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(54) **MECHANICALLY STABILISED SEMI-RIGID PAVEMENTS**

(71) Applicant: **TENSAR TECHNOLOGIES LIMITED**, Shadsworth (GB)

(72) Inventors: **Andrew Curson**, Burnley (GB); **Jacek Kawalec**, Skalna (PL); **Piotr Mazurowski**, Gdansk (PL); **Kasia Zamara**, Blackburn (GB)

(73) Assignee: **TENSAR TECHNOLOGIES LIMITED**, Shadsworth (GB)

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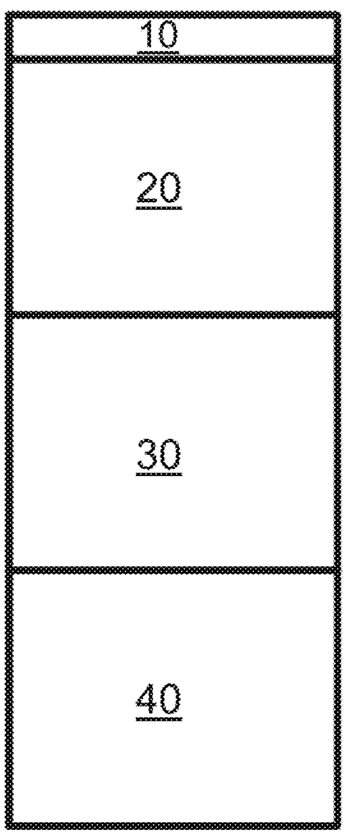
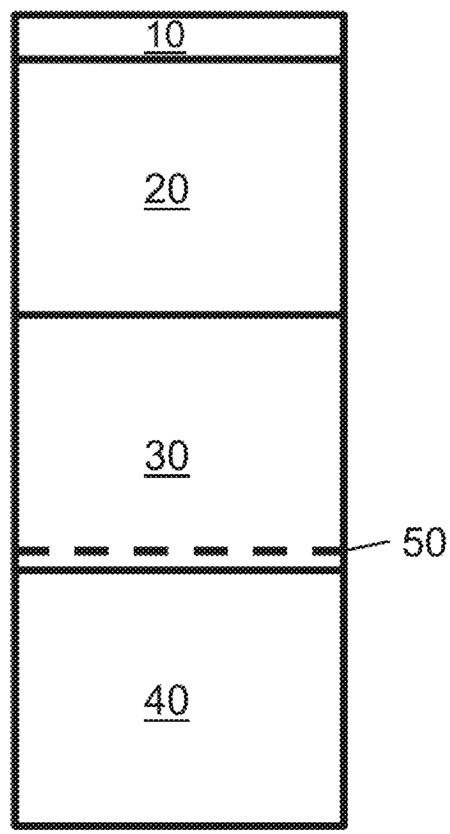
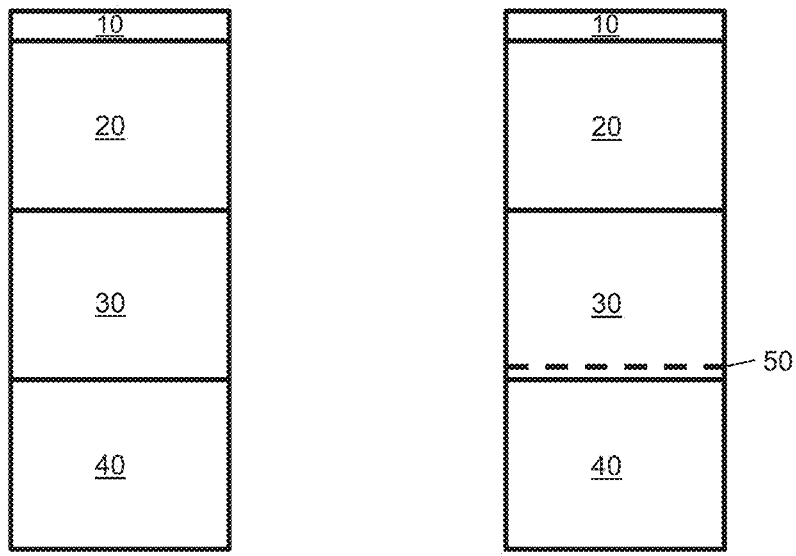
(57) **ABSTRACT**

The present invention relates to a semi-rigid pavement comprising: an upper course comprising upper course aggregate and a hydrocarbon binder; a support layer comprising chemically-stabilised aggregate, the support layer located below the upper course; and a subgrade, the subgrade located below the support layer; wherein a geosynthetic is at least partially embedded in the chemically-stabilised aggregate that comprises the support layer.



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20
30
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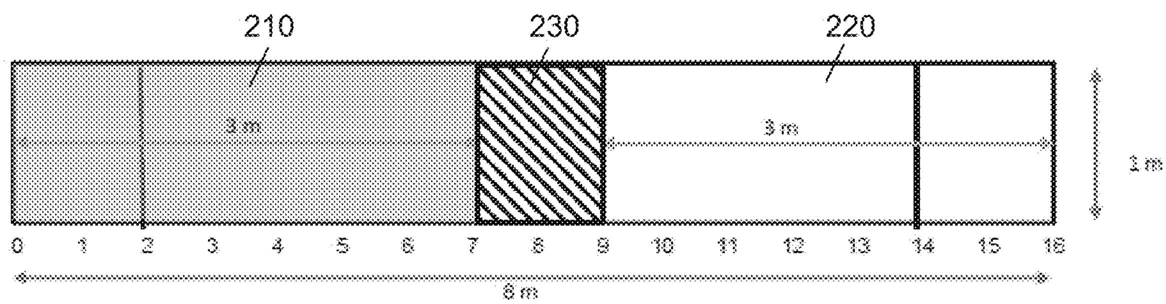
10
20
30
50
40

FIG.1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230
220
3 m
3 m
1 m
0
1
2
3
4
5
6
7
8
9
10
11
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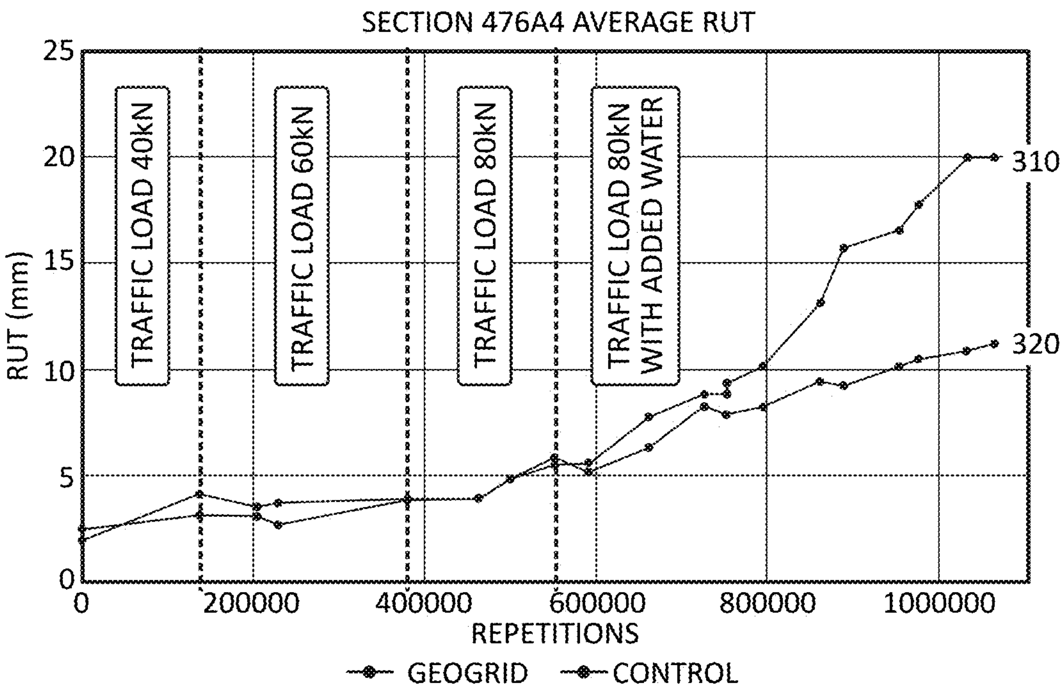
13
14
15
16
8 m

FIG.2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RUT (mm)
25
20
15
10
5
0
TRAFFIC LOAD 40kN
TRAFFIC LOAD 60kN
TRAFFIC LOAD 80kN
TRAFFIC LOAD 80kN WITH ADDED WATER
310
320
0
200000
400000
600000
800000
1000000
REPETITIONS
GEOGRID
CONTROL

