

STRAIN HARDENING CEMENTITIOUS COMPOSITE, METHOD OF PREPARING, AND USE THEREOF IN TACTILE INDICATOR

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of priority of Singapore patent application number 10202201489T, filed 16 February 2022, the content of which is incorporated herein by reference in its entirety for all purposes.

TECHNICAL FIELD

[0002] Various embodiments relate to a strain hardening cementitious composite, a method of preparing the strain hardening cementitious composite, and use of the strain hardening cementitious composite in a tactile indicator.

BACKGROUND

[0003] Tactile indicators may be used to provide hazard warnings and directional information for blind or visually impaired pedestrians to assist in navigation, particularly in an urban environment. They may be in the form of a series of raised studs or bars, which may be laid on the ground in the form of units or patterns. For example, tactile indicators with a series of raised bars may be made consistent with the prescribed direction of travel on the road, and may be used to safely guide pedestrians along a clear path. Tactile indicators with a grid pattern of raised studs may be used to alert blind or visually impaired pedestrians to obstacles and other potential hazards in their route, indicating that they should stop and assess nature of the danger before proceeding further. With help from patterns formed by the raised studs or bars, blind or visually impaired pedestrians can feel the change in texture through their foot or cane, so as to assist them in navigation.

[0004] In addition to indicating continuous accessible routes to avoid danger, tactile indicators may also be used to provide direction guidance in instances whereby deviation from continuous accessible paths is necessary to enter facilities such as public toilets and transportation facilities. In terms of assisting orientation, tactile indicators are able to provide blind or visually impaired pedestrians with opportunities to enter and/or walk safely and independently in communal spaces.

[0005] State of the art tactile indicators may be produced using materials such as porcelain and concrete. Porcelain-based or porcelain tactile indicators, for example, may be used on pathways in outside environment. Porcelain-based tactile indicators are usually made of clay as main raw materials, and calcined in a kiln at high temperatures. Advantages of porcelain-based tactile indicators may include simple production process, beautiful appearance, and low price. As such, they may be widely used. Porcelain-based tactile indicators have some disadvantages, however, such as lower skid resistance, brittleness, and fragility, resulting in a shorter service life. Moreover, the shattered tactile indicators and/or their dislodged chips also pose danger to pedestrians. In addition, the calcination/sintering process of porcelain involves high energy consumption and carbon footprint, thus rendering it unfriendly to the environment.

[0006] Concrete may also be used to make tactile indicators. Compared with porcelain tactile indicators, concrete tactile indicators may greatly improve skid resistance performance and may be more tough and durable. They may be used, for example, in places where vehicles may run over the tactile indicators or in close vicinity to roadways. To enhance their compressive strength, however, thickness of the concrete tactile indicators may be in the range of 40 mm to 60 mm, which is much larger than that of a porcelain-based tactile indicator (10 mm to 15 mm). As a result, a concrete tactile indicator may be much heavier than a porcelain-based tactile indicator. Similar to that of porcelain-based tactile indicators, production of concrete tactile indicators involves much material, with high cost and carbon footprint.

[0007] In view of the above, there remains a need for an improved material that may be used for manufacturing a tactile indicator.

SUMMARY

[0008] Various embodiments refer in a first aspect to a strain hardening cementitious composite. The strain hardening cementitious composite may comprise a binder, a fine aggregate, a polymer fiber and water, for use in the manufacture of a tactile indicator having a density in the range of about 1500 kg/m³ to about 2300 kg/m³, a compressive strength in the range of about 20 MPa to about 150 MPa, and a ductility in the range of about 1 % to about 5 %.

[0009] Various embodiments refer in a second aspect to a method of preparing a strain cementitious composite according to the first aspect. The method may comprise mixing a binder and a fine aggregate to form a dry mixture, adding water to the dry mixture under agitation to form a wet mixture, adding a polymer fiber to the wet mixture under agitation to form a fiber-dispersed mixture, and curing the fiber-dispersed mixture.

[0010] Various embodiments refer in a third aspect to a tactile indicator made from a strain hardening cementitious composite according to the first aspect, or a strain hardening cementitious composite prepared by a method according to the second aspect.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] In the drawings, like reference characters generally refer to the same parts throughout the different views. The drawings are not necessarily drawn to scale, emphasis instead generally being placed upon illustrating the principles of various embodiments. In the following description, various embodiments of the invention are described with reference to the following drawings.

[0012] **FIG. 1** is a graph showing typical tensile stress-strain curve and crack width development of strain hardening cementitious composites (SHCC) or engineered cementitious composites (ECC). Primary y-axis denotes tensile stress (MPa), secondary y-axis denotes crack width (μm), and x-axis denotes strain (%).

[0013] **FIG. 2** is a schematic diagram showing a dogbone tactile indicator specimen according to an embodiment. In the embodiment shown, length of the dogbone tactile indicator specimen is 350 mm, largest cross-sectional width is 87 mm, smallest cross-sectional width is 36 mm, and thickness is 15 mm.

[0014] **FIG. 3A** is a photograph showing a plan-view of a SHCC tactile indicator specimen according to an embodiment. Width of the specimen is about 300 mm.

[0015] **FIG. 3B** is a photograph showing a side-view of a SHCC tactile indicator specimen according to an embodiment. Thickness of the specimen is about 12 mm, and diameter of each stud is about 5 mm.

