

STRAIN HARDENING CEMENTITIOUS COMPOSITES FOR RIGID
PAVEMENT REHABILITATION

Cross-Reference to Related Application

- 5 **[0001]** This application claims the benefit of priority of Singapore Patent Application No. 10202302041P, filed 19 July 2023, the content of it being hereby incorporated by reference in its entirety for all purposes.

Technical Field

- 10 **[0002]** The present disclosure relates to a cementitious formulation and a method for forming the cementitious formulation.

Background

- 15 **[0003]** Pavements generally consist of two types, asphalt-based pavement and rigid pavement. Each type may have its strengths and weaknesses, and may be used for different purposes. In most countries, such as Singapore, flexible pavements may be mostly used on roadways. Rigid pavements may also be applied on roadways, but they may also be suitable for specific applications, namely bus bays, bus stops, and road intersections. Rigid pavement, if designed and constructed properly, may provide
20 excellent long-term performance with less maintenance required.

- 25 **[0004]** Asphaltic-based (flexible) pavement tend to be used for roadway because it offers a few benefits including a good roughness index, quick construction and fast open-to-traffic, and good comfort as there is no joint needed. However, there are disadvantages of flexible pavement, such as lower service-life compared to rigid pavement, and it may be prone to rutting. Rutting (permanent deformation, e.g., formation of grooves, tracks, depressions, surface wear off) tends to be a potential failure mode of flexible pavement. Truck and bus heavy wheel loadings, particularly when slow-moving or standing, and during hot weather, subject the flexible pavement to stress and/or strain conditions, which may cause rutting. Further, high stress and/or
30 strain conditions at intersections, bus bays, and sections of truck and bus routes with slow speeds (uphill, for instance) may accelerate the deformation even faster and more severely.

[0005] A few specific applications including road intersections, bus bays, and sections of truck and bus routes with slow speeds may be made of concrete-based (rigid) pavement. Yet, this may not be regarded as an ideal solution to rutting. Rigid pavement comes with its advantages and disadvantages. Rigid pavement may have higher resistance to rutting, and may be more durable than flexible pavement. However, rigid pavement when cast in situ requires a long time until the lane may be opened for use to traffic, as concrete may require 14 to 28 days (of curing) to achieve the desired strength. An additive may be used to accelerate performance, but it comes with consequences of higher cost. The longer a lane or pavement stays closed, the longer the disruption to the user, i.e., the delay affects the comfort of a user and significantly increases the user's time and/or cost from such delay. In the context of Singapore, the cost due to construction delay may be even more significant.

[0006] A pavement may deteriorate significantly after a few years of exposure to traffic and temperature loads. Thus, a pavement may need to be proactively maintained, which may be referred to as pavement preservation. Pavement preservation tends to include three components, i.e., preventive maintenance, routine maintenance, and minor rehabilitation (non-structural). Further, when required, (major) rehabilitation involving structural enhancement may need to be done to extend the service life of the existing pavement and/or improve its load-carrying capacity. Rehabilitation techniques may include restoration treatments and structural overlays. When rigid pavement experiences deformation, rehabilitation tends to be required. A few scenarios may be considered to rehabilitate the rutting. Traditionally, the scenarios may include Full-Depth Repair (FDR), bonded and unbonded concrete overlay (M&O), thin hot mix asphalt (HMA) overlays and stitching, dowel bar retrofit, joint repair, and/or diamond grinding. However, the three components and aforesaid scenarios may not be an ideal solution for specific applications including road intersections, bus bays, and bus stops. Compared with rehabilitation for flexible pavement, rehabilitation for rigid pavement tends to cost more, and if not done properly, similar distresses occur again, and additional repair/rehabilitation may then be required.

[0007] There may be a need to address one or more issues and/or limitations mentioned above.

Summary

[0008] In a first aspect, there is provided a cementitious formulation comprising:

a cement;

water;

a polymeric fiber; and

5 a water-reducing agent.

[0009] In another aspect, there is provided a method for forming the cementitious formulation described in embodiments of the first aspect of the present disclosure, the method comprising:

forming a liquid mixture comprising water, a water reducing agent, and a first portion of a superplasticizer;

mixing the liquid mixture and a cement to form a binder mixture; and

mixing the binder mixture first with a polymeric fiber then a second portion of the superplasticizer.

Brief Description of the Drawings

[0010] The drawings are not necessarily to scale, emphasis instead generally being placed upon illustrating the principles of the present disclosure. In the following description, various embodiments of the present disclosure are described with reference to the following drawings, in which:

[0011] FIG. 1 is a plot of the tensile stress and strain curve of a SHCC material formed from a cementitious formulation described in one non-limiting example of the present disclosure.