FIG.3

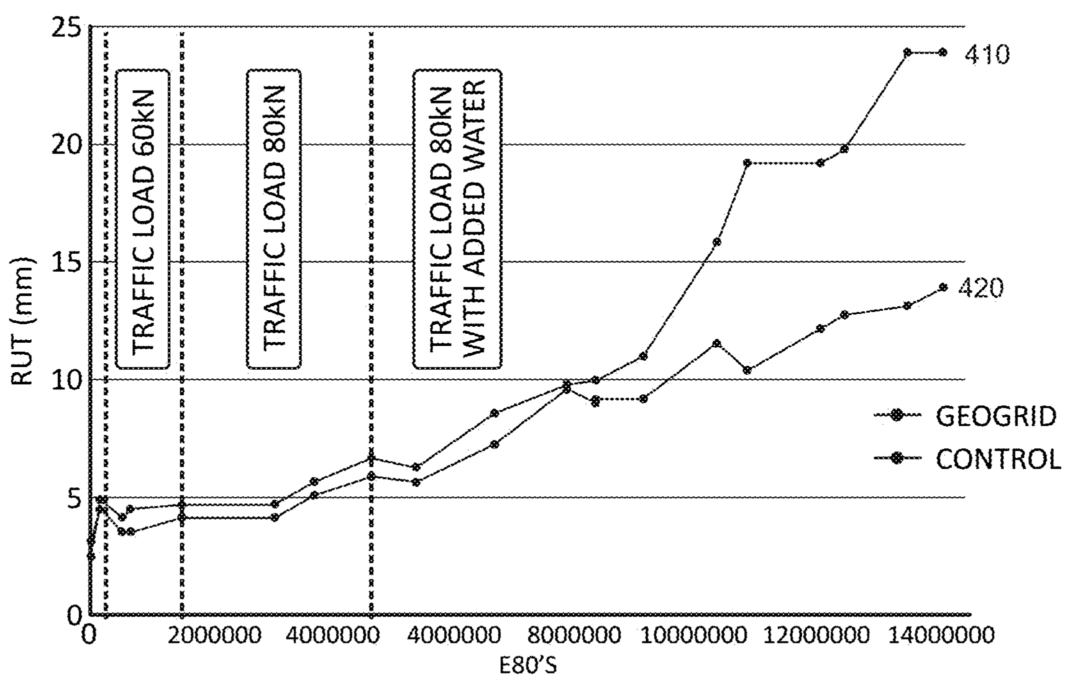
RUT (mm)
25
20
15
10
5
0
TRAFFIC LOAD 60kN
TRAFFIC LOAD 80kN
TRAFFIC LOAD 80kN WITH ADDED WATER
410
420
GEOGRID
CONTROL
0
2000000
4000000
4000000
8000000
10000000
12000000
14000000
E80'S

FIG.4

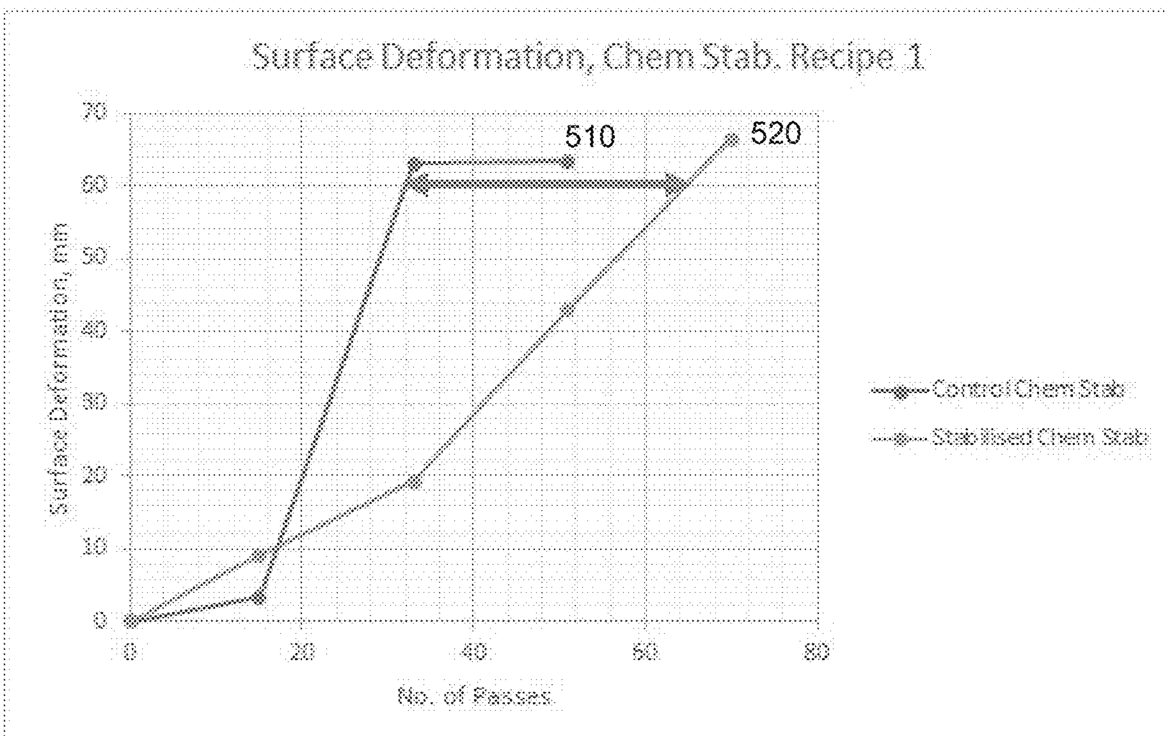
Surface Deformation, Chem Stab. Recipe 1
510
520
70
60
50
40
30
20
10
0
Surface Deformation, mm
0
20
40
60
80
No. of Passes
Control Chem Stab
Stabilised Chem Stab

FIG.5

MECHANICALLY STABILISED SEMI-RIGID PAVEMENTS

[0001] The present application relates to semi-rigid pavements incorporating geosynthetics, methods of constructing such pavements and other associated methods and uses.

BACKGROUND

[0002] A flexible pavement is defined by PIARC (World Road Association) as a "pavement with a bituminous surfacing and with a base layer with or without a hydrocarbon binder." A typical construction will include a bituminous surface dressing and one or more courses of aggregate that may be bound together with bituminous material, placed on a subbase, the subbase placed on the existing subgrade. The nature of the bituminous binder renders the pavement flexible, limiting cracking, but at the cost of reducing stiffness. This means that thicker layers are required to ensure adequate distribution of loads to the subbase. Failure of the pavement is typically through rutting, cracking, or aging of the asphalt layers or failure of the subbase.

[0003] A rigid pavement is defined by PIARC (World Road Association) as a "pavement substantially constructed of cement concrete" and is also referred to as a concrete pavement. A typical construction would include a concrete layer, or slab, placed on a subbase, the subbase placed on the existing subgrade. The concrete layer possesses a high cement content. The rigidity of the concrete layer permits the construction to broadly distribute applied loads across the entire area of the slab that contacts the subbase. Failure of the pavement is typically through cracking of the concrete slabs or failure at the joints between slabs.

[0004] A semi-rigid pavement is a pavement is defined by PIARC (World Road Association) as a "pavement with a bituminous surfacing and one or more courses that are treated with cementitious binders and which make a significant structural contribution (or courses treated with hydrocarbon binders and which by their stiffness or thickness cannot be considered as structurally flexible)". A typical construction would include a bituminous surface dressing and one or more of courses of aggregate that may be bound together with bituminous material, and a cementitious subbase (or a layer treated with bituminous binders of sufficient thickness to be considered non-flexible). The cementitious subbase typically has a cement content of up to 4% by weight and no more than 10% by weight, increasing its stiffness but being distinct from a concrete layer. In addition, the cementitious subbase is typically formed in situ by the addition of cement and water to a previously deposited aggregate, whereas a cement layer typically involves mixing aggregate and cement prior to deposition. The semi-rigid pavement effectively acts as a composite material, with the cementitious subbase reinforcing the higher flexible layers. Failure of a semi-rigid pavement typically occurs as a result of cracking of the subbase, after which the higher flexible layers rut excessively.

[0005] Semi-rigid pavements have properties, such as required depth, cost, and lifetime, that are in between those of flexible pavements and rigid pavements. It would be advantageous to improve these properties.

[0006] It is an object of the present invention to address at least one of the foregoing issues.

SUMMARY OF THE INVENTION

[0007] A first aspect of the present invention relates to a semi-rigid pavement comprising: an upper course comprising upper course aggregate and a hydrocarbon binder; a support layer comprising chemically-stabilised aggregate, the support layer located below the upper course; and a subgrade, the subgrade located below the support layer; wherein a geosynthetic is at least partially embedded in the chemically-stabilised aggregate that comprises the support layer.

[0008] The semi-rigid pavement may have two configurations:

- [0009] a first configuration wherein the support layer is monolithic, the support layer being chemically and mechanically stabilised; and
- [0010] a second configuration wherein the support layer is cracked, the support layer being mechanically stabilised.

[0011] The semi-rigid pavement may further comprise a base course and/or a layer of a granular fill.

[0012] The geosynthetic may be selected from geogrids, geotextiles, geonets, geocells, geocomposites, and combinations thereof. Preferably, the geosynthetic comprises a geogrid or is a geogrid. The geogrid may be a multiaxial geogrid, optionally the multiaxial geogrid is a triaxial geogrid or a geogrid with multiple geometries.

[0013] The triaxial geogrid may have one or more of the following properties:

- [0014] i) product weight of from 0.120 to 0.400 kg/m^2, more preferably of from 0.150 to 0.350 kg/m^2, most preferably of from 0.170 to 0.310 kg/m^2, for example from 0.180 to 0.300 kg/m^2; and/or
- [0015] ii) pitch of at least 30 mm, preferably of from 40 to 150 mm, more preferably of from 50 to 140, most preferably of from 65 to 125 mm; and/or
- [0016] iii) junction efficiency of at least 90% preferably at least 95%, more preferably of at least 97%, most preferably of at least 99%, for example of 100%.

[0017] The geogrid with multiple geometries may have one or more of the following properties:

- [0018] i. Apertures with triangular, trapezoidal, and hexagonal geometries; and/or
- [0019] ii. Pitch of at least 30 mm, preferably of from 40 to 150 mm, more preferably of from 50 to 140, most preferably of from 65 to 125 mm; and/or
- [0020] iii. Rib aspect ratio of at least 1, preferably, between 1 and 4; and/or
- [0021] iv. Minimum rib thickness of at least 3 mm, preferably at least 5 mm; and/or
- [0022] v. Where the geogrid has a solid inner layer and a two compressible outer layers, the two compressible outer layers are at least forty percent (40%) of the overall height of the geogrid, preferably at least seventy percent (70%).