[0016] **FIG. 4A** is a photograph showing a porcelain tactile indicator specimen after a steel ball was dropped on it a single time from 300 mm above the specimen. As can be seen, porcelain tactile indicator specimen severely damaged into a few pieces.

[0017] **FIG. 4B** is a photograph showing a SHCC tactile indicator specimen after a steel ball was dropped on it 10 times from heights of 300, 350, 430, 1180, 1180, 1180, 1180, 1180, 1180, and 1180 mm above the specimen. As can be seen, the SHCC tactile indicator specimen only showed very slight surface damage. From comparison with **FIG. 4A**, it is clear that SHCC tactile indicator had much better impact resistance than common porcelain tactile indicator.

DESCRIPTION

[0018] The following detailed description refers to the accompanying drawings that show, by way of illustration, specific details and embodiments in which the invention may be

practised. These embodiments are described in sufficient detail to enable those skilled in the art to practise the invention. Other embodiments may be utilized and structural, logical, and electrical changes may be made without departing from the scope of the invention. The various embodiments are not necessarily mutually exclusive, as some embodiments can be combined with one or more other embodiments to form new embodiments.

[0019] Various embodiments refer in a first aspect to a strain hardening cementitious composite.

[0020] As used herein, the term “strain hardening cementitious composite (SHCC)”, otherwise termed herein as “engineered cementitious composite (ECC)”, refers to a composition or mixture having characteristics of cement and which exhibits strengthening behaviour when a tensile strength is applied to the material. The strengthening behaviour may be exhibited by a cement-based structure or composite formed by the strain hardening cementitious composite.

[0021] Components of the strain hardening cementitious composite disclosed herein may include, but are not limited to, a binder, a fine aggregate, a polymer fiber, and water. The binder, fine aggregate and water may form a cementitious matrix within which the polymer fiber is dispersed. Strengthening behaviour of the strain hardening cementitious composite may result from interaction of the polymer fiber with the other components in the cementitious matrix, such that upon application of a force, the strain hardening cementitious composite is able to demonstrate superior tensile ductility. This may be in the form of formation of multiple microcracks with tight or limited crack width, instead of few large cracks seen in conventional concrete. The superior tensile ductility may result in stronger corrosion resistance and improve potential for cracks in SHCC-based structures to self-heal, to result in enhanced environmental durability.

[0022] Advantageously, strain hardening cementitious composites disclosed herein may be used to manufacture a tactile indicator having a density in the range of about 1500 kg/m³ to about 2300 kg/m³, a compressive strength in the range of about 20 MPa to about 150 MPa, and a ductility in the range of about 1 % to about 5 %. Due to the improved physical properties, for example in durability as well as crack and impact resistance, tactile indicators formed using the strain hardening cementitious composite disclosed herein may be particularly useful in places with high loading, such as at locations at or in close vicinity to vehicular roads whereby vehicles may go over them. As compared to state of the art porcelain-based tactile indicators, skid resistance performance of tactile indicators disclosed herein may also be greatly improved without adverse increase in thickness. Given the similarity in thickness, this may provide greater ease in replacement of existing porcelain-based tactile indicators, particularly in applications whereby high anti-slip performance is required.

[0023] In various embodiments, the strain hardening cementitious composite comprises a binder, a fine aggregate, a polymer fiber and water.

[0024] As used herein, the term "binder" refers to a material that is capable of attaching two or more materials to one another such that the two or more materials are held together. The binder may be selected from the group consisting of ordinary Portland cement, coal fly ash, a pozzolanic admixture, and a combination thereof.

[0025] In some embodiments, the binder comprises or consists of ordinary Portland cement. Ordinary Portland cement may be considered as a hydraulic cement, which refers to cement that sets and hardens in the presence of water. Portland cements may be classified under ASTM standards (C 150-04) into various types, such as Type I to V, depending on intended use. In some embodiments, the ordinary Portland cement comprises or consists of a Type I Portland cement of grade 42.5 or 52.5. Grade 42.5 refers to the Type I Portland cement having a strength

of 42.5 MPa (42.5 N/mm²), while grade 52.5 refers to the Type I Portland cement having a strength of 52.5 MPa (52.5 N/mm²).

[0026] In various embodiments, the binder comprises or consists of coal fly ash. Advantageously, coal fly ash may increase fluidity and may improve the rheological properties of the strain hardening cementitious composite. This may be due to its shape which may be spherical, which decreases inter-particle friction. Coal fly ash may be classified under ASTM standards (C 618) into two types: Class F and Class C. In some embodiments, the coal fly ash comprises or consists of a Class F fly ash. Class F fly ash may originate from anthracite and bituminous coals, and may comprise mainly of alumina and silica.

[0027] In various embodiments, the binder comprises or consists of a pozzolanic admixture. The term “pozzolanic admixture” as used herein refers generally to a material that is capable of setting and hardening upon contact with water. In so doing, a bonding effect may be provided by the pozzolanic admixture. The pozzolanic admixture may be selected from the group consisting of silica fume, ground granulated blast-furnace slag, and a combination thereof. The addition of such pozzolanic admixture as binders may greatly reduce cost of production since they may be obtained from industrial wastes, and may contribute to improved mechanical performance through cementitious and pozzolanic reactions.