15 [0012] FIG. 2 is a diagram showing the steps involved in precast SHCC slab construction, a precast method described in an example of the present disclosure. The top image shows a distressed rigid pavement, wherein the top layer is the full depth rigid pavement and the bottom layer is the base course (e.g., about 200 mm deep). In step 1 (removal of deteriorated rigid pavement), the rigid pavement is removed (e.g., a cut of about 225 mm deep). In step 2 (filling of asphalt), an asphaltic base course (e.g., about 95 mm deep) is deposited on the base course. In step 3 (lay and level pre-cast SHCC slab), pre-cast SHCC slabs (e.g., about 120 mm thick) of the present disclosure are laid on the deposited asphaltic base course. In step 4 (pump grout and seal joints),

the grout is pumped to seal any gaps so as to have the pre-cast SHCC slab joined and the grout forms a layer (e.g., about 10 mm) that joins the SHCC slabs to the asphaltic base course.

[0013] FIG. 3 shows the Formwork for precast SHCC slab.

5 **[0014]** FIG. 4 shows a silicone mat applied on freshly cast modified SHCC.

[0015] FIG. 5 shows a brushing process.

[0016] FIG. 6 shows removal of existing deteriorated rigid pavement (left image) and asphalt overlay (right image).

[0017] FIG. 7 shows the lifting with truck crane (left image) and leveling slab (right image).

[0018] FIG. 8 shows lifting of a slab using hooks bolt.

[0019] FIG. 9 shows positioning the first precast SHCC slab.

[0020] FIG. 10 shows positioning the second precast SHCC slab.

[0021] FIG. 11 shows a grout pumping process.

15 **[0022]** FIG. 12 shows pumping fast setting grout through ports (left image) and joint sealing (right image).

[0023] FIG. 13 is a diagram showing the steps involved in precast SHCC slab construction, a cast in situ method described in an example of the present disclosure. The top image shows a distressed rigid pavement, wherein the top layer is the full depth rigid pavement and the bottom layer is the base course (e.g., about 200 mm deep). In step 1 (removal of deteriorated rigid pavement), the rigid pavement is removed (e.g., a cut of about 225 mm deep). In step 2 (filling of asphalt), an asphaltic base course (e.g., about 105 mm deep) is deposited on the base course. In step 3 (cast in situ SHCC slab), the SHCC slabs (e.g., about 120 mm thick) are formed (i.e., cast) in situ on the asphaltic base course.

[0024] FIG. 14 shows a three-dimensional model of the SHCC slabs application at road intersection. The SHCC slabs are formed from the cementitious formulation of the present disclosure.

[0025] FIG. 15 shows a road intersection in Singapore having 16 precast SHCC slabs installed on two lanes. The SHCC slabs are formed from the cementitious formulation of the present disclosure.

Detailed Description

[0026] The following detailed description refers to the accompanying drawings that show, by way of illustration, specific details and embodiments in which the present disclosure may be practiced.

5 [0027] Features that are described in the context of an embodiment may correspondingly be applicable to the same or similar features in the other embodiments. Features that are described in the context of an embodiment may correspondingly be applicable to the other embodiments, even if not explicitly described in these other embodiments. Furthermore, additions and/or combinations and/or alternatives as
10 described for a feature in the context of an embodiment may correspondingly be applicable to the same or similar feature in the other embodiments.

[0028] The present disclosure relates to a cementitious formulation. The cementitious formulation may advantageously form a strain-hardening cementitious composite (SHCC) material, also referred to in the present disclosure as a modified SHCC
15 material. The present SHCC material, and understandably the cementitious formulation, are advantageous for rigid pavement rehabilitation, which may be via a white topping approach wherein the modified strain-hardening cementitious composite (SHCC) material may be placed directly on an existing pavement. The SHCC material arising from the present cementitious formulation may provide better mechanical
20 properties, including higher ductility, higher resistance to crack, and comparable or even higher compressive strength than traditional concrete. The cementitious formulation confers better structural and functional performance from the improved compressive strength and ductility. High functional performance may be rendered by involving hard and high-textured material in the SHCC matrix providing textures that
25 may be responsible for higher skid resistance and improved water surface drainage. For normal traffic and temperature loading in Singapore, rigid pavement rehabilitation by using a slab of such SHCC material may require only about 80 mm to 150 mm of thickness for typical public roads. Consequently, the weight may be less than half compared to traditional full-depth rigid pavement. The slab does not need (may be
30 absent of) steel-bar reinforcement and yet be able to help accelerate the construction process and there may be less hassle compared to the traditional rigid pavement.

[0029] The cementitious formulation may confer high structural performance to a SHCC material for rigid pavement rehabilitation. The cementitious formulation may include micro-fibers (e.g., polymeric fiber), which may be incorporated into a cementitious matrix to produce high compressive strength and very high ductility, helping to render the high structural performance. The terms “polymeric fiber”, “polymer fiber”, “micro-fibers”, or for brevity “fibers”, are used exchangeably in the present disclosure.

[0030] The cementitious formulation may confer high functional performance to a SHCC material for pavement rehabilitation. The cementitious formulation may include hard and high-textured material, which may be incorporated into a matrix of the SHCC material, providing textures that render higher skid resistance and improved water surface drainage, helping to render such functional performance.

[0031] The cementitious formulation is advantageous in that a SHCC material from the cementitious formulation is highly durable, e.g., having a service life of 50 years or more.

