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(54) **LOW-SLOPE ROOFING SYSTEM**

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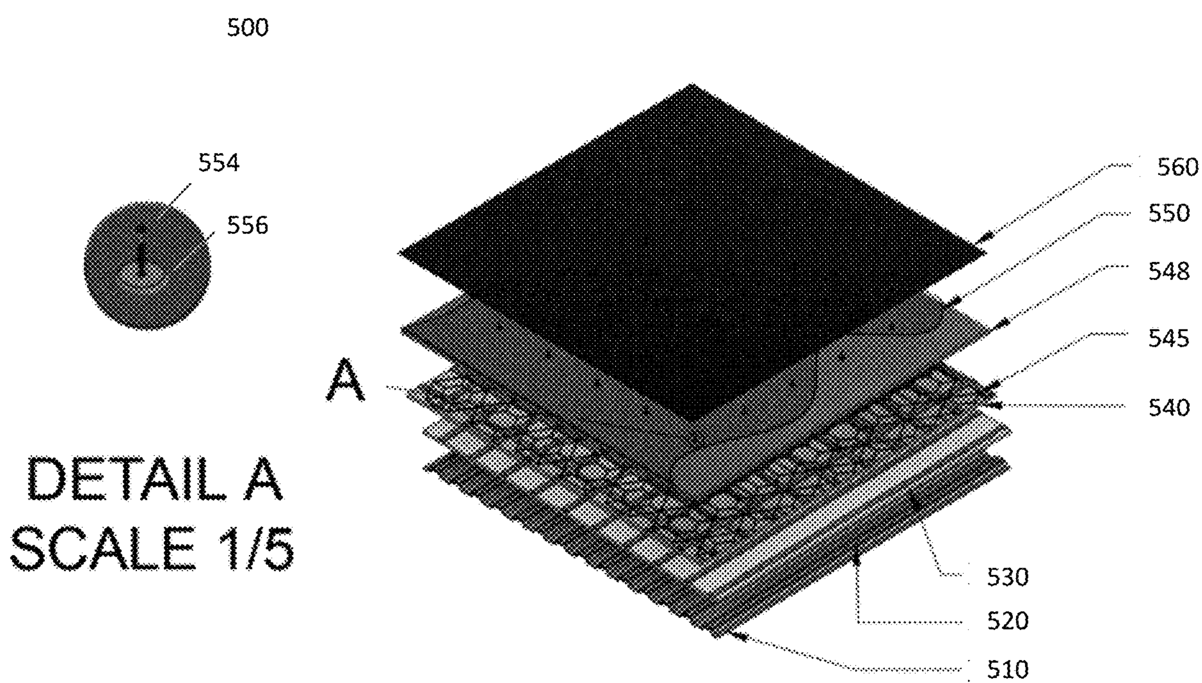
CPC ............ *E04D 3/35* (2013.01); *E04D 3/3606* (2013.01)

(57) **ABSTRACT**

Embodiments of the present invention may include a low-slope roofing system, the system comprising a geogrid layer, and a first coverboard layer, wherein the geogrid layer is attached to the first coverboard layer. Aspects of the present invention may also include a method of assembling a low-slope roofing system, comprising attaching a first coverboard layer, and attaching a geogrid layer to the first coverboard layer.