[0028] In addition to a binder, the strain hardening cementitious composite disclosed herein may comprise a fine aggregate. As used herein, the term “fine aggregate” refers to aggregates or particles which are relatively small in size, such as particles having a size range as defined in ASTM C33. The fine aggregate may be used to adjust physical and mechanical properties of the strain hardening cementitious composite depending on intended use.

[0029] In various embodiments, the fine aggregate comprised in the strain hardening cementitious composite comprises or consists of micro silica sand. The micro silica sand may have a size in the range of about 100 μm to about 180 μm, such as in the range of about 120

μm to about 180 μm, about 140 μm to about 180 μm, about 160 μm to about 180 μm, about 100 μm to about 160 μm, about 100 μm to about 140 μm, about 100 μm to about 120 μm, about 120 μm to about 160 μm, or about 110 μm to about 150 μm.

[0030] As mentioned above, the strain hardening cementitious composite may comprise water in addition to the binder and the fine aggregate. Weight ratio of water to the binder may be in the range of about 0.15 to about 0.5, such as about 0.2 to about 0.5, about 0.3 to about 0.5, about 0.15 to about 0.4, about 0.15 to about 0.3, or about 0.2 to about 0.4.

[0031] In various embodiments, the strain hardening cementitious composite further comprises a water reducing agent. The water reducing agent may be selected from the group consisting of carboxylated polymer, gypsum, anhydrite, and a combination thereof.

[0032] The water reducing agent may be present, or varied in amounts depending on the amount of water present, to adjust rheological properties such as viscosity of the strain hardening cementitious composite according to requirements or intended use. Weight ratio of the water reducing agent to the binder may be in the range of about 0.004 to about 0.02. For example, weight ratio of the water reducing agent to the binder may be in the range of about 0.005 to about 0.02, about 0.01 to about 0.02, about 0.015 to about 0.02, about 0.004 to about 0.015, about 0.004 to about 0.01, or about 0.01 to about 0.015.

[0033] In various embodiments, the strain hardening cementitious composite comprises a polymer fiber. As mentioned above, the polymer fiber may be dispersed in a cementitious matrix formed by the binder, fine aggregate and water. Due to interaction of the polymer fiber with components in the cementitious matrix, strengthening of the strain hardening cementitious composite may result, and strain hardening as well as superior tensile ductility of a cement-based structure or composite, such as a tactile indicator, formed by the strain hardening cementitious composite may be achieved.

[0034] In various embodiments, the polymer fiber is selected from the group consisting of a polyvinyl alcohol fiber, a polyethylene fiber, a polypropylene fiber, and a combination thereof.

[0035] In some embodiments, the polymer fiber is a polyvinyl alcohol fiber. The polyvinyl alcohol fiber may have a length of about 6 mm to about 18 mm, diameter of about 10 μm to about 100 μm and density of about 1200 kg/m^3 to about 1500 kg/m^3 .

[0036] For example, the polyvinyl alcohol fiber may have a length of about 6 mm to about 18 mm, such as about 8 mm to about 18 mm, about 10 mm to about 18 mm, about 12 mm to about 18 mm, about 14 mm to about 18 mm, about 6 mm to about 16 mm, about 6 mm to about 14 mm, about 6 mm to about 12 mm, about 6 mm to about 10 mm, about 8 mm to about 16 mm, or about 10 mm to about 14 mm.

[0037] As a further example, the polyvinyl alcohol fiber may have a diameter of about 10 μm to about 100 μm . The term “diameter” is used herein to describe a maximal cross-sectional width of the fiber, regardless of the cross-sectional shape of the fiber, which could be circular or non-circular. In various embodiments, the polyvinyl alcohol fiber may have a diameter of about 20 μm to about 100 μm , about 30 μm to about 100 μm , about 40 μm to about 100 μm , about 50 μm to about 100 μm , about 60 μm to about 100 μm , about 10 μm to about 90 μm , about 10 μm to about 80 μm , about 10 μm to about 70 μm , about 10 μm to about 60 μm , about 10 μm to about 50 μm , about 10 μm to about 40 μm , about 20 μm to about 90 μm , about 30 μm to about 80 μm , about 30 μm to about 60 μm , or about 30 μm to about 40 μm .

[0038] The polyvinyl alcohol fiber may have a density of about 1200 kg/m^3 to about 1500 kg/m^3 , such as about 1250 kg/m^3 to about 1500 kg/m^3 , about 1300 kg/m^3 to about 1500 kg/m^3 , about 1350 kg/m^3 to about 1500 kg/m^3 , about 1400 kg/m^3 to about 1500 kg/m^3 , about 1200 kg/m^3 to about 1450 kg/m^3 , about 1200 kg/m^3 to about 1400 kg/m^3 , about 1200 kg/m^3 to about 1350 kg/m^3 , about 1200 kg/m^3 to about 1300 kg/m^3 , about 1250 kg/m^3 to about 1450 kg/m^3 , or about 1300 kg/m^3 to about 1400 kg/m^3 .

[0039] In specific embodiments, the polyvinyl alcohol fiber has a length of about 12 mm, diameter of about 39 μm and density of about 1300 kg/m^3 .