[0032] The cementitious formulation may confer durable surface properties. Due to the improved compositional configuration of the cementitious formulation, the resultant SHCC material may be formed into a slab having durable surface textures that can be used for more than 20 years with normal traffic loading. Durable surface textures provide a longer safety window for users, due to having higher skid resistance and improved water surface drainage that reduce or eliminate risk of accidents arising from hydroplaning.

[0033] The cementitious formulation is advantageous for forming thinner and lighter SHCC slabs. Compared to traditional rehabilitation techniques involving full-depth repair of rigid pavement which tends to require a thickness of 250 mm to 300 mm, a SHCC slab formed from the present cementitious formulation may require a lesser thickness of 80 mm to 150 mm for use in public roads. This means that only half of the thickness is needed compared to traditional means. Consequently, the weight of the SHCC slab from the present cementitious formulation is considerably lower than traditional full-depth rigid pavement.

[0034] A SHCC material from the cementitious formulation allows quick and easy construction process. A SHCC slab from the cementitious formulation may be

advantageously applied via a method described in the present disclosure (e.g., a precast method), which may require a lesser downtime of about one day before the rehabilitated lane can be open to traffic again. This eases the burden on road authorities and users, and consequently, results in lower delay cost compared to a traditional cast in situ method which requires 14 to 28 days of closure time.

5 [0035] In summary, the cementitious formulation of the present disclosure (understandably also the method for forming the cementitious formulation) are advantageous in that the individual properties of each component forming the cementitious formulation are not adversely altered nor does the presence of one component negatively affect another, yet the various components together are able to confer synergistic effects in that the resultant cementitious formulation confers improved properties (e.g., better skid resistance, better water surface drainage, improved mechanical properties such as better compressive strength, ductility, shorter curing/faster formation, etc.) to any concrete slab and pavement involving or formed using the cementitious formulation.

15 [0036] Details of various embodiments of the cementitious formulation, and a method for forming the cementitious formulation, and advantages associated with the various embodiments are described below. Where the embodiments and advantages are described in the examples section further hereinbelow, they shall not be iterated for brevity.

20 [0037] The present disclosure describes a cementitious formulation in a first aspect. The cementitious formulation may comprise a cement, water, a polymeric fiber, and a water-reducing agent.

[0038] In various embodiments, the cement may comprise 5 wt% to 70 wt%, 10 wt% to 70 wt%, 20 wt% to 70 wt%, 30 wt% to 70 wt%, 40 wt% to 70 wt%, 50 wt% to 70 wt%, 60 wt% to 70 wt%, etc., of the cementitious formulation. In various embodiments, the cement may comprise Portland cement. The cement present in these ratios advantageously provides a better binding effect on the other components, if more may cause undesirable agglomeration, if less the binding effect may not suffice.

30 [0039] In various embodiments, the water may comprise 10 wt% to 25 wt%, 15 wt% to 25 wt%, 20 wt% to 25 wt%, 10 wt% to 20 wt%, 15 wt% to 20 wt%, etc., of the cementitious formulation. The water advantageously aids in chemical reaction (e.g.,

hydration) to form calcium silicate hydrate (C-S-H), which renders strength and durability to the resultant cement-based product formed. If too much water (beyond aforesaid wt% is used), it may weaken the cement-based product, as excess water creates more space between the cement particles, and the resulting C-S-H becomes not as strong. Conversely, the hydration reaction may be incomplete if water less than aforesaid wt% is present. This may result in a weak and crumbly cement-based product that is difficult to work with. In the present disclosure, where used, weight percentage is denoted "wt%".

5 [0040] In various embodiments, the polymeric fiber may comprise polyethylene or polyvinyl alcohol.

10 [0041] In various embodiments, the cementitious formulation may comprise a superplasticizer. In various embodiments, the water-reducing agent and the superplasticizer each may comprise 0.1 wt% to 0.5 wt%, 0.2 wt% to 0.5 wt%, 0.3 wt% to 0.5 wt%, 0.4 wt% to 0.5 wt%, etc., of the cementitious formulation. Advantageously, 15 the water-reducing agent improves workability of the cementitious formulation while maintaining desired strength and durability. The water-reducing agent helps to disperse and separate the cement particles more effectively, which may in turn help to reduce the amount of water needed to achieve a desired consistency. This improves the workability of the concrete mix, making it easier to place, compact, and finish without 20 compromising the resultant product's strength. With aforesaid range, the water-reducing agent is able to confer aforesaid effects without excessively reducing (or eliminating or affecting) the water content for the present cementitious formulation.

[0042] In various embodiments, the water-reducing agent may be absent of chloride. In various embodiments, the water-reducing agent may be non-corrosive. 25 Advantageously, without chloride, the risks of chloride-induced corrosion and leaching of harmful chloride into the environment are eliminated.

[0043] In various embodiments, the superplasticizer may include a polymer-based superplasticizer which is absent of chloride. Advantageously, superplasticizer helps to deflocculate cement particles. This allows for easier flow and placement of cement and concrete without adding excessive water. As a result, a cementitious mixture/concrete 30 mix becomes more fluid and easier to pump, place, and finish. Advantageously, without

chloride, the risks of chloride-induced corrosion and leaching of harmful chloride into the environment are eliminated.