[0023] The geogrid may have a multilayer structure, optionally wherein the geogrid has a solid inner layer and compressible outer layers.

[0024] The geosynthetic may be located at the base of the support layer.

[0025] The chemically-stabilised aggregate may comprise a biochemical binder, a polymeric binder, a hydrocarbon binder, lime, cement, or a combination thereof. Preferably, the chemically stabilised aggregate comprises cement, optionally up to 10% by weight cement, further optionally from 0.1 to 8% by weight cement, optionally from 0.5 to 5% by weight cement, yet further optionally from 1 to 4% by weight cement, and still further optionally from 1.5 to 3% by weight cement.

[0026] The support layer may have a thickness of from 50 to 400 mm, optionally of from 75 to 300 mm, further optionally from 100 to 200 mm, yet further optionally of about 150 mm.

[0027] The upper course may have a thickness of from 10 to 100 mm, optionally of from 25 to 75 mm, further optionally of about 50 mm.

[0028] A second aspect of the present invention provides a method of constructing a semi-rigid pavement, the method comprising:

- **[0029]** a) providing a geosynthetic above a subgrade;
- **[0030]** b) providing aggregate and binder over the geosynthetic such that the geosynthetic is at least partially embedded in the aggregate;
- **[0031]** c) setting the binder to form a support layer comprising chemically-stabilised aggregate; and
- **[0032]** d) providing an upper course comprising an upper course aggregate and a hydrocarbon binder above the support layer.

[0033] A third aspect of the present invention provides a method of constructing a semi-rigid pavement with an improved lifespan, the method comprising:

- **[0034]** a) at least partially embedding a geosynthetic within an aggregate and a binder; and
- **[0035]** b) setting the binder to form a support layer comprising chemically-stabilised aggregate,
- **[0036]** wherein the support layer is incorporated into the semi-rigid pavement during construction.

[0037] A fourth aspect of the present invention provides a method of constructing a semi-rigid pavement with a reduced thickness, the method comprising:

- **[0038]** a) at least partially embedding a geosynthetic within an aggregate and a binder; and
- **[0039]** b) setting the binder to form a support layer comprising chemically-stabilised aggregate,
- **[0040]** wherein the support layer is incorporated into the semi-rigid pavement during construction.

[0041] In any of the second, third, or fourth aspects of the present invention, the semi-rigid pavement that is constructed may be as defined in the first aspect of the present invention.

[0042] A fifth aspect of the present invention provides the use of a geosynthetic to increase the lifespan of a semi-rigid pavement, the use comprising at least partially embedding a geosynthetic within an aggregate that is chemically-stabilised with a binder and incorporating into the semi-rigid pavement.

[0043] A six aspect of the present invention provides the use of a geosynthetic to decrease the thickness of a semi-rigid pavement with a pre-determined lifespan, the use comprising at least partially embedding a geosynthetic within an aggregate that is chemically-stabilised with a binder and incorporating into the semi-rigid pavement.

[0044] In either of the fifth or sixth aspects of the present invention, the use of the geosynthetic may result in the semi-rigid pavement being as defined in the first aspect of the present invention.

[0045] A seventh aspect of the present invention provides a method of operating a semi-rigid pavement, the semi-rigid pavement comprising a subgrade, a support layer of chemically-stabilised aggregate above the subgrade, wherein a geosynthetic is at least partially embedded in the layer of chemically-stabilised aggregate, and an upper course above the chemically-stabilised aggregate, wherein the semi-rigid pavement is capable of exhibiting:

- **[0046]** a first operating mode wherein the support layer is substantially monolithic, the support layer being chemically and mechanically stabilised such that load applied to the upper course is transferred to the subgrade; and
- **[0047]** a second operating mode wherein the support layer is at least partially cracked, the support layer being mechanically stabilised such that load applied to the upper course is transferred to the subgrade;
- **[0048]** the method comprising permitting traffic to pass over the semi-rigid pavement in at least one of the first and second operating modes.

[0049] The semi-rigid pavement used in the method of the seventh aspect of the present invention may be as defined in the first aspect of the present invention.

[0050] An eighth aspect of the present invention relates to a method of designing a semi-rigid pavement for a location, the semi-rigid pavement comprising:

- **[0051]** an upper course comprising upper course aggregate and a hydrocarbon binder;
- **[0052]** a support layer comprising chemically-stabilised aggregate, the support layer located below the upper course; and
- **[0053]** a subgrade, the subgrade located below the support layer;
- **[0054]** wherein a geosynthetic is at least partially embedded in the chemically-stabilised aggregate that comprises the support layer;

the method comprising:

- **[0055]** a) determining a target lifespan for the semi-rigid pavement;
- **[0056]** b) determining the properties of the subgrade present at the location;
- **[0057]** c) selecting the support layer of chemically-stabilised aggregate above the subgrade, wherein a geosynthetic is at least partially embedded in the layer of chemically-stabilised aggregate;
- **[0058]** d) selecting the upper course;
- **[0059]** e) predicting a predicted lifespan of the semi-rigid pavement comprising the subgrade, the selected support layer, and the selected upper course;
- **[0060]** f) comparing the predicted lifespan with the target lifespan; and
- **[0061]** g) repeating steps c) to f) if the predicted lifespan is less than the target lifespan.

[0062] The semi-rigid pavement may further comprise a base course and/or a granular fill and the method further comprises additional steps of selecting a base course and/or a granular fill.

[0063] The semi-rigid pavement designed by the method of the eighth aspect of the present invention may be as defined in the first aspect of the present invention

[0064] A ninth aspect of the present invention provides a method of designing a semi-rigid pavement for a location, the method comprising:

- **[0065]** a) determining a target lifespan for the semi-rigid pavement;
- **[0066]** b) determining the properties of a subgrade present at the location;

[0067] c) selecting a pre-designed semi-rigid pavement for the location, the pre-designed semi-rigid pavement comprising the subgrade, the selected support layer, and the selected upper course;

[0068] d) predicting a predicted lifespan of the pre-designed semi-rigid pavement;

[0069] e) comparing the predicted lifespan with the target lifespan;

[0070] f) if the predicted lifespan is less than the target lifespan, at least partially embedding a geosynthetic in the support layer and repeating steps d) and e).

[0071] The semi-rigid pavement designed by the method of the ninth aspect of the present invention may be as defined in the first aspect of the present invention

[0072] A tenth aspect of the present invention provides a method of maintaining a semi-rigid pavement, the semi-rigid pavement comprising:

[0073] an upper course comprising upper course aggregate and a hydrocarbon binder;

[0074] a support layer comprising chemically-stabilised aggregate, the support layer located below the upper course; and

[0075] a subgrade, the subgrade located below the support layer;

[0076] wherein a geosynthetic is at least partially embedded in the chemically-stabilised aggregate that comprises the support layer;

the method comprising:

[0077] a) determining acceptable values for one or more properties of the semi-rigid pavement;

[0078] b) waiting a survey period;

[0079] c) surveying the semi-rigid pavement and determining if the one or more properties of the semi-rigid pavement satisfy the acceptable values;

[0080] d) undertaking maintenance if the one or more properties of the semi-rigid pavement do not satisfy the acceptable values; and

[0081] e) repeating steps a) to d).

[0082] The semi-rigid pavement maintained in the method of the tenth aspect of the present invention may be as defined in the first aspect of the present invention.

Definitions

[0083] A Heavy Vehicle Simulator (HVS) test is a form of accelerated full scale pavement testing, repeatedly subjecting a pavement to heavy loads under close observation in controlled conditions.

[0084] By "chemically stabilised aggregate" it is meant that the particles that comprise the aggregate have been rendered substantially immobile relative to one another by being at least partially embedded within a binder. Any suitable binder may be used, including cement, lime, hydrocarbon binders, biochemical binders, polymeric binders, and combinations thereof. Preferably the binder is cement.

[0085] By "mechanically stabilised aggregate" it is meant that the particles that comprise the aggregate have been rendered substantially immobile relative to one another by being restrained by a geosynthetic. Any suitable geosynthetic may be used, including geogrids, geocomposites that incorporate geogrids, and combinations thereof. Preferably the geosynthetic is a geogrid. Where a geogrid is used the aggregate and geogrid may form a mechanically stabilised layer wherein the mesh of the geogrid and particles of aggregate are mechanically interlocked (i.e. the particles of aggregate are immobilised relative to one another).

[0086] By "particle size" it is meant the size of the particle as determined by sieving. For example, particles defined as having a particle size between 5 and 32 mm will pass through a 32 mm sieve and be retained by a 5 mm sieve, particles with a size up to 32 mm will pass through a 32 mm sieve, and particles with a size of at least 5 mm will be retained by a 5 mm sieve.

DETAILED DESCRIPTION

Semi-Rigid Pavement

[0087] A semi-rigid pavement comprises an upper course comprising upper course aggregate and a hydrocarbon binder; a support layer comprising chemically-stabilised aggregate, the support layer located below the upper course; and a subgrade, the subgrade located below the support layer; wherein a geosynthetic is at least partially embedded in the chemically-stabilised aggregate that comprises the support layer.

[0088] The skilled person will understand that such pavements may comprise further layers above the upper course, between the upper course and the support layer, between the support layer and the subgrade, and combinations thereof. In embodiments, the semi-rigid pavement, from top to bottom, consists of the upper course, the support layer, and subgrade. In other embodiments, the semi-rigid pavement, from top to bottom, comprises or consists of the upper course, a granular base, the support layer, and the subgrade. In yet other embodiments, the semi-rigid pavement, from top to bottom, comprises or consists of the upper course, the support layer, a granular fill, and the subgrade. In yet other embodiments, the semi-rigid pavement, from top to bottom, comprises or consists of the upper course, a granular base, the support layer, a granular fill, and the subgrade.