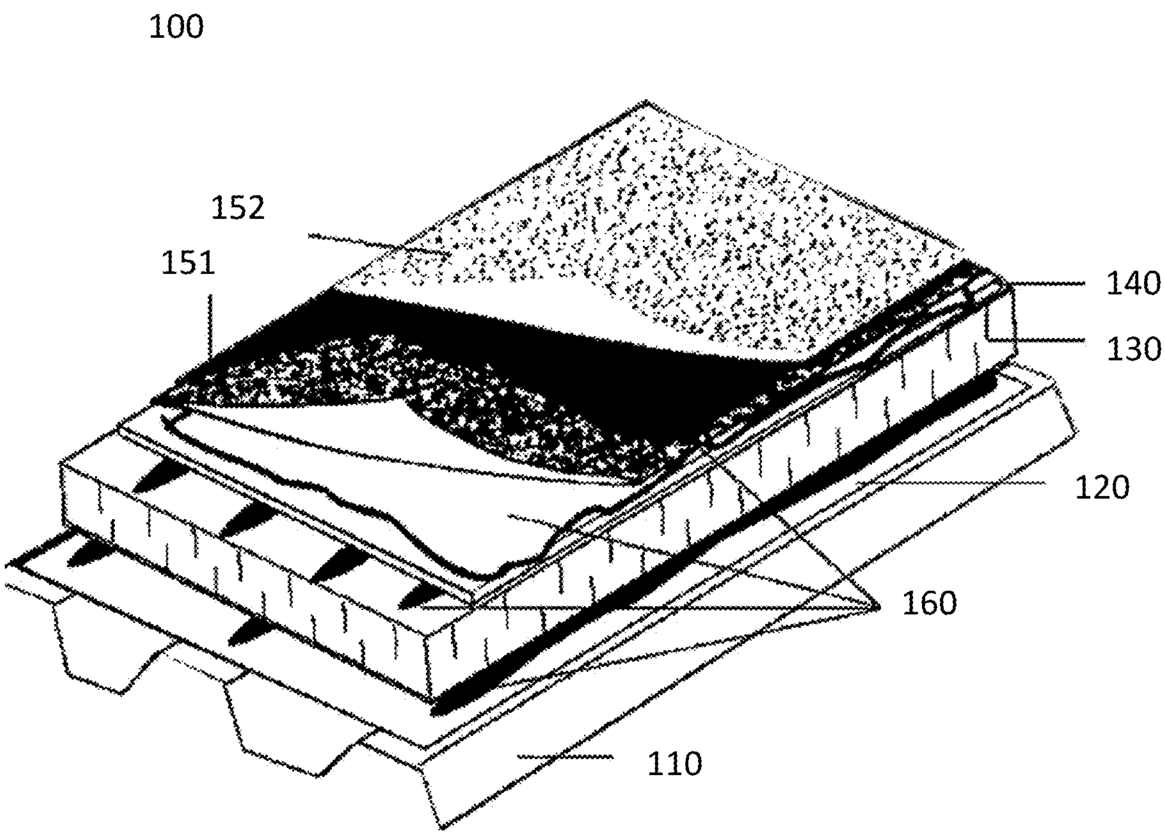
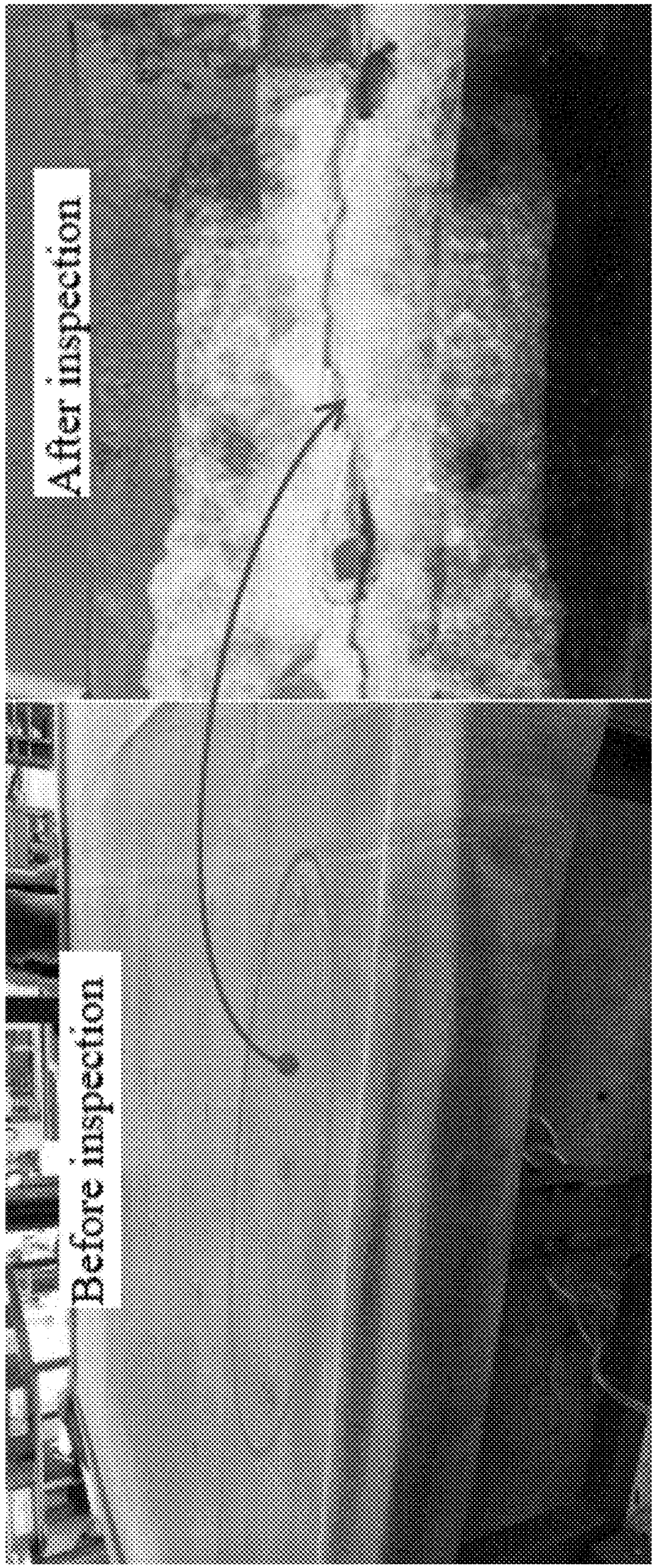