[0044] In various embodiments, the cement, the water, the polymeric fiber, the water-reducing agent, and the superplasticizer, may be present in a weight ratio of 5 to 70 : 10 to 25 : 0.5 to 2 : 0.1 to 0.5 : 0.1 to 0.5, etc. These weight ratios help to achieve desirable performance in the resultant cement-based product, as these weight ratios help control and improve the structural configuration and/or interactions between fibres, the matrix of the resultant cement-based product, and/or the fibre-matrix interface.

[0045] In various embodiments, the cementitious formulation may include a cementitious material, an aggregate, zeolite, a retarder, and/or a viscosity modifying agent. In various embodiments, the cementitious material may include fly ash, silica fume, and/or ground granulated blast furnace slag (GGBS). In various embodiments, the cementitious formulation may further include fly ash, silica fume, an aggregate, zeolite, a retarder, and/or a viscosity modifying agent. The present cementitious formulation is advantageous in that it can include or accommodate these components. The cementitious material is advantageous in that it reduces the use of any carbon (or carbon-based material) embedded in the resultant cement-based product and help to lower cost.

[0046] For example, the present cementitious formulation is advantageous in that it can include silica fume. Silica fume, advantageously, may react with calcium hydroxide, a byproduct of cement hydration. This reaction forms additional calcium silicate hydrate (CSH), which is the primary binding phase in any resultant cement-based or concrete-based product (formed from the present cementitious formulation), to render a denser matrix with improved compressive strength, flexural strength, and abrasion resistance. Hence, silica fume helps densify the microstructure to enhance the strength of the resultant cement-based product. With the increased density, the fine particles of silica fume may fill the spaces between cement particles and other particles, which in turn reduces the size of pores in the product, thereby lowering permeability to water and any undesirable chemicals. Silica fume may also improve the workability of the cementitious formulation due to its small size and spherical (or substantially spherical) shape, which allows for better flow of a cementitious mix without needing to increase water content significantly. Silica fume may help to absorb or dissipate the heat evolved

from hydration in forming the resultant cement-based and concrete-based product, which is beneficial in mass concrete applications where controlling temperature rise may help prevent thermal cracks from developing. Silica fume also helps improve the fibre/matrix interfacial bond strength in the resultant cement-based product.

5 [0047] As a further example, the present cementitious formulation is advantageous in that it can accommodate a retarder. The retarder may be any suitable compound or any suitable chemical mixture that helps to extend the time available for handling, placing, and finishing concrete before it starts to set. This is particularly useful in large construction projects or in hot weather conditions where rapid setting can hinder
10 workability. The retarder helps control rate of hardening, i.e., the retarders may help to slow down hydration of cement, which is a chemical reaction between cement and water that causes the concrete to harden. By delaying hydration, the initial setting (i.e., curing) time of the concrete may be prolonged.

[0048] As a further example, the present cementitious formulation is advantageous in
15 that it can accommodate a viscosity modifying agent, which helps to adjust the workability of the cementitious formulation, especially when the workability is affected by temperature and/or humidity.

[0049] In various embodiments, the silica fume may comprise an average size of 110 μm and/or a maximum size of 200 μm . The term “size”, in the context of the present
20 disclosure and in the context of particles, such as silica fume particles, refers to the maximum length measured across a particle. If a particle happens to be spherical or substantially spherical (not a perfect sphere), then the size of such particle may refer to its diameter.

[0050] In various embodiments, the aggregate may comprise a sand. The sand may be
25 river sand and/or micro silica sand. The terms “aggregate” and “fine aggregate” herein are used exchangeably.

[0051] In various embodiments, the retarder may be absent of chloride. In various
embodiments, the retarder may be non-corrosive. Advantageously, without chloride, the risks of chloride-induced corrosion and leaching of harmful chloride into the
30 environment are eliminated.

[0052] In various embodiments, the viscosity modifying agent may be absent of chloride and may be non-corrosive.

[0053] In various embodiments, the fly ash, the silica fume, the aggregate, the zeolite, the retarder, and the viscosity modifying agent, may be present in a weight ratio of 0 to 55 : 0 to 10 : 0 to 20 : 0 to 5 : 0 to 5 : 0 to 5. These weight ratios help to achieve desirable performance in the resultant cement-based product, as these weight ratios may help control and improve the structural configuration and/or interactions between fibres, the matrix of the resultant cement-based product, and/or the fibre-matrix interface.

[0054] In various embodiments, the fly ash, the aggregate, and the zeolite, may be present in a weight ratio of 0 to 55 : 0 to 20 : 0 to 5. These weight ratios help to achieve desirable performance in the resultant cement-based product, as these weight ratios may help control and improve the structural configuration and/or interactions between fibres, the matrix of the resultant cement-based product, and/or the fibre-matrix interface.

[0055] The present disclosure also relates to a method for forming the cementitious formulation described in various embodiments of the first aspect of the present disclosure. Embodiments and advantages described for the cementitious formulation of the first aspect can be analogously valid for the present method described herein, and vice versa. Where the various embodiments and advantages have already been described above and in the examples section further hereinbelow, they shall not be iterated for brevity.

