silicone (co)polymer;

and wherein the particulate material is selected from: calcium carbonate; barium sulphate; talcum powder; kaolin clay; huntite; wollastonite; boron nitride; silica; zinc oxide; zinc phosphate and titanium dioxide; or a combination thereof.

29. A dispersion for use in preparing a composite material according to claim 26 or claim 27.

5 30. A method of forming a composite material, the method including the steps of spreading onto a substrate a dispersion including:

- an aqueous carrier;
- a water dispersible binder;
- particulate material;

10 so as to form a composite material including:

- the water dispersible binder;
- the particulate material having a critical pigment volume concentration (CPVC); and
- voids;

15 wherein the particulate material is bound by the binder, and the pigment volume concentration (PVC) of the particulate material is higher than the CPVC so as to provide a composite material having voids that form from 1% to 40% by volume of the composite material.

31. The method of claim 30 further including the step of allowing the dispersion spread on the substrate to harden by drying or curing so as to form a composite material.

20 32. A method of forming a composite material, the method including the steps of spreading onto a substrate a dispersion including:

- an aqueous carrier;
- a water dispersible binder;
- particulate material;

so as to form a composite material including:

25 • the water dispersible binder;

- the particulate material having a critical pigment volume concentration (CPVC); and

- voids;

wherein particulate material is bound by the binder, and the ratio of volume of particulate material to volume of binder is from 1:1 to 10:1, and the voids form from 1% to 40% by volume of the composite material.

5 33. A coating system for coating at least part of a substrate, including:

- a composite material according to any one of claims 1 to 12, 23, 26, or 27 applied to a substrate; and
- a surface coating applied to the composite material.

34. A method of applying the coating system of claim 33, the method including the steps of
10 performing the method of any one of claims 30 to 32 so as to provide a composite material prior to performing the additional step of applying a liquid to the surface of the composite material, such that the liquid becomes the surface coating.

35. A method for increasing atmospheric condensation on a surface coating, the method including the steps of:

- 15 i) applying the coating system of claim 33 to a substrate so as to provide a substrate coated in the composite material and the surface coating;
- ii) exposing the composite material on the substrate to solar radiation so that water condenses on the surface coating.

36. The method of claim 35 further including the step of collecting at least some of the water that
20 condenses on the surface coating.

37. The composite material, dispersion, system, or method according to any one of claims 26 to 36 wherein the particulate material is boron nitride.

38. The composite material according to claim 26 or claim 27 including a first sub-layer and a second sub-layer, wherein the first sub-layer is substantially UV-Vis reflective and the second sub-layer is
25 substantially Vis-Near IR reflective.

39. The composite material according to claim 38 wherein the first sub-layer includes a particulate material selected from: boron nitride; calcite; and/or barium sulphate, or a combination thereof.
40. The composite material according to claim 38 wherein the second sub-layer includes a particulate material selection from: titanium dioxide; zinc oxide; and/or calcite, or a combination thereof.
- 5
41. A method for reducing temperature gain on a surface of a substrate due to solar radiation, the method including the step of interposing the composite material according to any one of claims 1 to 12, 23, 26 to 27, or 38 to 40 or the system according to any one of claims 13 to 15, or 33 between the surface of the substrate and the solar radiation.
- 10
42. The method according claim 41 wherein the composite material according to any one of claims 1 to 12, 23, 26 to 27, or 38 to 40 or the system according to any one of claims 13 to 15, or 33 forms at least part of a coating on the surface of the substrate.