**Figure 1 (prior art)**




a b

Figure 2

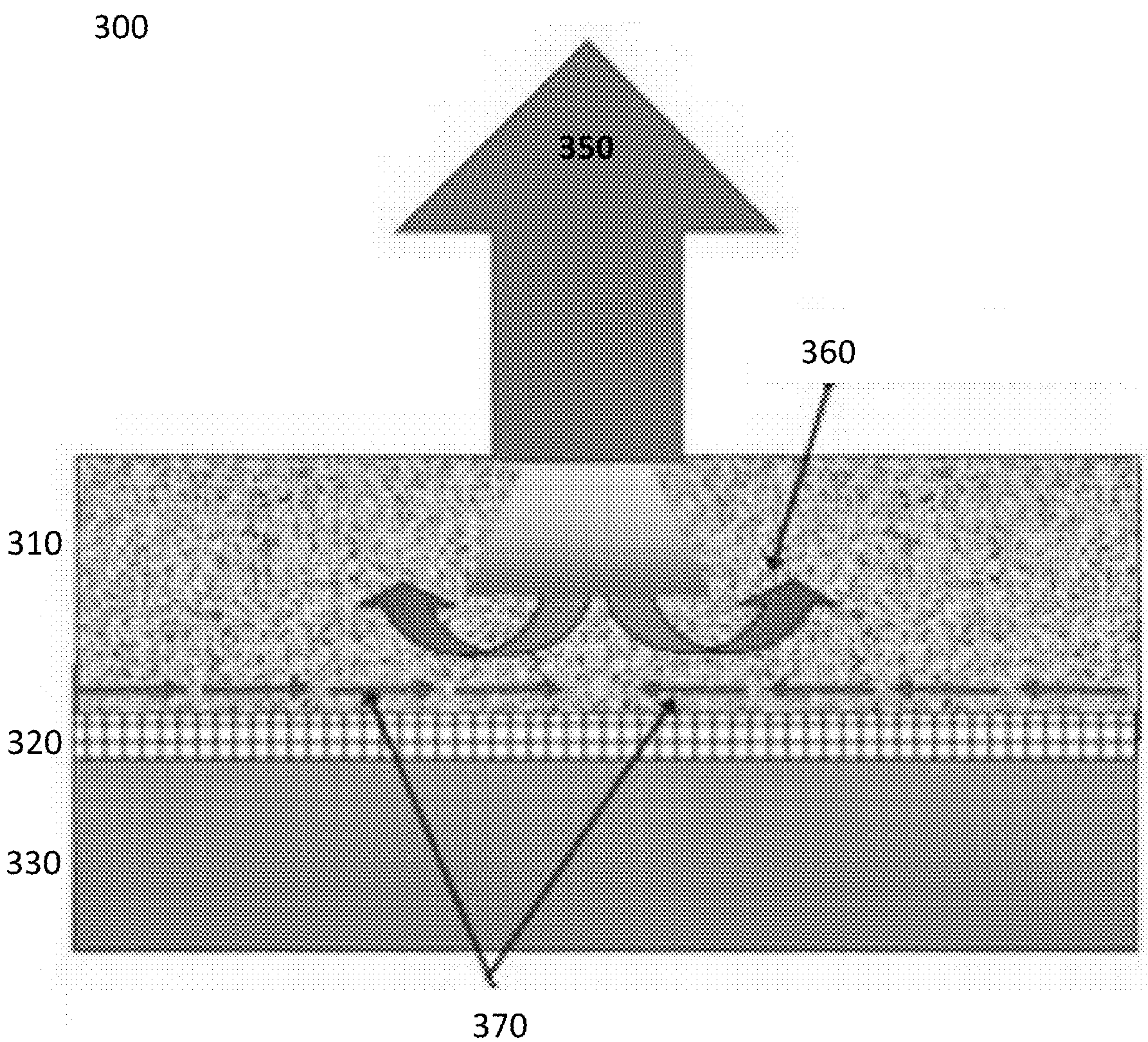



Figure 3