[0056] The method for forming the cementitious formulation described in embodiments of the first aspect of the present disclosure may include forming a liquid mixture comprising water, a water reducing agent, and a first portion of a superplasticizer; mixing the liquid mixture and a cement to form a binder mixture; and mixing the binder mixture first with a polymeric fiber then a second portion of the superplasticizer. In the present disclosure, the expression "mixing a component A and a component B" may include within its meaning mixing component A with component B, or mixing component B with component A. For example, mixing the liquid mixture and a cement may be carried out by mixing the liquid mixture with the cement or mixing the cement with the liquid mixture.

[0057] In various embodiments, forming the liquid mixture may further comprise mixing the water, the water reducing agent, and the superplasticizer with a retarder.

[0058] In various embodiments, mixing the liquid mixture and the cement may comprise mixing the liquid mixture and the cement with fly ash.

[0059] In various embodiments, the method may further comprise forming a solid mixture comprising a silica fume, an aggregate, and zeolite, and mixing the solid mixture and the liquid mixture prior to mixing the liquid mixture and the cement.

[0060] In various embodiments, the method may further comprise mixing the binder mixture with a third portion of the superplasticizer or a viscosity modifying agent prior to the mixing of the binder mixture first with the polymeric fiber then a second portion of the superplasticizer.

[0061] The word “substantially” does not exclude “completely” e.g. a composition which is “substantially free” from Y may be completely free from Y. Where necessary, the word “substantially” may be omitted from the definition of the present disclosure.

[0062] In the context of various embodiments, the articles “a”, “an” and “the” as used with regard to a feature or element include a reference to one or more of the features or elements.

[0063] In the context of various embodiments, the term “about” or “approximately” as applied to a numeric value encompasses the exact value and a reasonable variance.

[0064] As used herein, the term “and/or” includes any and all combinations of one or more of the associated listed items.

[0065] Unless specified otherwise, the terms “comprising” and “comprise”, and grammatical variants thereof, are intended to represent “open” or “inclusive” language such that they include recited elements but also permit inclusion of additional, unrecited elements.

Examples

[0066] The present disclosure relates to a cementitious formulation and a method for forming the cementitious formulation.

[0067] The present disclosure describes a rehabilitation technique based on a precast method using a modified SHCC material, e.g., formed from the cementitious formulation. The method is advantageous in that it offers a quick pavement rehabilitation that can be applied for high stress-strain applications, including road intersections, bus bays, and bus stops. Briefly, a SHCC material formed from the

cementitious formulation is used to improve structural performance, namely high strength performance, and very high ductility. A hard aggregate may be incorporated into the cementitious formulation (and hence incorporated in the SHCC material) to improve the texture properties of a slab formed using the SHCC material for improving the functional performance, namely skid resistance and water surface drainage.

[0068] The SHCC slab can be constructed with both precast and cast in situ methods. The precast method can be done with a method involving a reverse casting method and a special silicone mat to confer good texture on the surface and high shear nodes at the bottom of the slab. A lifting levelling device may be embedded to ease the casting, processing, handling, and installation of the slab. SHCC slabs formed from the cementitious formulation can be produced via casting in situ to produce jointless rigid pavement.

[0069] The present cementitious formulation and method for forming the cementitious formulation, and the various applications (including the slabs), are described in further details, by way of non-limiting examples, as set forth below.

[0070] Example 1: General description

[0071] The present disclosure, including the examples, describe for a rehabilitation technique for rigid pavement by using a SHCC material formed from the cementitious formulation. The resultant SHCC material (due to the cementitious formulation) provides high structural and functional performance. It results in high compressive strength and very high ductility. High functional performance was achieved by using hard and high-textured material in the SHCC matrix providing textures that conferred higher skid resistance and improved water surface drainage. For normal traffic and temperature loading in Singapore, rehabilitation by using the present SHCC slab material requires only 80 mm to 150 mm of thickness for public roads. Consequently, the weight is less than half compared to traditional full-depth rigid pavement.

[0072] High structural performance was achieved by incorporating micro-fibers into the cementitious formulation (and hence in the SHCC matrix), which conferred compressive strength and very high ductility. High fatigue performance of SHCC require less maintenance of the slab, therefore reducing life cycle cost. High functional performance was achieved by incorporating hard and high-textured material in the

SHCC matrix providing textures that confer the higher skid resistance and improved water surface drainage.

[0073] The SHCC material can be cast via precast and cast in situ methods, which offer different advantages. The precast method offers a quick pavement rehabilitation. This method allows a one day closure time only, before the rehab lane can be opened to traffic. This eases road authorities and users and consequently saves a delay cost compared to the cast in situ method which may require 14 to 28 days of closure time. That said, the cast in situ method offers a jointless roadway resulting in more durable and comfort for the road users.

[0074] A SHCC slab formed from the present cementitious formulation does not need steel bar reinforcement. This helps accelerate the casting process and in lowering costs compared to traditional rigid pavement that required wire mesh. As the SHCC slab requires only 80 mm to 150 mm of thickness for public roads, the weight is less than half compared to traditional full-depth rigid pavement. The lighter slab allows quicker construction time, lighter lifting equipment, and less manpower for handling the slab production and construction.