[0089] The semi-rigid pavement of the present invention exhibits an improved lifespan compared to state of the art semi-rigid pavements. The improvement may be a 50% or greater improvement in lifespan, a 75% or greater improvement in lifespan, a 100% or greater improvement in lifespan, a 150% or greater improvement in lifespan, or a 200% or greater improvement in lifespan. References to lifespan refer to the number of 80 kN equivalent standard axle loads (E80s) that can pass over the semi-rigid pavement before its performance becomes unacceptable (e.g. rutting exceeds the accepted limit, for example, 20 mm). This improved lifespan may at least partly result from the pavement being capable of exhibiting two configurations: a first configuration wherein the support layer is monolithic, the support layer being chemically and mechanically stabilised; and a second configuration wherein the support layer is cracked, the support layer being mechanically stabilised. Conversely, state of the art semi-rigid pavements are capable of exhibiting only a single configuration where the support layer is chemically stabilised. Without wishing to be bound by theory, it is thought that inclusion of the geosynthetic leads to an extension of the first configuration by providing additional mechanical support to the chemical-stabilised aggregate of the support layer and enables the existence of the second configuration which takes place after the first configuration (e.g. after effective chemical stabilisation has ceased or at least significantly reduced). In the first configuration, the particles of the aggregate that forms the support layer are immobilised by a chemical binder and by formation of a mechanically stabilised layer with the geosynthetic. In the second configuration, the action of the chemical binder is reduced (e.g. by the formation of cracks), but movement of the aggregate particles is prevented by the geosynthetic (e.g. mechanical interlocking of the particles of aggregate). Use of the geosynthetic and consequent immobilisation of the aggregate also prevents downward movement of the aggregate within the support layer. This prevents formation of a 'slip layer' of loose material at the base of the support layer.

[0090] The semi-rigid pavement of the present invention may be used for any application that is subjected to a dynamic load cycles (e.g. by traffic passing over it). For example, the semi-rigid pavement may be used as, or as part of, a roadway (e.g. for passenger or freight vehicles), a railway (e.g. for traditional or high speed trains), or an airfield. Alternatively, the semi-rigid pavement may be used as a component of a surface for a roadway or a railway (e.g. further comprising sleepers, rails, and/or ballast over the upper course).

Upper Course

[0091] The upper course comprises an upper course aggregate and a hydrocarbon binder. Typically, the upper course is an asphalt concrete, comprising particles of crushed rock held in a solid matrix of bitumen. Alternatively or additionally, the bound aggregate is another composite material, comprising an upper course aggregate and a hydrocarbon binder that is suitable for use as a wearing course (i.e. the top course of the semi-rigid pavement). The upper course may be what is commonly referred to as the surface course (i.e. the exposed course with which traffic has direct contact).

[0092] The particle size of the upper course aggregate is typically in the range of 0 to 35 mm, preferably 10 to 32 mm. The particle size of the upper course aggregate may be up to 11 mm, up to 16 mm, up to 22 mm, or up to 32 mm. The particle size of the aggregate may be at least 5 mm, at least 11 mm, at least 16 mm, or at least 22 mm

[0093] The upper course aggregate may be a continuously graded (or well-graded) aggregate, such as those defined in BS 6100-6.3:1984. Such upper course aggregates have a continuous gradation curve, allowing for good particle interaction and efficacious binding, and are in contrast to gap graded aggregates (such as those used for macadam), which contain open voids due to poor packing of the upper course aggregate. The upper course aggregate may be a particle distribution of as defined in BS EN 14227-1:2013 or BS EN 14227-15:2015.

[0094] The upper course aggregate may be selected from sand, gravel, stone dust, crushed rock, fill, tailings, processed stone, rock, soil, recycled stone, recycled concrete, road planings, and combinations thereof.

[0095] The depth of the upper course will depend on the purpose and specification of the semi-rigid pavement. Generally, the depth of the upper course will be 10 to 100 mm, optionally of from 25 to 75 mm, further optionally of about 50 mm, with a thicker layer of the bound aggregate being required to support heavier applied loads.

Supporting Layer

[0096] The supporting layer comprises a chemically-stabilised aggregate.

[0097] Any suitable aggregate may be used. The aggregate may be selected from sand, gravel, stone dust, crushed rock, fill, tailings, processed stone, rock, soil, recycled stone, recycled concrete, road planings, and combinations thereof.

[0098] The particle size of the aggregate may be in the range of 0 to 35 mm, preferably 10 to 32 mm. The particle size of the aggregate may be up to 11 mm, up to 16 mm, up to 22 mm, or up to 32 mm. The particle size of the aggregate may be at least 5 mm, at least 11 mm, at least 16 mm, or at least 22 mm.

[0099] The aggregate may be a continuously graded (or well-graded) aggregate, such as those defined in BS 6100-6.3:1984. Such aggregates have a continuous gradation curve, allowing for good particle interaction and efficacious binding, and are in contrast to gap graded aggregates (such as those used for macadam), which contain open voids due to poor packing of the aggregate. The particle size distribution of the aggregate may be as defined in BS EN 14227-1:2013 or BS EN 14227-15:2015.

[0100] The binder may be selected from cement, lime, hydrocarbon binders, biochemical binders, polymeric binders, organosilanes, and combinations thereof.

[0101] In embodiments where cement is used as the binder, the cement may be present in an amount less than 10% by weight of the supporting layer. The cement content of the supporting layer may be from 0.1 to 8% by weight, preferably from 0.5 to 5% by weight, more preferably from 1 to 4% by weight, and most preferably from 1.5 to 3% by weight.

[0102] Lime refers to calcium oxides and calcium hydroxides. These are hydrated and mixed with the aggregate, reacting with carbon dioxide to form carbonates that bind the aggregate.

[0103] Hydrocarbon binders include asphalt and tar and may include modifiers to alter their viscosity, hardness, and melting temperature. Hydrocarbon binders may be applied by hot methods or cold methods. In hot methods, the hydrocarbon binder is heated to a flowable, liquid state and then mixed with the aggregate. As the hydrocarbon binder cools it solidifies, binding the aggregate in place. In cold methods, the viscosity of the hydrocarbon binder is reduced through mixing with a solvent or through emulsification, the resulting fluid mixed with the aggregate. As the solvent (and, if present, water) evaporates, the hydrocarbon binder sets to bind the aggregate.

[0104] Biochemical binders are generally comparable to asphaltic binders, polymeric binders, or cement but are of a biological origin. For example, bio-oils, bio-binders, and bio-asphalts are materials produced by processing of organic matter (e.g. by pyrolysis, hydrolysis, high-pressure liquefaction) and may be used alone or in combination with asphalt binders. Further examples include polymers formed from biologically derived monomers, often referred to as renewable polymers, which may be used alone or in combination with conventional monomers, polymers derived directly from biological sources, such as xantham gum and lignin, and derivatives thereof, such as lignosulfonates. Yet further examples include the use microorganisms or enzymes to induce calcite precipitation in situ or to stabilise clays.

[0105] Polymeric binders use polymers to bind the aggregate. These may be applied as melts or solutions of polymers, which then set as they cool or the solvent evaporates, or they may be applied as mixtures comprising one or more monomers, initiators, and/or cross-linking agents which undergo polymerization in situ with the aggregate. Polymeric binders may include epoxy polymers, polyurethanes, acrylic resins, methacrylic resins, polyesters, polystyrenes, xanthum gum, lignin, copolymers thereof, and mixtures thereof.

[0106] Organosilanes react with silicates in the aggregate, rendering the aggregate hydrophobic. This stabilises the aggregate by limiting, or preventing, water ingress.

[0107] The thickness of the support layer may be from 50 to 250 mm, preferably from 100 to 200 mm, more preferably from 125 to 175 mm, most preferably about 150 mm.

[0108] The geosynthetic may be placed at the base of the support layer. Alternatively, the geosynthetic may be embedded within the top portion of the support layer.

Geosynthetic

[0109] A geosynthetic is one of a class of materials used to reinforce and/or stabilise particulate matter such as aggregates or soils.

[0110] The geosynthetic may be selected from geogrids, geotextiles, geonets, geocells, geocomposites, and combinations thereof. Each of these classes of geosynthetic is used for the stabilisation of particulate materials.

[0111] Geogrids are geoengineering constructions that comprise a planar mesh of material with relatively large apertures for the reinforcement and/or stabilisation of loose aggregates. Geogrids for the present invention may be formed of a number of materials, including mineral filaments (such as glass filament or basalt filament), metals (such as steel), and polymers (such as polyesters, polyethylenes, or polypropylenes). Preferably, the geogrids are formed of polypropylene. Geogrids can be produced by a number of processes, each of which is suitable for different materials and imparts different properties on the resulting geogrids.

[0112] One class of geogrids suitable for the present invention are integral geogrids, formed from a single piece of polymeric material (i.e. not strands that are welded, adhered, or otherwise attached into a mesh pattern). Certain integral geogrids, such as those produced by Tensar®, comprise molecularly orientated material, the mesh being formed of elongate tensile elements (or ribs) interconnected by junctions (or nodes). The geogrids are formed by creating holes or depressions in a polymer sheet and then stretching to convert the holes or depressions into apertures and the polymer into elongate tensile elements and junctions. In embodiments, the reverse process is employed with the polymer sheet being stretched and apertures formed in the stretched sheet. It is widely believed in industry that the benefits of geogrids arise from their tensile strength. However, more recent thinking has indicated that the benefits of integral geogrids arise from their interaction with aggregate materials they are placed in, with the interlocking of the aggregate and geogrid resulting in a mechanically stabilised layer wherein the aggregate acts similarly to a chemically bound layer (i.e. the particles of the aggregate are immobile).