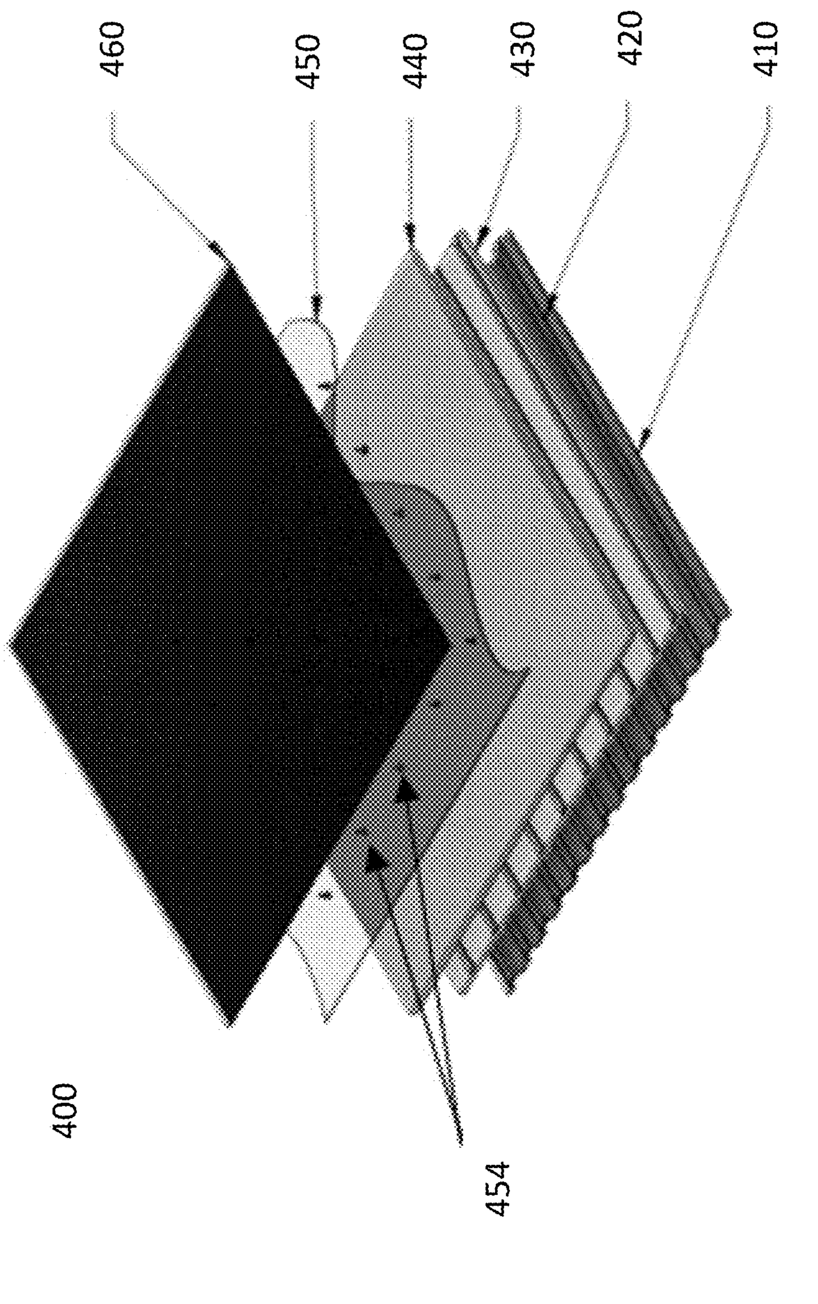



**Figure 4 (reference specimen)**

(prior