[0075] The rehabilitation technique may involve a white topping approach made of the SHCC material formed from the cementitious formulation. This method produces high-performance, high-stress-strain properties that can be used for rigid pavement rehabilitation.

[0076] Example 2A: Materials for the cementitious formulation

[0077] Type I Portland cement, class F fly ash (FA), water, silica fume (mean and maximum grain size of 110 µm and 200 µm, respectively), river sand, zeolite, polyethylene (PE) fibers (length of 12 mm, a diameter of 39 µm, a nominal tensile strength of 1600 MPa), high-range water reducing, and superplasticizer (SP) were used for the mixture design. To enhance the texture properties, river sand with a maximum particle size of 2.38 mm was used as fine aggregates for improving the surface textures of SHCC.

[0078] The slab size is 3400 mm × 2400 mm × 120 mm, thus, the volume of the precast SHCC slab is 980 L (liter). The estimated volume for one precast SHCC slab is 1200 L including the 20% wastage, and the mix proportion shown in Table 1A below summarizes the mixture design of the modified SHCC.

[0079] Table 1A: Mixture proportion for one precast SHCC slab (1200 L) (in kg)

Cement	Fly Ash	Water	Silica Fume	River Sand	Zeolite	PE Fiber	Water Reducer	SP
650	800	300	100	270	50	22	8	8

[0080] **Example 2B: Materials for the cementitious formulation**

[0081] Various non-limiting examples of the cementitious formulation are demonstrated herein. The cementitious formulation has an advantageous compositional configuration that allows its to be quickly deployed for rigid pavement rehabilitation. The SHCC material formed from the cementitious formulation can be cast using precast and cast in situ methods, which are further described in examples 4 and 5 below, respectively. The cast in situ method can be used to construct a jointless rigid pavement. The precast method advantageously requires only a one day closure before the lane is opened again to traffic.

[0082] Non-limiting examples of the cementitious formulation included the following components: Cement (e.g., Portland cement), fly ash, water, silica fume (which may have an average and a maximum grain diameter of 110 μm and 200 μm, respectively), river sand, zeolite (e.g., natural zeolite with particle size of 0 to 1mm, purchased from Henan, China), polyethylene (PE) polyvinyl alcohol (PVA) fibers (length of 12 mm, a diameter of 39 μm), water reducer (also termed water-reducing agent), and/or a superplasticizer (e.g., polymer-based superplasticizer for high strength concrete application (purchased from a Singapore company)).

[0083] Non-limiting examples of the cementitious formulation included the following components: 5 to 70 weight% cement (e.g., 29.4384 weight %), 0 to 55 weight % fly ash, (e.g., 36.2319 weight %), 10 to 25 weight % water (e.g., 13.5870 weight %), 0 to 10 weight % silica fume (e.g., 4.5290 weight %), 0 to 20 weight % river sand (e.g., 12.2283 weight %), 0 to 5 weight % zeolite (e.g., 2.2645 weight %), 0.5 to 2 weight % PE fibers (e.g., 0.9964 weight %), 0.1 to 0.5 weight % water reducer (e.g., 0.3623 weight %), and/or 0.1 to 0.5 weight % superplasticizer (e.g., 0.3623 weight %). Zeolite was purchased from Tejin. In this non-limiting instance, the water reducer was ADVA 181N. In this non-limiting instance, the superplasticizer was Mighty 86. Non-limiting examples of the viscosity modifying agent may include cellulose ether, a natural gum

(e.g., xanthan, welan), and/or starch. Non-limiting examples of the superplasticizer (SP) may include sulfonated naphthalene formaldehyde condensate, sulfonated melamine formaldehyde condensate, acetone formaldehyde condensate, and/or polycarboxylates ethers.

5 [0084] Preparation of formulation:

[0085] Considering the transport time and casting time of the mixture, an amount of retarder may be included as follows. A viscosity modifying agent (VMA) may be used to tailor the properties, when necessary.

10 [0086] Table 1B: A compositional configuration of one non-limiting example of the present cementitious formulation. The term “Fly ash (Old)” and “Fly ash (New)” are merely used to denote two batches of fly ash used.

Estimated Volume	1200	L
Cement	720	kg
Fly ash (Old)	225	kg
Fly ash (New)	645	kg
Water	343	kg
Micro silica sand	200	kg
River sand	300	kg
Zeolite	49	kg
PE fiber	24	kg
SP (ADVA 181N)	9	kg
Retarder	3.9	kg
Viscosity modified agent (VMA)	1	kg
Total weight	2518.9	kg

[0087] Standard mixing procedure:

[0088] The mixing procedure is shown in the table 1C below.