[0040] In some embodiments, the polymer fiber is a polyethylene fiber. The polyethylene fiber may have a length of about 6 mm to about 18 mm, diameter of about 10 μm to about 80 μm and density of about 800 kg/m^3 to about 1000 kg/m^3 .

[0041] The polyethylene fiber may, for example, have a length of about 6 mm to about 18 mm, such as about 8 mm to about 18 mm, about 10 mm to about 18 mm, about 12 mm to about 18 mm, about 14 mm to about 18 mm, about 6 mm to about 16 mm, about 6 mm to about 14 mm, about 6 mm to about 12 mm, about 6 mm to about 10 mm, about 8 mm to about 16 mm, or about 10 mm to about 14 mm.

[0042] In various embodiments, the polyethylene fiber may have a diameter of about 10 μm to about 80 μm , such as about 20 μm to about 80 μm , about 30 μm to about 80 μm , about 40 μm to about 80 μm , about 50 μm to about 80 μm , about 60 μm to about 80 μm , about 10 μm to about 70 μm , about 10 μm to about 60 μm , about 10 μm to about 50 μm , about 10 μm to about 40 μm , about 20 μm to about 70 μm , about 30 μm to about 60 μm , about 10 μm to about 20 μm , or about 15 μm to about 25 μm .

[0043] The polyethylene fiber may have a density of about 800 kg/m^3 to about 1000 kg/m^3 , such as about 850 kg/m^3 to about 1000 kg/m^3 , about 900 kg/m^3 to about 1000 kg/m^3 , about 950 kg/m^3 to about 1000 kg/m^3 , about 800 kg/m^3 to about 950 kg/m^3 , about 800 kg/m^3 to about 900 kg/m^3 , about 800 kg/m^3 to about 850 kg/m^3 , or about 850 kg/m^3 to about 950 kg/m^3 .

[0044] In specific embodiments, the polyethylene fiber has a length of about 18 mm, diameter of about 19 μm and density of about 950 kg/m^3 .

[0045] The polymer fiber may be present in the strain hardening cementitious composite, such that volume ratio of the polymer fiber to the strain hardening cementitious composite is in the range of about 0.01 to about 0.02. For example, volume ratio of the polymer fiber to the

strain hardening cementitious composite may be in the range of about 0.012 to about 0.02, about 0.015 to about 0.02, about 0.01 to about 0.018, about 0.01 to about 0.016, or about 0.012 to about 0.018.

[0046] Various embodiments of a strain hardening cementitious composites disclosed herein have compositions suitable for use in the manufacture of a tactile indicator having a density in the range of about 1500 kg/m³ to about 2300 kg/m³, a compressive strength in the range of about 20 MPa to about 150 MPa, and a ductility in the range of about 1 % to about 5 %.

[0047] The term “tactile” as used herein refers to a characteristic or feature that is perceptible or distinguishable by a sense of touch. Examples may include, but are not limited to, textures, temperature, softness, and/or patterns. The term “tactile indicator” refers accordingly to a structure or device providing a characteristic or feature that is perceptible or distinguishable by a sense of touch of a user. As mentioned above, tactile indicators may be used to provide hazard warnings and directional information for visually impaired individuals to assist in their navigation. By placing tactile indicators at areas near to danger zones, such as pavement areas near to vehicular road kerbs, visually impaired individuals are alerted to these danger zones upon contact of the tactile indicators by their feet or walking cane, and can therefore avoid them.

[0048] In various embodiments, the tactile indicator has a density in the range of about 1500 kg/m³ to about 2300 kg/m³. The density may be determined using procedures set out in ASTM D792. Examples of suitable densities may include density within a range such as about 1600 kg/m³ to about 2300 kg/m³, about 1700 kg/m³ to about 2300 kg/m³, about 1800 kg/m³ to about 2300 kg/m³, about 1900 kg/m³ to about 2300 kg/m³, about 2000 kg/m³ to about 2300 kg/m³, about 2100 kg/m³ to about 2300 kg/m³, about 1500 kg/m³ to about 2200 kg/m³, about 1500 kg/m³ to about 2100 kg/m³, about 1500 kg/m³ to about 2000 kg/m³, about 1500 kg/m³ to about

1900 kg/m³, about 1600 kg/m³ to about 2200 kg/m³, about 1700 kg/m³ to about 2100 kg/m³, or about 1800 kg/m³ to about 2000 kg/m³.

[0049] Compressive strength may provide measure of a material's ability to withstand an external force. The compressive strength may be determined using procedures set forth in ASTM C39. In various embodiments, the tactile indicator has a compressive strength in the range of about 20 MPa to about 150 MPa, such as about 30 MPa to about 150 MPa, about 40 MPa to about 150 MPa, about 50 MPa to about 150 MPa, about 60 MPa to about 150 MPa, about 70 MPa to about 150 MPa, about 80 MPa to about 150 MPa, about 90 MPa to about 150 MPa, about 100 MPa to about 150 MPa, about 120 MPa to about 150 MPa, about 20 MPa to about 140 MPa, about 20 MPa to about 130 MPa, about 20 MPa to about 120 MPa, about 20 MPa to about 100 MPa, about 20 MPa to about 80 MPa, about 20 MPa to about 60 MPa, about 30 MPa to about 140 MPa, about 40 MPa to about 120 MPa, or about 50 MPa to about 100 MPa.