[0113] Uniaxial geogrids possess elongate elements running parallel to a single axis (hence uniaxial) and affixed at each end to a bar, which can be considered a continuous node running across the single axis. The elongate elements usually form a continuous end-to-end run along the length of the geogrid, passing through the bars.

[0114] Biaxial geogrids possess elongate elements, each running parallel to one of two axes (hence biaxial). Where the ends of the elongate elements meet, nodes are formed. In general, the elongate elements running parallel to each axis are equally spaced, and the spacing is the same for elongate elements running parallel to each of the two axes. Typically, the axes are perpendicular to one another, resulting in a geogrid with apertures that are rectangular or square in construction. Other angles may be used, resulting in a geogrid with apertures that are a parallelogram or a rhombus in shape.

[0115] Multiaxial geogrids, which are defined herein as geogrids that possess elongate elements, each running parallel to one of at least three axes. For example, triaxial geogrids have elongate elements, each running parallel to one of three axes. In general, the spacing between elongate elements running parallel to each axis is equal, and this spacing is the same for the elongate elements running parallel to each of the three axes. Usually the axes are arranged at mutual 60° angles, such that the elongate elements form equilateral triangles arranged into hexagons. This arrangement permits the geogrid to distribute load more evenly across its structure. Triaxial geogrids and methods for their production are described in WO 2004/003303, incorporated by reference herein.

[0116] Triaxial geogrids may have one or more of the following properties:

[0117] Product weight, specified in terms of weight per unit area. Typical geogrid product weights are at least preferably of from 0.120 to 0.400 kg/m^2, more preferably of from 0.150 to 0.350 kg/m^2, most preferably of from 0.170 to 0.310 kg/m^2, for example from 0.180 to 0.300 kg/m^2.

[0118] Pitch, geogrids have a repeating structure and the pitch of the geogrid is the dimension of the repeating unit. In a triaxial geogrid, the repeating unit is a hexagon and the distance of the hexagonal pitch is the separation of the parallel sides of the hexagon. The pitch is usually of at least 30 mm, preferably of from 40 to 150 mm, more preferably of from 50 to 140, most preferably of from 65 to 125 mm.

[0119] Junction efficiency, being the strength of the node expressed a percentage of the strength of the elongate elements and is indicative of the ability of the geogrid to transfer loads between elongate elements at each node (junction). Suitable junction efficiencies are at least 90% preferably at least 95%, more preferably of at least 97%, most preferably of at least 99%, for example of 100%.

[0120] Preferably, the geogrids of the present invention comprise multiple geometries, such as InterAx® geogrids produced and sold by Tensar® and described in WO 2021/262958 A1 and WO 2022/182411 A1, incorporated by reference herein in their entirety. In one embodiment, the geogrid comprises a plurality of interconnected oriented strands and partially oriented junctions forming a repeating pattern of outer hexagons having an array of openings therein. Oriented ribs extending inwardly from each of said outer hexagons support and surround a smaller inner hexagon having oriented strands thus forming a plurality of trapezoidal openings and a single hexagonal opening. The oriented strands and partially oriented junctions of the outer hexagons form a plurality of linear strong axis strands that extend continuously throughout the entirety of the geogrid and form additional triangular openings. The geogrid thus includes three different repeating geometric shapes (i.e. hexagons, trapezoids, and triangles). In embodiments, the geogrid is of multi-layered construction, optionally having a solid core layer and compressible outer layers.

[0121] The geogrid comprising multiple geometries may have one or more of the following properties:

[0122] Apertures with triangular, trapezoidal, and hexagonal geometries.

[0123] Pitch (i.e. distance between adjacent, parallel continuous strands) of at least 30 mm, preferably of from 40 to 150 mm, more preferably of from 50 to 140, most preferably of from 65 to 125 mm.

[0124] Rib aspect ratio (as measured at the midpoint of the ribs) of at least 1. Preferably, the rib aspect ratio is between 1 and 4.

[0125] Minimum rib thickness of at least 3 mm, preferably at least 5 mm.

[0126] The two compressible outer layers being at least forty percent (40%) of the overall height of the geogrid, and preferably at least seventy percent (70%).

[0127] Multiaxial geogrids, such as trixial geogrids and geogrids with multiple geometries, are particularly effective in achieving interlocking and immobilisation of the particles of the aggregate.

[0128] Alternatively, geogrids may be formed from polymers by arranging strips of material into a grid and attaching where the strips overlap. Such geogrids may be made of mineral fibres (e.g. glass or basalt), metals (e.g. steel) or polymer (e.g. polyester, polyethylene, or polypropylene). The attaching may be achieved by the tying of material, adhesives, or welding processes. A subset of these geogrids are woven geogrids, wherein flexible fibres are woven together.

[0129] As a further alternative, the geogrid may be a cast geogrid formed by casting the molten material into the shape of the geogrid. Such geogrids may be made of metals (e.g. steel) or polymer (e.g. polyester, polyethylene, or polypropylene).

[0130] Geotextiles are geoengineering constructions that comprise a fabric that may be woven or non-woven. Geotextiles are typically formed of polymer fibres (such as polyester, polyethylene, or polypropylene) or natural fibres. The geotextile may have a product weight of at least 0.080 kg/m^2, preferably of from 0.100 to 0.200 kg/m^2, more preferably of from 0.110 to 0.180 kg/m^2, most preferably of from 0.120 to 0.150 kg/m^2. Alternatively, the geotextile element may have a product weight of from 0.03 to 0.4 kg/m^2.

[0131] Geonets are geoengineering constructions that comprise planes of parallel ribs that are arranged in a stack, the ribs in different planes arranged at angles. The geonets are produced by extrusion and the arrangements may be biplanar (i.e. having two sets of parallel ribs at different angles) or triplanar (i.e. having three sets of parallel ribs at different angles). The function of geonets is to facilitate the flow of fluids while retaining solid particles. Geonets are typically made of polyethylene.

[0132] Geocells, also known as cellular confinement systems, are geoengineering constructions comprising an array of cells with a significant depth that are used to confine material placed therein. Strips of material are arranged into cells with triangular, square, rectangular, or honeycomb geometry, the strips being affixed, typically by welding. The material is usually a polymer, such as polyethylene.

[0133] Geocomposites are geoengineering constructions that comprise two or more of the aforementioned geosynthetics. For example, a geogrid bonded to a geotextile.

Subgrade

[0134] The subgrade is the bottommost layer of the construction and may be material present prior to construction of the semi-rigid pavement. For example, where excavation has taken place to build the semi-rigid pavement, the subbase is the material at the bottom of the trench. Alternatively, the subgrade may be material that has been placed for the purpose of the construction. For example, an embankment where the semi-rigid pavement is required to be at a higher level than the surrounding location, optionally the embankment comprising native materials. Further alternatively, the subgrade may be a pre-existing construction, or part of a pre-existing construction. For example, an existing road in need of rejuvenation or replacement may be planed and/or excavated to a required depth and the semi-flexible pavement prepared on top of the remaining elements of the existing road.

[0135] The subgrade is tested to determine its properties. If insufficient, a further layer may be inserted between the supporting layer and the subgrade, for example, a granular fill.

Further (Optional) Courses

[0136] The semi-rigid pavement may comprise further layers to those set out above.

[0137] In embodiments where the upper course is not the surface course, a wear course may be included above the upper course. The wear course comprises a wear aggregate and a binder. In an embodiment, the wear course is an asphalt.

[0138] A base layer may be included between the upper course and the support layer. The base layer comprises a base aggregate, which may be selected from sand, gravel, stone dust, crushed rock, fill, tailings, processed stone, rock, soil, recycled stone, recycled concrete, road planings, and combinations thereof. The base layer may have a depth of from 50 to 250 mm, preferably from 100 to 200 mm, more preferably from 125 to 175 mm, most preferably about 150 mm.

[0139] A granular fill may be present between the support layer and the subgrade. The granular fill provides additional support and is used in cases where the subgrade's physical condition does not permit direct placement of the support layer thereon. The granular fill may be selected from sand, gravel, stone dust, crushed rock, fill, tailings, processed stone, rock, soil, recycled stone, recycled concrete, road planings, and combinations thereof. The granular fill may have a depth of from 100 mm to 500 mm, preferably from 200 mm to 400 mm, most preferably about 300 mm.

[0140] A levelling course may be present between the support layer and the subgrade. A levelling course may be present in embodiments wherein the subgrade is a pre-existing construction or part of a pre-existing construction.

[0141] Where the semi-rigid pavement is to be used as, or as part of, a railway, it may further comprise ballast, sleepers, and/or rails over the upper course.

Method of Construction

[0142] The method of constructing a semi-rigid pavement comprises:

[0143] a) providing a geosynthetic above a subgrade;

[0144] b) providing aggregate and binder over the geosynthetic such that the geosynthetic is at least partially embedded in the aggregate;

[0145] c) setting the binder to form a support layer comprising chemically-stabilised aggregate; and

[0146] d) providing an upper course comprising an upper course aggregate and a hydrocarbon binder above the support layer.

[0147] The subgrade may be compacted prior to provision of the geosynthetic. The geosynthetic may be pinned in place prior to provision of the aggregate and binder.