15 [0089] Table 1C: Procedures and steps for forming the cementitious formulation

Step	Action	Ingredients	Weight	Duration	Remark
1	To charge all aggregates	Micro silica sand	200 kg	5 mins	

		River sand	300 kg		
		Zeolite	49 kg		
2	To charge all liquids	Water	343 kg	10 mins	To soak aggregates
		SP	4.5 kg		
		Retarder	3.9 kg		
3	To charge all binders and mixing	Cement	720 kg	10 mins	To check the fresh* properties (workable and sticky)
		Fly ash (Old)	225 kg		
		Fly ash (New)	645 kg		
4 (optional)	To charge SP or VMA	SP (AVDA 181N) or VMA	X# kg	X# mins	Adjust the fresh property
5	To charge PE fiber	PE fiber	8 kg	5 mins	Slowly add with certain rate, check fiber dispersion
	To charge SP	SP (AVDA 181N)	1.5 kg	5 mins	
	To charge PE fiber	PE fiber	8 kg	5 mins	
	To charge SP	SP (AVDA 181N)	1.5 kg	5 mins	
	To charge PE fiber	PE fiber	8 kg	5 mins	
	To charge SP	SP (AVDA 181N)	1.5 kg	5 mins	

*X denotes an adjustable amount.

*Fresh refers to a mixture

[0090] Example 3: Mechanical Properties

[0091] Table 2 summarizes the mechanical properties of the SHCC formed from a cementitious formulation of the present disclosure (see example 1). The compressive strength of the SHCC after 28 days is 58.4 MPa. As shown in FIG. 1, the SHCC possessed an adequate tensile strain capacity more than 2% at the age of 28 days.

[0092] Table 2: Mechanical Properties

Mixture Design	28 Days
Compressive Strength (in MPa)	58.4
Tensile Strength (in MPa)	4.6

[0093] **Example 4: Construction with Precast Method**

[0094] The SHCC material can be cast with both precast and cast-in-situ methods offering different advantages. The precast method offers a quick rigid pavement rehabilitation This method allows a 1-day closure time only before the rehab lane can be open to traffic.

[0095] The construction can be done, generally, in three simple steps, including milling the deteriorated existing rigid pavement, installing the precast SHCC slab, and then lastly grouting and joint scaling. The procedures (steps) are illustrated in FIG. 2.

[0096] *Manufacture precast SHCC slab:*

[0097] For the precast method, the precast slab casting process is done by using formwork. A formwork with a size of 3400 mm × 2400 mm with a thickness of 120 mm was prepared. Lifting levelling devices and grouting ports were prepared and positioned according to the design. When required, dowels and slots can be prepared (see FIG. 3). Once the formwork is done, fresh modified SHCC can be poured. The casting is done reversely. After the modified SHCC material is laid and levelled, silicone mats are applied (see FIG. 4).

[0098] After three days of curing, the precast SHCC slab needs to be brushed by using a brushing machine (see FIG. 5). This process exposes the river sand aggregates on the surface responsible for skid resistance and water surface drainage performance.

[0099] *Mill-off existing deteriorated existing rigid pavement:*

[00100] The first step is to mill off the existing deteriorated rigid pavement (see FIG. 6). The layers underneath was checked on its performance, whether the layers are still usable or to be replaced or to be treated.

[00101] Once the supporting layer underneath is prepared, an additional asphalt layer can be topped up to compensate for the gap and to provide a space for the precast slab and grout with a thickness of 120 mm and 10 mm, respectively.

[00102] *Precast SHCC slab installation:*

[00103] The second step is the installation of the precast SHCC slab. The ready-to-be-installed slab was transported from the casting yard to the site. Lifting and positioning the precast SHCC slab can be done easily by using a truck crane (see FIG. 7). The crane
5 is equipped with a chain to lift the slab by using the lifting levelling device embedded in the slab (see FIG. 8). The chain is connected to the lifting bolts which are screwed to the lifting levelling device. The slab needs to be lifted and positioned in consequence (see FIG. 9 and FIG. 10).

[00104] After the slabs are already positioned according to the required layout, the
10 lifting bolts are removed and replaced with levelling screws. The level of the slab can be adjusted by rotating the screws. The slabs are to be levelled according to the required level. The levelling process is done in sequence. Finally, the level of the slab is to be checked by using a (digital) total station.

[00105] *Grouting and joint sealing:*

15 **[00106]** Lastly, after the level of the slab is adjusted, the pumping process for the grout can be started. The grout can be pumped into the designated holes port to ensure the bond between the precast SHCC slab and the asphaltic layer underneath (see FIG. 11 and FIG. 12). The holes and joints are checked to be filled with grout.

[00107] **Example 5: Construction with Cast In Situ Method**

20 **[00108]** The SHCC material can be cast with both precast and cast-in-situ method offering different advantages. The cast-in-situ methods provides a relatively straightforward construction for jointless rigid pavement. With the cast in situ method, the SHCC material can be directly cast into the site once all the supporting layers are built according to the standard, which considers the specification of material and
25 thickness required.

[00109] The construction can be done, generally, in two simple steps, including milling the deteriorated existing rigid pavement and casting the SHCC material. The procedure is illustrated in FIG. 13.

[00110] *Mill-off existing deteriorated existing rigid pavement:*

30 **[00111]** The first step is to mill off the deteriorated existing rigid pavement. The layers underneath was checked on its performance, whether the layers are still usable or to be replaced or to be treated.

[00112] Once the supporting layer has been prepared, an additional asphalt layer can be topped up to 105 mm to compensate for the gap and to provide a space for the SHCC slab with a thickness of 120 mm.