[0050] Ductility may provide measure of a material's ability to deform under tensile stress, and may refer to a percentage increase in length of the material prior to its failure in a tensile test. In various embodiments, the tactile indicator has a ductility in the range of about 1 % to about 5 %, such as about 2 % to about 5 %, about 3 % to about 5 %, about 4 % to about 5 %, about 1 % to about 4 %, about 1 % to about 3 %, about 1 % to about 2 %, about 2 % to about 4 %, or about 2 % to about 3 %.

[0051] Various embodiments refer in a second aspect to a method of preparing a strain cementitious composite according to the first aspect.

[0052] The method may comprise mixing a binder and a fine aggregate to form a dry mixture, adding water to the dry mixture under agitation to form a wet mixture, adding a polymer fiber to the wet mixture under agitation to form a fiber-dispersed mixture, and curing the fiber-dispersed mixture.

[0053] Suitable binder, fine aggregate and polymer fiber, and their respective amounts and/or relative proportions have already been discussed above.

[0054] For example, the binder may be selected from the group consisting of ordinary Portland cement, coal fly ash, a pozzolanic admixture, and a combination thereof. In specific embodiments, the binder comprises or consists of ordinary Portland cement, which may in turn, comprise or consist of a Type I Portland cement of grade 42.5 or 52.5. Alternatively or additionally, the binder may comprise coal fly ash, such as a Class F fly ash.

[0055] As mentioned above, the fine aggregate comprised in the strain hardening cementitious composite may comprise or consist of micro silica sand, and the polymer fiber may be selected from the group consisting of a polyvinyl alcohol fiber, a polyethylene fiber, a polypropylene fiber, and a combination thereof.

[0056] Mixing of the binder and the fine aggregate to form a dry mixture may be carried out using any suitable agitating device or mixer, such as a concrete or mortar mixer. Mixing may be carried out at a suitable speed, such as a mixing speed in the range from about 40 rpm to about 60 rpm, and for a suitable duration, such as a few minutes, for example about 3 minutes to about 5 minutes.

[0057] Water may be added to the dry mixture under agitation to form a wet mixture. For example, water may be mixed into the dry mixture under continuous mixing at a suitable speed, such as a mixing speed in the range from about 100 rpm to about 120 rpm, for a suitable time period, such as within one minute or for a few minutes.

[0058] In various embodiments, adding water to the dry mixture comprises adding a water reducing agent along with the water to the dry mixture. As mentioned above, the water reducing agent may be selected from the group consisting of carboxylated polymer, gypsum, anhydrite, and a combination thereof.

[0059] By adding a water reducing agent along with the water to the dry mixture, rheological properties such as viscosity of the strain hardening cementitious composite may be adjusted according to requirements or intended use.

[0060] The method disclosed herein may comprise adding a polymer fiber to the wet mixture under agitation to form a fiber-dispersed mixture. The mixing may be carried out for a suitable duration and at a suitable mixing speed to achieve suitable fiber dispersion homogeneity depending on intended use. For example, mixing may be carried out at a mixing speed in the range from about 70 rpm to about 90 rpm, for few minutes such as about 3 minutes to about 15 minutes.

[0061] In so doing, the polymer fiber may be embedded in the wet mixture, and interaction of the polymer fiber with the other components, such as binder and fine aggregate, in the strain hardening cementitious composite may take place.

[0062] In various embodiments, the method disclosed herein comprises curing the fiber-dispersed mixture.

[0063] The curing may be carried out for any suitable duration, such as in the range from about 7 days to about 28 days, about 10 days to about 28 days, about 14 days to about 28 days, about 21 days to about 28 days, about 7 days to about 21 days, or about 14 days to about 21 days. An increased curing duration may advantageously result in improvement in tensile strength and reduction in strain hardening.

[0064] In some embodiments, curing the fiber-dispersed mixture comprises disposing the fiber-dispersed mixture in a mould, and curing the fiber-dispersed mixture under ambient conditions.

[0065] By the term “ambient conditions”, this may refer to a temperature selected from a range from about 25 °C to about 40 °C, such as about 28 °C to about 40 °C, about 30 °C to about 40 °C, about 25 °C to about 35 °C, or about 30 °C to about 35 °C, at atmospheric pressure

such as about 1.0 to about 1.2 atmospheres, and at a suitable relative humidity, such as a relative humidity of above 50 %, such as above 60 %, above 70 %, above 80 %, or about 90 %.

[0066] In some embodiments, the curing may be carried out at elevated temperatures such as a temperature in the range of 50 °C to 90 °C. The curing may be carried out via steam curing. Advantageously, use of elevated temperatures may accelerate cement hydration and reduce curing time period. In embodiments whereby the strain cementitious composite is cured in a mould, the mould may be removed within a shorter timeframe for reuse. This may result in improved productivity.

[0067] In various embodiments, the tactile indicator can be cured in saturated lime water. By the term “saturated lime water”, this refers to water which is saturated with calcium hydroxide (lime). This may be used for strain cementitious composites containing concrete to prevent leaching of calcium or calcium carbonate from the concrete comprised in the strain cementitious composite.