[0148] The step of providing aggregate and binder over the geosynthetic may comprise providing aggregate and binder sequentially, providing aggregate and binder simultaneously, or mixing the aggregate and binder prior to provision over the geosynthetic. In an embodiment, the aggregate is provided over the geosynthetic and binder is then added to the aggregate, the binder being allowed to percolate through the aggregate or being mixed with the aggregate in situ. Alternatively, the aggregate and binder are provided simultaneously as separate streams, mixing and providing the aggregate and binder in one step. Further alternatively, the aggregate and binder are mixed (either on site or in a plant) and then provided over the geosynthetic as a mixture. After provision over the geosynthetic, the aggregate may be compacted prior to the binder setting or as the binder sets.

[0149] Setting of the binder occurs over time as the binder cures or solidifies. Prior to setting of the binder, the aggregate may be compacted.

[0150] Providing the upper course may be done by any suitable technique known in the art.

Method of Constructing a Semi-Rigid Pavement with an Improved Lifespan

[0151] The method comprises: a) at least partially embedding a geosynthetic within an aggregate and a binder; and b) setting the binder to form a support layer comprising chemically-stabilised aggregate, wherein the support layer is incorporated into the semi-rigid pavement during construction.

[0152] By lifespan it is meant the number of equivalent standard axle loads of 80 kN (E80) that the semi-rigid pavement may be subjected to prior to failure. By failure, it is meant that the semi-rigid pavement has deformed to the point that it is no longer fit for purpose, for example, it has rutted to a depth of 20 mm or more, or has cracked extensively. By improved lifespan it is meant that the semi-rigid pavement has a lifespan exceeding that of an equivalent semi-rigid pavement in the absence of the geosynthetic. The improvement may be a 50% or greater improvement in lifespan, a 75% or greater improvement in lifespan, a 100% or greater improvement in lifespan, a 150% or greater improvement in lifespan, or a 200% or greater improvement in lifespan.

Method of Constructing a Semi-Rigid Pavement with a Reduced Thickness

[0153] The method comprises: a) at least partially embedding a geosynthetic within an aggregate and a binder; and b) setting the binder to form a support layer comprising chemically-stabilised aggregate, wherein the support layer is incorporated into the semi-rigid pavement during construction. The support layer may be a support layer as described herein. The semi-rigid pavement may be a semi-rigid pavement as described herein.

[0154] By reduced thickness it is meant that the semi-rigid pavement has a thickness less than that of an equivalent semi-rigid pavement in the absence of the geosynthetic that is designed to have the same lifespan. The thickness of the semi-rigid pavement may be due to the reduction in the thickness of the support layer alone. The thickness of the support layer may be reduced by 10% or greater, reduced by 20% or greater, reduced by 30% or greater, or reduced by 50% or greater. In embodiments, the thickness of the support layer may be from 50 to 250 mm, preferably from 100 to 200 mm, more preferably from 125 to 175 mm, most preferably about 150 mm. Alternatively, the reduction in thickness may be due to a reduction of the thickness of the support layer in addition to a reduction in the thickness of other layers. The thickness of the semi-rigid pavement may be reduced by 5% or greater, reduced by 10% or greater, reduced by 20% or greater, or reduced by 30% or greater.

Use of a Geosynthetic to Increase the Lifespan of a Semi-Rigid Pavement

[0155] The use comprises at least partially embedding a geosynthetic within an aggregate that is chemically-stabilised with a binder and incorporating into the semi-rigid pavement. The aggregate and binder may form a support layer as described herein. The semi-rigid pavement may be a semi-rigid pavement as described herein.

[0156] By lifespan it is meant the number of equivalent standard axle loads of 80 kN (E80) that the semi-rigid pavement may be subjected to prior to failure. By failure, it is meant that the semi-rigid pavement has deformed to the point that it is no longer fit for purpose, for example, it has rutted to a depth of 20 mm or more. By improved lifespan it is meant that the semi-rigid pavement has a lifespan exceeding that of an equivalent semi-rigid pavement in the absence of the geosynthetic. The improvement may be a 50% or greater improvement in lifespan, a 75% or greater improvement in lifespan, a 100% or greater improvement in lifespan, a 150% or greater improvement in lifespan, or a 200% or greater improvement in lifespan.

Use of a Geosynthetic to Decrease the Thickness of a Semi-Rigid Pavement with a Pre-Determined Lifespan

[0157] The use comprises at least partially embedding a geosynthetic within an aggregate that is chemically-stabilised with a binder and incorporating into the semi-rigid pavement. The aggregate and binder may form a support layer as described herein. The semi-rigid pavement may be a semi-rigid pavement as described herein.

Method of Operating a Semi-Rigid Pavement

[0158] The semi-rigid pavement of the method comprises a subgrade, a support layer of chemically-stabilised aggregate above the subgrade, wherein a geosynthetic is at least partially embedded in the layer of chemically-stabilised aggregate, and an upper course above the chemically-stabilised aggregate, wherein the semi-rigid pavement is capable of exhibiting: a first operating mode wherein the support layer is substantially monolithic, the support layer being chemically and mechanically stabilised such that load applied to the upper course is transferred to the subgrade;

and a second operating mode wherein the support layer is at least partially cracked, the support layer being mechanically stabilised such that load applied to the upper course is transferred to the subgrade; the method comprising permitting traffic to pass over the semi-rigid pavement in at least one of the first and second operating modes.

[0159] The support layer may be a support layer as described herein. The semi-rigid pavement may be a semi-rigid pavement as described herein.

[0160] In the first configuration the support layer is monolithic, the support layer being chemically and mechanically stabilised. The particles of aggregate are held immobile relative to one another, predominantly by the binder, allowing loads that are applied to the support layer (e.g. by traffic passing over the upper course) to be efficiently transmitted to and spread over the subgrade. In the second configuration the support layer is cracked (i.e. the binder has ceased to effectively immobilise the aggregate), and the support layer is instead mechanically stabilised, enabling distribution of loads applied to the support layer. All semi-rigid pavements have the first configuration, however, in conventional semi-rigid pavement failure of the chemical stabilisation rapidly leads to failure of the semi-rigid pavement as loads are not distributed effectively. Conversely, the semi-rigid pavement of the present invention continues to operate effectively even after failure of the chemical stabilisation.

Method of Designing a Semi-Rigid Pavement

[0161] In a first method of designing a semi-rigid pavement for a location, the semi-rigid pavement comprising an upper course comprising upper course aggregate and a hydrocarbon binder; a support layer comprising chemically-stabilised aggregate, the support layer located below the upper course; and a subgrade, the subgrade located below the support layer; wherein a geosynthetic is at least partially embedded in the chemically-stabilised aggregate that comprises the support layer; and the method comprises:

- **[0162]** a) determining a target lifespan for the semi-rigid pavement;
- **[0163]** b) determining the properties of the subgrade present at the location;
- **[0164]** c) selecting the support layer of chemically-stabilised aggregate above the subgrade, wherein a geosynthetic is at least partially embedded in the layer of chemically-stabilised aggregate;
- **[0165]** d) selecting the upper course;
- **[0166]** e) predicting a predicted lifespan of the semi-rigid pavement comprising the subgrade, the selected support layer, and the selected upper course;
- **[0167]** f) comparing the predicted lifespan with the target lifespan; and
- **[0168]** g) repeating steps c) to f) if the predicted lifespan is less than the target lifespan.

[0169] The person of skill in the art is aware of many methods by which the lifespan of the semi-rigid pavement may be predicted. For example, mechanistic-empirical pavement design method (such as that described in "Mechanistic-Empirical Pavement Design Guide. A Manual of Practice", American Association of State Highway and Transportation Officials, 2020) or empirical pavement design method (such as that described in "AASHTO Guide for Design of Pavement Structures: American Association of State Highway and Transportation Officials, 1993). Prediction of the lifespan of the semi-rigid pavement takes into account the benefits of including the geosynthetic in the form of life improvement factors and/or material layer parameter improvement factors, said factors being determined based on the results of accelerated pavement tests, such as the full scale tests described herein.

[0170] The semi-rigid pavement may further comprise a base course and/or a granular fill and the method may further comprise additional steps of selecting a base course and/or a granular fill.

[0171] In an alternative method of designing a semi-rigid pavement for a location, the method comprises:

- **[0172]** a) determining a target lifespan for the semi-rigid pavement;
- **[0173]** b) determining the properties of a subgrade present at the location;
- **[0174]** c) selecting a pre-designed semi-rigid pavement for the location, the pre-designed semi-rigid pavement comprising the subgrade, the selected support layer, and the selected upper course;
- **[0175]** d) predicting a predicted lifespan of the pre-designed semi-rigid pavement;
- **[0176]** e) comparing the predicted lifespan with the target lifespan;
- **[0177]** f) if the predicted lifespan is less than the target lifespan, at least partially embedding a geosynthetic in the support layer and repeating steps d) and e).

[0178] The person of skill in the art is aware of many methods by which the lifespan of the semi-rigid pavement may be predicted. For example, mechanistic-empirical pavement design method (such as that described in "Mechanistic-Empirical Pavement Design Guide. A Manual of Practice", American Association of State Highway and Transportation Officials, 2020) or empirical pavement design method (such as that described in "AASHTO Guide for Design of Pavement Structures: American Association of State Highway and Transportation Officials, 1993). When a geosynthetic is incorporated into the support layer, prediction of the lifespan of the semi-rigid pavement takes into account the benefits of including the geosynthetic in the form of life improvement factors and/or material layer parameters improvement factors, said factors being determined based on the results of accelerated pavement tests, such as the full scale tests described herein.