[00113] *Cast in situ SHCC:*

5 [00114] The last step is to cast the SHCC material with a thickness of 120 mm. The level of the slab needs to be checked by using (digital) a total station. Joints between the SHCC slab and existing pavement, either rigid or flexible pavement, may need to be configured and constructed to comply with (local) standard.

[00115] After three days of curing, the top surface of the SHCC slab needs to be
10 brushed by using a brushing machine (see FIG. 4). This process exposes the river sand aggregates on the surface which helps improve skid resistance and water surface drainage performance.

[00116] **Example 6: Summary and Applications**

[00117] On top of the results achieved in the laboratory, the full-size SHCC slabs have
15 been demonstrated at one road intersection for two lanes in the Tampines area located in Singapore (see FIG. 14).

[00118] The cementitious formulation, slabs and techniques have a great potential for more installation at different locations, and more various applications, including bus bays, bus stops, dedicated bus and or truck lanes, and automated goods vehicle lanes.

20 [00119] While the present disclosure has been particularly shown and described with reference to specific embodiments, it should be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the present disclosure as defined by the appended claims. The scope of the present disclosure is thus indicated by the appended claims and all changes
25 which come within the meaning and range of equivalency of the claims are therefore intended to be embraced.

CLAIMS

1. A cementitious formulation comprising:
a cement;
5 water;
a polymeric fiber; and
a water-reducing agent.
2. The cementitious formulation of claim 1, wherein the cement comprises 5 wt%
10 to 70 wt% of the cementitious formulation.
3. The cementitious formulation of claim 1 or 2, wherein the cement comprises
Portland cement.
- 15 4. The cementitious formulation of any one of claims 1 to 3, wherein the water
comprises 10 wt% to 25 wt% of the cementitious formulation.
5. The cementitious formulation of any one of claims 1 to 4, wherein the polymeric
fiber comprises polyethylene or polyvinyl alcohol.
20
6. The cementitious formulation of any one of claims 1 to 5, further comprising a
superplasticizer.
7. The cementitious formulation of claim 6, wherein the water-reducing agent and
25 the superplasticizer each comprises 0.1 wt% to 0.5 wt% of the cementitious
formulation.
8. The cementitious formulation of any one of claims 1 to 7, wherein the water-
reducing agent is absent of chloride and is non-corrosive.
30

9. The cementitious formulation of any one of claims 6 to 8, wherein the superplasticizer comprises a polymer-based superplasticizer which is absent of chloride.
10. The cementitious formulation of any one of claims 6 to 9, wherein the cement,
5 the water, the polymeric fiber, the water-reducing agent, and the superplasticizer, are present in a weight ratio of 5 to 70 : 10 to 25 : 0.5 to 2 : 0.1 to 0.5 : 0.1 to 0.5.
11. The cementitious formulation of any one of claims 1 to 10, further comprising:
a cementitious material;
an aggregate;
10 zeolite;
a retarder; and/or
a viscosity modifying agent,
wherein the cementitious material comprises fly ash, silica fume, or ground granulated blast furnace slag.
12. The cementitious formulation of claim 11, wherein the silica fume comprises an
15 average size of 110 μm and/or a maximum size of 200 μm .
13. The cementitious formulation of claim 11 or 12, wherein the aggregate comprises a sand.
14. The cementitious formulation of any one of claims 11 to 13, wherein the retarder
20 is absent of chloride and is non-corrosive.
15. The cementitious formulation of any one of claims 11 to 14, wherein the viscosity modifying agent is absent of chloride and is non-corrosive.
16. The cementitious formulation of any one of claims 11 to 15, wherein the fly ash, the silica fume, the aggregate, the zeolite, the retarder, and the viscosity modifying agent, are present in a weight ratio of 0 to 55 : 0 to 10 : 0 to 20 : 0 to 5 : 0 to 5 : 0 to 5.

17. The cementitious formulation of any one of claims 11 to 16, wherein the fly ash, the aggregate, and the zeolite, are present in a weight ratio of 0 to 55 : 0 to 20 : 0 to 5.
18. A method for forming the cementitious formulation of any one of claims 1 to 5 17, the method comprising:
forming a liquid mixture comprising water, a water reducing agent, and a first portion of a superplasticizer;
mixing the liquid mixture and a cement to form a binder mixture; and
mixing the binder mixture first with a polymeric fiber then a second portion of 10 the superplasticizer.
19. The method of claim 18, wherein forming the liquid mixture further comprises mixing the water, the water reducing agent, and the superplasticizer with a retarder.
20. The method of claim 18 or 19, wherein mixing the liquid mixture and the cement 15 comprises mixing the liquid mixture and the cement with fly ash.
21. The method of any one of claims 18 to 20, further comprising:
forming a solid mixture comprising a silica fume, an aggregate, and zeolite, and
mixing the solid mixture and the liquid mixture prior to mixing the liquid 20 mixture and the cement.
22. The method of any one of claims 18 to 21, further comprising:
mixing the binder mixture with a third portion of the superplasticizer or a viscosity modifying agent prior to the mixing of the binder mixture first with the 25 polymeric fiber then a second portion of the superplasticizer.