[0068] Various embodiments refer in a third aspect to a tactile indicator made from a strain hardening cementitious composite according to the first aspect or prepared by a method according to the second aspect.

[0069] Advantageously, because of their ability to achieve high ductility value which may be up to 3 % in direct tension as well as multiple small crack width, strain hardening cementitious composites disclosed herein may be more tough, durable and sustainable than ordinary concrete material. Therefore, unlike normal concrete tactile indicators which is much thicker than porcelain tactile indicators, tactile indicators disclosed herein can be made into the same thickness and shape as conventional porcelain tactile indicators but can have the properties of better durability and crack resistance, which may lead to longer service time.

[0070] In various embodiments, the tactile indicator has a thickness in the range of about 8 mm to about 15 mm, such as about 10 mm to about 15 mm, about 12 mm to about 15 mm,

about 8 mm to about 12 mm, about 8 mm to about 10 mm, about 10 mm to about 13 mm, or about 9 mm to about 14 mm.

[0071] The tactile indicator may have any suitable shape and dimension, and/or patterns and textures formed thereon.

[0072] In order that the invention may be readily understood and put into practical effect, particular embodiments will now be described by way of the following non-limiting examples.

[0073] **EXAMPLES**

[0074] Embodiments disclosed herein relate to a novel type of tactile indicators made of Strain Hardening Cementitious Composites (SHCC), which are also called Engineered Cementitious Composites (ECC). They are a special class of High Performance Fibre Reinforced Cementitious Composites (HPFRCC) which are distinct for the tensile strain-hardening behaviour and tensile ductility contrasting to the quasi-brittle nature of ordinary concrete and fibre reinforced concrete (FRC). SHCC may contain special types of synthetic fibers besides cement and aggregate. Micromechanics-based design approach may be used to guide component tailoring to ensure synergetic interaction among different components and to maintain the required strength and ductility of SHCC for various applications. Typical tensile stress-strain curve and crack width development of SHCC are shown in **FIG. 1**.

[0075] The SHCC tactile indicators according to embodiments disclosed herein have strain hardening properties. They can be made into the same thickness and shape as the conventional porcelain tactile indicators. Compared with the concrete tactile indicator, thickness and weight of the SHCC tactile indicator as presently disclosed can be greatly reduced. On the other hand, slip resistance, durability and crack resistance of the SHCC tactile indicator disclosed herein may be greatly improved compared with porcelain tactile indicators, which provides them with much longer service time.

[0076] Compared with state of the art tactile indicators such as porcelain tactile indicators and ordinary concrete tactile indicators, the SHCC tactile indicators disclosed herein have demonstrated strain hardening performance and therefore are much more durable and resistant to crack and impact.

[0077] Compared with ordinary concrete tactile indicators, the SHCC tactile indicators disclosed herein have much reduced thickness and weight, which reduces the use of raw materials, as well as cost like transportation and construction.

[0078] The SHCC tactile indicators disclosed herein have demonstrated skid resistance value of above 44 BPN after 100,000 load cycles (500 N applied load from a wheel tracking machine).

[0079] Service time of the SHCC tactile indicators disclosed herein is much longer than state of the art tactile indicators, such as traditional porcelain tactile indicators and ordinary concrete tactile indicators, and therefore, from the view of whole life cycle, cost and carbon footprint can be reduced.

[0080] In various embodiments, the SHCC tactile indicators have a thickness between 8 and 15 mm, a density between 1500 and 2300 kg/m³, a compressive strength between 20 and 150 MPa, and a ductility performance between 1 and 5 percentage. The design of such SHCC tactile indicators with aforementioned physical and mechanical properties are based on the understanding of the performance of SHCC disclosed herein.

[0081] In various embodiments, SHCC disclosed herein may comprise binder, fine aggregate, water, and polymer fiber. Other constituents, such as water reducing agent, may be used to adjust thixotropic rheology and viscosity characteristics to achieve adequate workability and dispersion of fiber.

[0082] The binder may comprise ordinary Portland cement (OPC), coal fly ash, and other pozzolanic admixtures. In various embodiments, the OPC comprises or consists of Type I

Portland cement with grade of 42.5 or 52.5. In some embodiments, coal fly ash comprises or consists of class F fly ash. Other pozzolanic admixtures may refer to any supplementary cementitious materials that has pozzolanic reaction with hydrated cement, which includes but not limited to a group consisting of silica fume and ground granulated blast-furnace slag.

[0083] Fine aggregates may comprise micro silica sand with a size between 100 and 180 micros in SHCC. Advantageously, fine aggregate may be used in SHCC to achieve desired physical and mechanical properties.

[0084] In various embodiments, water may be present in the fresh mixture in conjunction with water reducing agent to achieve desired rheological properties. A water-to-binder ratio between 0.15 and 0.5 may be used to achieve desired strength. Water reducing agent may be used to adjust workability after the water content in the composite is determined, and the quantity used may vary with the water-to-binder ratio and the type of water reducing agent. An illustrative water reducing agent comprises superplasticizer available as ADVA 181 from W. R. Grace & Co., IL, USA, and amount used in embodiments disclosed herein may be about 0.004 to 0.02 in weight ratio of the water reducing agent to binder.