[0179] By "pre-designed semi-rigid pavement", it is meant a pavement design that has been selected from those that are known and commercially available ("Guidelines for the standardisation of pavement structures of traffic areas RStO 12", Road and Transportation Research Association, Germany, 2012; or "CD 226 Design for new pavement construction", Design Manual for Roads and Bridges, U K, 2020; or "Catalogue of Typical Flexible and Semi-Rigid Pavement Structures", General Directorate of State Roads and Highways, Poland, 2014; or "IRC 37-2018 Guidelines for the Design of Flexible Pavements", Indian Road Congress, India, 2018).

Method of Maintaining a Semi-Rigid Pavement

[0180] The present invention also relates to a method of maintaining a semi-rigid pavement, the semi-rigid pavement comprising:

- **[0181]** an upper course comprising upper course aggregate and a hydrocarbon binder;

[0182] a support layer comprising chemically-stabilised aggregate, the support layer located below the upper course; and

[0183] a subgrade, the subgrade located below the support layer;

[0184] wherein a geosynthetic is at least partially embedded in the chemically-stabilised aggregate that comprises the support layer;

the method comprising:

[0185] a) determining acceptable values for one or more properties of the semi-rigid pavement;

[0186] b) waiting a survey period;

[0187] c) surveying the semi-rigid pavement and determining if the one or more properties of the semi-rigid pavement satisfy the acceptable values;

[0188] d) undertaking maintenance if the one or more properties of the semi-rigid pavement do not satisfy the acceptable values; and

[0189] e) repeating steps a) to d).

[0190] The one or more properties of the geogrid may include the extent of surface deformation, the number of cracks in the semi-rigid pavement, the depth of and cracks in the semi-rigid pavement, the length of any cracks in the semi-rigid pavement

[0191] The survey period may be a period of 1 month to 5 years, preferably 2 months to 2 years, more preferably 3 months to 1 year, most preferably about 6 months.

DESCRIPTION OF THE DRAWINGS

[0192] FIG. **1** depicts a schematic cross-section of constructions tested in Example 1 described below. The left hand figure relates to the control construction, which comprises, from top to bottom, a 50 mm upper course (**10**), a 150 mm granular base (**20**), a 150 mm cement-stabilised subbase (**30**), and a 300 mm granular fill (**40**). The right hand figure relates to a construction according to the present invention, which comprises, from top to bottom, a 50 mm upper course (**10**), a 150 mm granular base (**20**), a 150 mm cement-stabilised subbase (**30**) including a geosynthetic (**50**) near its base, and a 300 mm granular fill (**40**). Below each construction would be an in situ subgrade, which has been compacted, but this is omitted from both figures for clarity.

[0193] FIG. **2** depicts a plan view of a Heavy Vehicle Simulator (HVS) test section used in Example 1. The left hand area (**210**) is of the construction according to the present invention, the right hand area (**220**) is of the control construction, and between these areas is a transition area (**230**), which is ignored for evaluation.

[0194] FIG. **3** is a graph showing an average rut depth per repetition for the testing undertaken in Example 1. The upper trace (**310**) relates to the control, while the lower trace (**320**) relates to a construction according to the present invention.

[0195] FIG. **4** is a graph showing a maximum rut depth per equivalent standard 80 kN axle loads (E80) for the testing undertaken in Example 1. The upper trace (**410**) relates to the control, while the lower trace (**420**) relates to a construction according to the present invention.

[0196] FIG. **5** is a graph showing the surface deformation per pass for the testing undertaken in Example 2. The left-hand trace (**510**) shows the deformation for a control construction, while the right-hand trace (**520**) shows the deformation for a construction additionally comprising a geogrid.

EXAMPLES

[0197] Materials specified herein (e.g. G5, G9) are specified as per COTO (2020) technical specifications.

Example 1—Full Scale Trafficking Testing

Test Pavement Design

[0198] A schematic of the test bed is shown in FIG. **1**. The control pavement comprised a 50 mm upper course of continuously graded asphalt (Class A), a 150 mm granular base of graded crushed stone (Class G1), a 150 mm cement-stabilised subbase (Class C3), and a 300 mm granular fill comprised of a 150 mm layer of gravel soil (Class G5) over a 150 mm layer of gravel soil (G9). In the geogrid containing pavement, a 20 m length of InterAx® geogrid was incorporated into the cement-stabilised subbase. An 8 m HVS test section was designated (see FIG. **2**), the test section centred on the transition point between the control pavement and test pavement.

Test Pavement Construction

[0199] A test bed with a length of 30 m and a width of 4.5 m was excavated to the required depth and the existing subgrade compacted.

[0200] A layer of G9 material was deposited and compacted to a depth of 150 mm, followed by a layer of G5 material being deposited and compacted to a depth of 150 mm. Taken together, these layers form the 300 mm granular fill depicted in FIG. **1**.

[0201] A 20 m length of InterAx® NX750™ geogrid was placed at one end of the test bed. The InterAx® NX750™ geogrid comprises multiple aperture geometries including hexagons, trapezoids, and triangles, as is described in WO 2021/262958 A1, with the ribs being three layers of coextruded polypropylene the outer two layers being foamed, as is described in WO 2022/182411 A1. The ribs are rectangular and have a pitch of 80 mm and an aspect ratio of >1.0. G5B material was then deposited along the entire length of the test bed, and treated with cement at a loading of 2 wt %, and compacted to a depth of 150 mm to form the C3 subbase.

[0202] A layer of G1 material was deposited and compacted to a depth of 150 mm, followed by deposition of 50 mm of continuously graded asphalt.

Heavy Vehicle Simulator Test

[0203] The following HVS dual wheel load applications were applied to the control pavement and geogrid containing pavement simultaneously, using a constant tyre pressure of 740 kPa:

[0204] 135,282 repetitions of a 40 kN dual wheel load (simulating a standard 80 kN axle load);

[0205] 245,056 repetitions of a 60 kN dual wheel load (simulating a 120 kN axle load);

[0206] 171,507 repetitions of a 80 kN dual wheel load in the dry condition (simulating a 160 kN axle load); and

[0207] 512,979 repetitions of a 80 kN dual wheel load in the wet condition (simulating a 160 KN axle load).

[0208] The total number of repetitions applied to the test bed is 1,030,523. This equates to approximately 14 million equivalent standard 80 kN axle loads (E80) (using a damage coefficient of 4.2).

[0209] A Wireless Laser Profilometer was used to measure the surface permanent deformation/total rut depth. During HVS testing, profilometer readings are typically measured at 0.5 m intervals along a portion of the 8 m HVS test section, and at intervals of 1 cm across the HVS test section. The maximum permanent deformation/total rut depth values as well as the average maximum values of the surface permanent deformation at each point are calculated from this data.

[0210] The variation in average rut depth per repetition (i.e. the average rut depth recorded for each pavement on a given repetition) is shown in FIG. **3**. It can be seen that there is a small improvement for the geogrid-containing pavement including the geogrid compared to the control pavement in the early testing under dry conditions. Under wet conditions, from around 750,000 repetitions onwards, this improvement increases dramatically and by the end of the testing the control pavement had an average rut depth of 20 mm while the geogrid-containing pavement had an average rut depth of only 10.9 mm.

[0211] The variation in maximum rut depth per E80 is shown in FIG. **4**. Again, it can be seen that there is a small improvement for the geogrid-containing pavement under dry conditions, which becomes more evident under the more challenging wet conditions. By the end of the testing, the control pavement had a maximum rut depth of 23.9 mm, compared to 13 mm for the geogrid-containing pavement. The control pavement reached the maximum acceptable rut depth of 20 mm at around 1,240,000 million E80s. The geogrid containing pavement did not reach the maximum acceptable rut depth, even after 14,000,000 E80s.

[0212] Overall, inclusion of the geogrid in the cement-treated subbase lead to an almost 100% improvement in performance.

[0213] The main mode of failure was rutting in the granular base layer due to the aggressive trafficking combined with in-depth water addition and the cracking of the cement-stabilised layer that reduced the support to the base. No cracking was observed in the upper course. Without wishing to be bound by any particular theorem, it is reasonable to conclude that the geogrid is improving the properties of the cement-stabilised layer both before and after cracking of this layer. The maximum rutting on the geogrid section was about half of that of the control section, indicating that the expected life of the pavement structure when the geogrid is included in the cement-stabilised layer is potentially at least double that of the equivalent structure without a geogrid. Alternatively, incorporation of a geogrid in the cement stabilised layer could permit a reduction in the thickness of the layer, or other layers in the construction, while achieving the same lifetime.

Example 2—Small Scale Trafficking Testing

[0214] The performance of a chemically-stabilised support layer containing a geosynthetic for resisting rutting due to vehicle traffic was evaluated using a small scale trafficking test. Such tests, such as the one described in Webster, S. L.; "Geogrid Reinforced Base Course for Flexible Pavements for Light Aircraft: Test Section Construction, Behavior Under Traffic, Laboratory Tests, and Design Criterial," *Report DOT/FAA/RD*-92, December 1992, are well established in the field of pavement design for determining the performance of pavements. The small scale test was designed to reproduce the results of the full scale trafficking test in terms of the differences between the support layers containing geosynthetics and those without geosynthetics, without requiring the extensive time and material commitments of the full scale testing. In other words, it is the relative difference in performance that is important, not the absolute difference.

[0215] In general, a test section consisting of an underlying clay subgrade and a support layer of chemically-stabilised aggregate geogrid, the latter optionally containing a geosynthetic. The test section is subjected to the load of a single weighted wheel. The wheel traverses the test section along a single horizontal path, constantly reversing direction from one end of the test section to the other until failure of the test section. The surface deformation (i.e. rutting) of the test section is monitored throughout. A control test with no geogrid present will fail rapidly under such testing.