[0085] In various embodiments, the polymer fiber comprises polyvinyl alcohol (PVA) fiber and polyethylene (PE) fiber. Polymer fiber may be used in SHCC to achieve strain hardening performance and desired ductility. An exemplary PVA fiber is 12 mm in length, 39 μm in diameter, and 1300 kg/m^3 in density, available from Kuraray Ltd., Japan. An exemplary PE fiber is 18 mm in length, 19 μm in diameter, and 950 kg/m^3 in density, available as Dyneema[®] from DSM. The typical amount of polymer fiber used may be in the range of about 0.01 to 0.02 in volumetric ratio of the total mix.

[0086] The mix preparation according to embodiments can be practiced in any type of concrete or mortar mixer. Binders and fine aggregate may first be dry-mixed. Water and water reducer may then be added into the dry mixture and mixed till the required rheology of mortar.

Polymer fiber may then be gradually added into mortar and mixed till the required fiber dispersion homogeneity followed by casting, rising, pre-curing, and curing. Curing may be done in room temperature, saturated lime water, or elevated temperature (e.g. steam curing).

[0087] **Example 1**

[0088] The exemplary mix here below for preparing Strain Hardening Cementitious Composites (SHCC) tactile indicators are tabulated in **TABLE 1**.

[0089] **TABLE 1:** Mix proportion of Example 1

Mix ID	OPC kg/m ³	Fly ash kg/m ³	Micro silica sand kg/m ³	Water kg/m ³	Water reducing agent kg/m ³	PVA fiber kg/m ³
SHCC	570	684	455	331	4.9	26

[0090] The mixture was prepared in a mortar mixer with a planetary rotating blade. OPC, fly ash, and micro silica sand were dry mixed with a low mixing speed of 40-60 rpm for three minutes, followed by gradually addition of water and water reducer within one minute. The mortar mixed continuously for another three to five minutes with a high mixing speed of 100-120 rpm to achieve the required rheology of paste. Afterwards, the PVA fiber were gradually added into the mixture with a medium mixing speed of 70-90 rpm within three minutes, followed by continuously mixing for another five to eight minutes to achieve required fiber dispersion homogeneity.

[0091] The fresh mixture was cast into moulds with proper vibration. The moulds were covered with plastics to prevent water evaporation and the specimens were cured in lab ambient for 24 hours. Specimen were demoulded after 24 hours and then cured in laboratory air for 28 days.

[0092] Compression tests were conducted using 50 mm cube specimen at the age of 28 days. The loading rate was 0.50 mm/min and only peak loads were recorded. The average of the compressive strength of SHCC was 50.2 MPa.

[0093] Direct tension tests were conducted using dogbone specimen as shown in **FIG. 2**. The loading rate was 0.50 mm/min under uniaxial tensile loading. The average tensile strain was 2.7 %, and the average maximum tensile strength was 4.96 MPa.

[0094] Impact resistance tests were conducted using tactile indicator specimens with the width of 300 mm and thickness of 12 mm as shown in **FIG. 3A** and **FIG. 3B**. A state of the art porcelain tactile indicator with the same size, i.e. one having same thickness and width, as the SHCC one was used as a control group. The impact resistance was determined using a 6.5 kg steel ball dropped on the middle of the tactile indicator specimen from 300-1180 mm above the specimen.

[0095] The porcelain tactile indicator specimen severely damaged into a few pieces after a single drop of steel ball from 300 mm above the specimen as shown in **FIG. 4A**. However, the SHCC tactile indicator specimen only showed very slight surface damage even after the steel ball was dropped 10 times from heights of 300, 350, 430, 1180, 1180, 1180, 1180, 1180, 1180, 1180 mm respectively as shown in **FIG. 4B**. From the results obtained, it is clear that SHCC tactile indicator had much better impact resistance than common porcelain tactile indicator.

[0096] The above results indicate that using Strain Hardening Cementitious Composites (SHCC) to make tactile indicators is viable and could potentially lead to significant reduction in terms of cost and carbon footprint from the view of whole life cycle. Due to good properties of durability and crack and impact resistance, this type of tactile indicators is particularly useful in places where vehicles may cross over the tactile indicators or in close vicinity to roadways. In addition, compared with porcelain tactile indicators, the skid resistance performance of SHCC tactile indicators may be greatly improved, while the thickness can be kept unchanged, which makes it possible to replace existing porcelain tactile indicators where high anti-slip performance is required.

[0097] By “comprising” it is meant including, but not limited to, whatever follows the word “comprising”. Thus, use of the term “comprising” indicates that the listed elements are required or mandatory, but that other elements are optional and may or may not be present.

[0098] By “consisting of” is meant including, and limited to, whatever follows the phrase “consisting of”. Thus, the phrase “consisting of” indicates that the listed elements are required or mandatory, and that no other elements may be present.

[0099] The inventions illustratively described herein may suitably be practiced in the absence of any element or elements, limitation or limitations, not specifically disclosed herein. Thus, for example, the terms “comprising”, “including”, “containing”, etc. shall be read expansively and without limitation. Additionally, the terms and expressions employed herein have been used as terms of description and not of limitation, and there is no intention in the use of such terms and expressions of excluding any equivalents of the features shown and described or portions thereof, but it is recognized that various modifications are possible within the scope of the invention claimed. Thus, it should be understood that although the present invention has been specifically disclosed by preferred embodiments and optional features, modification and variation of the inventions embodied therein herein disclosed may be resorted to by those skilled in the art, and that such modifications and variations are considered to be within the scope of this invention.

[00100] By “about” in relation to a given numerical value, such as for temperature and period of time, it is meant to include numerical values within 10% of the specified value.

[00101] The invention has been described broadly and generically herein. Each of the narrower species and sub-generic groupings falling within the generic disclosure also form part of the invention. This includes the generic description of the invention with a proviso or negative limitation removing any subject matter from the genus, regardless of whether or not the excised material is specifically recited herein.

[00102] Other embodiments are within the following claims and non- limiting examples. In addition, where features or aspects of the invention are described in terms of Markush groups, those skilled in the art will recognize that the invention is also thereby described in terms of any individual member or subgroup of members of the Markush group.

CLAIMS

1. A strain hardening cementitious composite comprising a binder, a fine aggregate, a polymer fiber and water, for use in the manufacture of a tactile indicator having a density in the range of about 1500 kg/m³ to about 2300 kg/m³, a compressive strength in the range of about 20 MPa to about 150 MPa, and a ductility in the range of about 1 % to about 5 %.
2. The strain hardening cementitious composite according to claim 1, wherein the binder is selected from the group consisting of ordinary Portland cement, coal fly ash, a pozzolanic admixture, and a combination thereof.
3. The strain hardening cementitious composite according to claim 2, wherein the ordinary Portland cement comprises or consists of a Type I Portland cement of grade 42.5 or 52.5.
4. The strain hardening cementitious composite according to claim 2 or 3, wherein the coal fly ash comprises or consists of a Class F fly ash.
5. The strain hardening cementitious composite according to any one of claims 2 to 4, wherein the pozzolanic admixture is selected from the group consisting of silica fume, ground granulated blast-furnace slag, and a combination thereof.
6. The strain hardening cementitious composite according to any one of claims 1 to 5, wherein the fine aggregate comprises or consists of micro silica sand.

7. The strain hardening cementitious composite according to claim 6, wherein the micro silica sand has a size in the range of about 100 μm to about 180 μm .
8. The strain hardening cementitious composite according to any one of claims 1 to 7, wherein weight ratio of water to the binder is in the range of about 0.15 to about 0.5.
9. The strain hardening cementitious composite according to any one of claims 1 to 8, wherein the strain hardening cementitious composite further comprises a water reducing agent.
10. The strain hardening cementitious composite according to claim 9, wherein the water reducing agent is selected from the group consisting of carboxylated polymer, gypsum, anhydrite, and a combination thereof.
11. The strain hardening cementitious composite according to claim 9 or 10, wherein weight ratio of the water reducing agent to the binder is in the range of about 0.004 to about 0.02.
12. The strain hardening cementitious composite according to any one of claims 1 to 11, wherein the polymer fiber is selected from the group consisting of a polyvinyl alcohol fiber, a polyethylene fiber, a polypropylene fiber, and a combination thereof.
13. The strain hardening cementitious composite according to claim 12, wherein the polymer fiber is a polyvinyl alcohol fiber.

14. The strain hardening cementitious composite according to claim 13, wherein the polyvinyl alcohol fiber has a length of about 6 mm to about 18 mm, diameter of about 10 μm to about 100 μm and density of about 1200 kg/m^3 to about 1500 kg/m^3 .
15. The strain hardening cementitious composite according to claim 13 or 14, wherein the polyvinyl alcohol fiber has a length of about 12 mm, diameter of about 39 μm and density of about 1300 kg/m^3 .
16. The strain hardening cementitious composite according to claim 12, wherein the polymer fiber is a polyethylene fiber.
17. The strain hardening cementitious composite according to claim 16, wherein the polyethylene fiber has a length of about 6 mm to about 18 mm, diameter of about 10 μm to about 80 μm and density of about 800 kg/m^3 to about 1000 kg/m^3 .
18. The strain hardening cementitious composite according to claim 16 or 17, wherein the polyethylene fiber has a length of about 18 mm, diameter of about 19 μm and density of about 950 kg/m^3 .
19. The strain hardening cementitious composite according to any one of claims 1 to 18, wherein volume ratio of the polymer fiber to the strain hardening cementitious composite is in the range of about 0.01 to about 0.02.
20. A method of preparing a strain cementitious composite according to any one of claims 1 to 19, the method comprising:

mixing a binder and a fine aggregate to form a dry mixture,
adding water to the dry mixture under agitation to form a wet mixture,
adding a polymer fiber to the wet mixture under agitation to form a fiber-dispersed mixture, and
curing the fiber-dispersed mixture.

21. The method according to claim 20, wherein adding water to the dry mixture comprises adding a water reducing agent along with the water to the dry mixture.
22. The method according to claim 21, wherein curing the fiber-dispersed mixture comprises disposing the fiber-dispersed mixture in a mould, and curing the fiber-dispersed mixture under ambient conditions.
23. A tactile indicator made from a strain hardening cementitious composite according to any one of claims 1 to 19 or prepared by a method according to any one of claims 20 to 22.
24. The tactile indicator according to claim 23, wherein the tactile indicator has a thickness in the range of about 8 mm to about 15 mm.