[0216] A control test was performed using a cement-stabilised layer with a thickness of 65 mm over a normal clay subgrade with a thickness of 75 mm. The clay subgrade was a brown slightly sandy clay developed for trafficking testing. The clay has a typical California Bearing Ratio (CBR) measurement of 0.5% when measured with a MEXE CBR probe, an undrained shear strength of 19 kPa when measured with a hand shear vane and a typical moisture content of 32% when measured to BS EN ISO 17892-1: 2014. The cement-stabilised layer used 0-10 mm graded aggregate with 3 wt % cement, which was compacted and allowed to cure for 5 days. The single weighted wheel with a contact area of 100 cm^2 was loaded to provide a force of 4 kN and an applied pressure of approximately 400 kPa. After 29 passes, the surface deformation of the control exceeded 50 mm and was judged to have failed.

[0217] The test was repeated, with the addition of an NX750 geogrid (a geogrid comprising multiple geometries as described herein) embedded in the base of the cement-stabilised layer. After 56 passes, the surface deformation of the geogrid-containing test bed exceed 50 mm and was judged to have failed.

[0218] The results are illustrated graphically in FIG. **5**, which shows that the inclusion of the geogrid in the chemically-stabilised layer nearly doubles the lifetime under the test conditions used.

1. A semi-rigid pavement comprising:
an upper course comprising upper course aggregate and a hydrocarbon binder;
a support layer comprising chemically-stabilised aggregate, the support layer located below the upper course; and
a subgrade, the subgrade located below the support layer;
wherein a geosynthetic is at least partially embedded in the chemically-stabilised aggregate that comprises the support layer.

2. The semi-rigid pavement of claim **1**, wherein the semi-rigid pavement has two configurations:
a first configuration wherein the support layer is monolithic, the support layer being chemically and mechanically stabilised; and
a second configuration wherein the support layer is cracked, the support layer being mechanically stabilised.

3. The semi-rigid pavement of claim **1**, further comprising a base course.

4. The semi-rigid pavement of claim **1**, further comprising a layer of a granular fill.

5. The semi-rigid pavement of claim **1**, wherein the geosynthetic is selected from geogrids, geotextiles, geonets, geocells, geocomposites, and combinations thereof.

6. The semi-rigid pavement of claim **5**, wherein the geosynthetic comprises a geogrid or is a geogrid.

7. The semi-rigid pavement of claim **6**, wherein the geogrid is a multiaxial geogrid, optionally the multiaxial geogrid is a triaxial geogrid or a geogrid with multiple geometries.

8. The semi-rigid pavement of claim **7**, wherein the triaxial geogrid has one or more of the following properties:

i. product weight of from 0.120 to 0.400 kg/m^2, more preferably of from 0.150 to 0.350 kg/m^2, most preferably of from 0.170 to 0.310 kg/m^2, for example from 0.180 to 0.300 kg/m^2; and/or

ii. pitch of at least 30 mm, preferably of from 40 to 150 mm, more preferably of from 50 to 140, most preferably of from 65 to 125 mm; and/or

iii. junction efficiency of at least 90% preferably at least 95%, more preferably of at least 97%, most preferably of at least 99%, for example of 100%.

9. The semi-rigid pavement of claim **7**, wherein the geogrid with multiple geometries has one or more of the following properties:

i. Apertures with triangular, trapezoidal, and hexagonal geometries; and/or

ii. Pitch of at least 30 mm, preferably of from 40 to 150 mm, more preferably of from 50 to 140, most preferably of from 65 to 125 mm; and/or

iii. Rib aspect ratio of at least 1, preferably, between 1 and 4; and/or

iv. Minimum rib thickness of at least 3 mm, preferably at least 5 mm; and/or

V. Where the geogrid has a solid inner layer and a two compressible outer layers, the two compressible outer layers are at least forty percent (40%) of the overall height of the geogrid, preferably at least seventy percent (70%).

10. The semi-rigid pavement of claim **6**, wherein the geogrid has a multilayer structure, optionally wherein the geogrid has a solid inner layer and compressible outer layers.

11. The semi-rigid pavement of claim **1**, wherein the geosynthetic is located at the base of the support layer.

12. The semi-rigid pavement of claim **1**, wherein the chemically-stabilised aggregate comprises a biochemical binder, a polymeric binder, a hydrocarbon binder, lime, cement, or a combination thereof, optionally wherein the chemically stabilised aggregate comprises cement, optionally up to 10% by weight cement, further optionally from 0.1 to 8% by weight cement, optionally from 0.5 to 5% by weight cement, yet further optionally from 1 to 4% by weight cement, and still further optionally from 1.5 to 3% by weight cement.

13. The semi-rigid pavement of claim **1**, wherein the chemically stabilised aggregate and/or the upper course aggregate comprise a continuously graded aggregate.

14. The semi-rigid pavement of claim **1**, wherein the support layer has a thickness of from 50 to 400 mm, optionally of from 75 to 300 mm, further optionally from 100 to 200 mm, yet further optionally of about 150 mm.

15. The semi-rigid pavement of claim **1**, wherein the upper course has a thickness of from 10 to 100 mm, optionally of from 25 to 75 mm, further optionally of about 50 mm.

16. A method of constructing a semi-rigid pavement, the method comprising:

a) providing a geosynthetic above a subgrade;

b) providing aggregate and binder over the geosynthetic such that the geosynthetic is at least partially embedded in the aggregate;

c) setting the binder to form a support layer comprising chemically-stabilised aggregate; and

d) providing an upper course comprising an upper course aggregate and a hydrocarbon binder above the support layer.

17. A method of constructing a semi-rigid pavement with an improved lifespan, the method comprising:

a) at least partially embedding a geosynthetic within an aggregate and a binder; and

b) setting the binder to form a support layer comprising chemically-stabilised aggregate,

wherein the support layer is incorporated into the semi-rigid pavement during construction.

18. A method of constructing a semi-rigid pavement with a reduced thickness, the method comprising:

a) at least partially embedding a geosynthetic within an aggregate and a binder; and

b) setting the binder to form a support layer comprising chemically-stabilised aggregate,

wherein the support layer is incorporated into the semi-rigid pavement during construction.

19. Use of a geosynthetic to increase the lifespan of a semi-rigid pavement, the use comprising at least partially embedding a geosynthetic within an aggregate that is chemically-stabilised with a binder and incorporating into the semi-rigid pavement.

20. Use of a geosynthetic to decrease the thickness of a semi-rigid pavement with a pre-determined lifespan, the use comprising at least partially embedding a geosynthetic within an aggregate that is chemically-stabilised with a binder and incorporating into the semi-rigid pavement.

21. A method of operating a semi-rigid pavement, the semi-rigid pavement comprising a subgrade, a support layer of chemically-stabilised aggregate above the subgrade, wherein a geosynthetic is at least partially embedded in the layer of chemically-stabilised aggregate, and an upper course above the chemically-stabilised aggregate, wherein the semi-rigid pavement is capable of exhibiting:

a first operating mode wherein the support layer is substantially monolithic, the support layer being chemically and mechanically stabilised such that load applied to the upper course is transferred to the subgrade; and

a second operating mode wherein the support layer is at least partially cracked, the support layer being mechanically stabilised such that load applied to the upper course is transferred to the subgrade;

the method comprising permitting traffic to pass over the semi-rigid pavement in at least one of the first and second operating modes.

22. A method of designing a semi-rigid pavement for a location, the semi-rigid pavement comprising:

an upper course comprising upper course aggregate and a hydrocarbon binder;

a support layer comprising chemically-stabilised aggregate, the support layer located below the upper course; and

a subgrade, the subgrade located below the support layer;

wherein a geosynthetic is at least partially embedded in the chemically-stabilised aggregate that comprises the support layer:

the method comprising:

a) determining a target lifespan for the semi-rigid pavement;

b) determining the properties of the subgrade present at the location;

c) selecting the support layer of chemically-stabilised aggregate above the subgrade, wherein a geosynthetic is at least partially embedded in the layer of chemically-stabilised aggregate;

d) selecting the upper course;

e) predicting a predicted lifespan of the semi-rigid pavement comprising the subgrade, the selected support layer, and the selected upper course;

f) comparing the predicted lifespan with the target lifespan; and

g) repeating steps c) to f) if the predicted lifespan is less than the target lifespan.

23. The method of claim **22**, wherein the semi-rigid pavement further comprises a base course and/or a granular fill and the method further comprises additional steps of selecting a base course and/or a granular fill.

24. A method of designing a semi-rigid pavement for a location, the method comprising:

a) determining a target lifespan for the semi-rigid pavement;

b) determining the properties of a subgrade present at the location;

c) selecting a pre-designed semi-rigid pavement for the location, the pre-designed semi-rigid pavement comprising the subgrade, the selected support layer, and the selected upper course;

d) predicting a predicted lifespan of the pre-designed semi-rigid pavement;

e) comparing the predicted lifespan with the target lifespan;

f) if the predicted lifespan is less than the target lifespan, at least partially embedding a geosynthetic in the support layer and repeating steps d) and e).

25. A method of maintaining a semi-rigid pavement, the semi-rigid pavement comprising:

an upper course comprising upper course aggregate and a hydrocarbon binder;

a support layer comprising chemically-stabilised aggregate, the support layer located below the upper course; and

a subgrade, the subgrade located below the support layer;

wherein a geosynthetic is at least partially embedded in the chemically-stabilised aggregate that comprises the support layer;

the method comprising:

a) determining acceptable values for one or more properties of the semi-rigid pavement;

b) waiting a survey period;

c) surveying the semi-rigid pavement and determining if the one or more properties of the semi-rigid pavement satisfy the acceptable values;

d) undertaking maintenance if the one or more properties of the semi-rigid pavement do not satisfy the acceptable values; and

e) repeating steps a) to d).

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