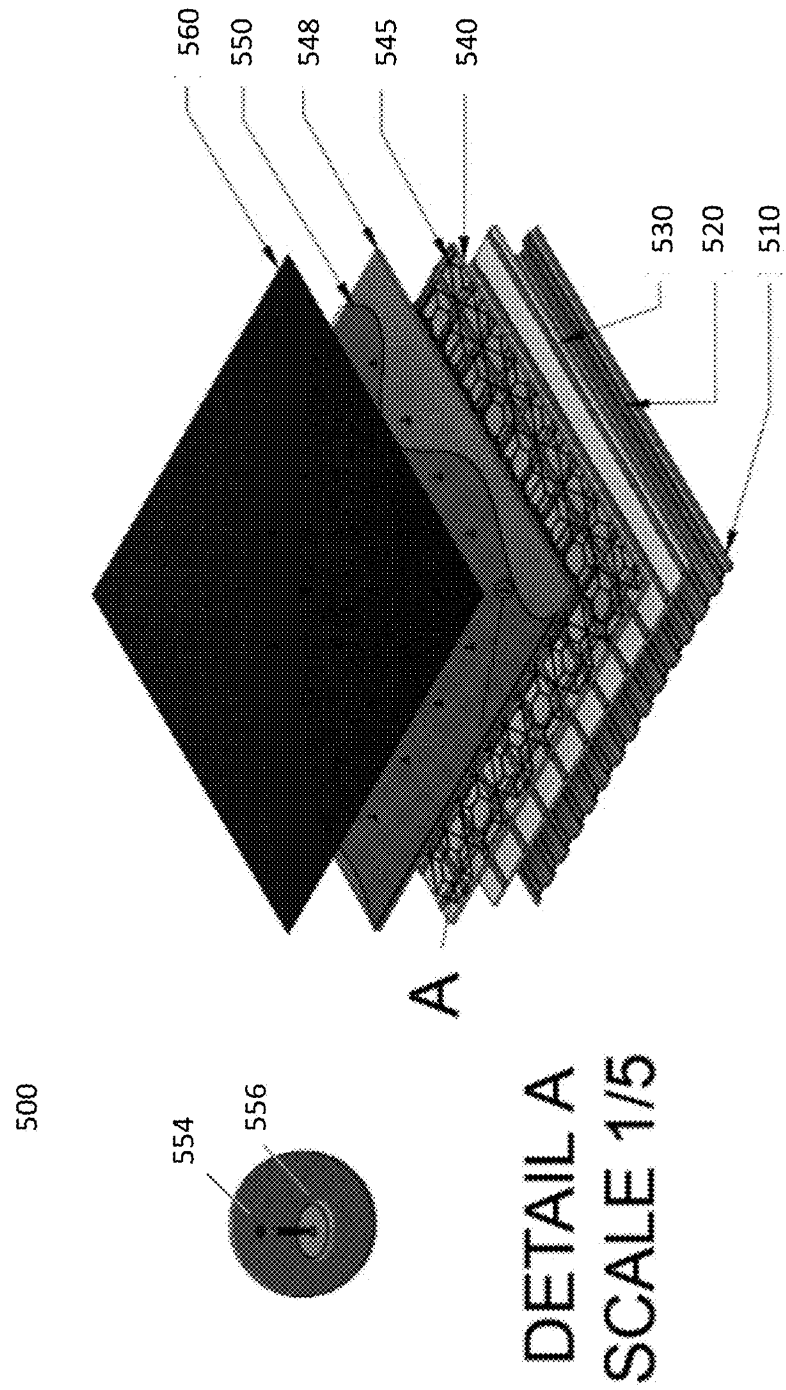



Figure 5

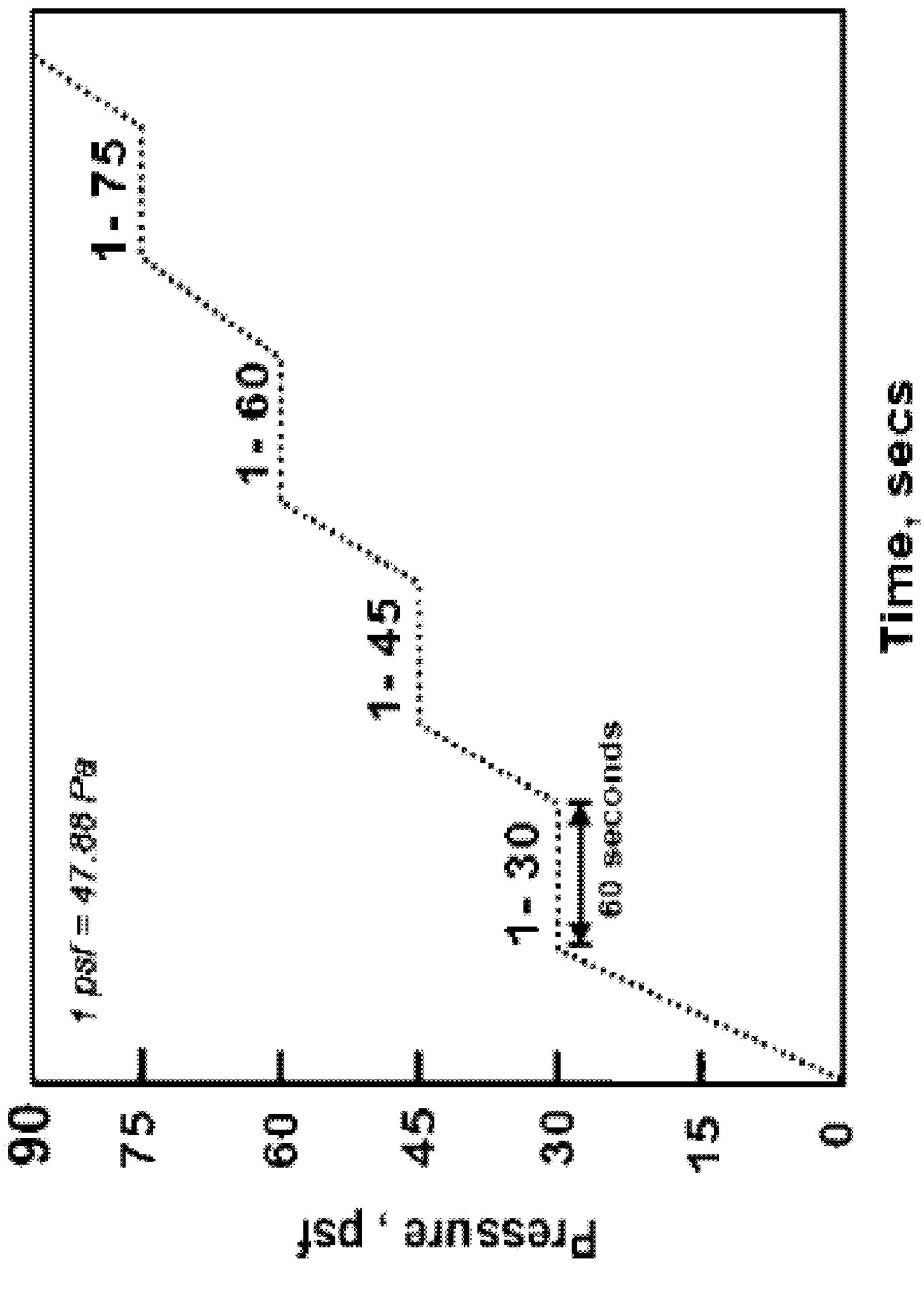

1 psf = 47.88 Pa
1 - 30
60 seconds
1 - 45
1 - 60
1 - 75
Pressure , psf
0
15
30
45
60
75
90
Time, secs

Figure 6

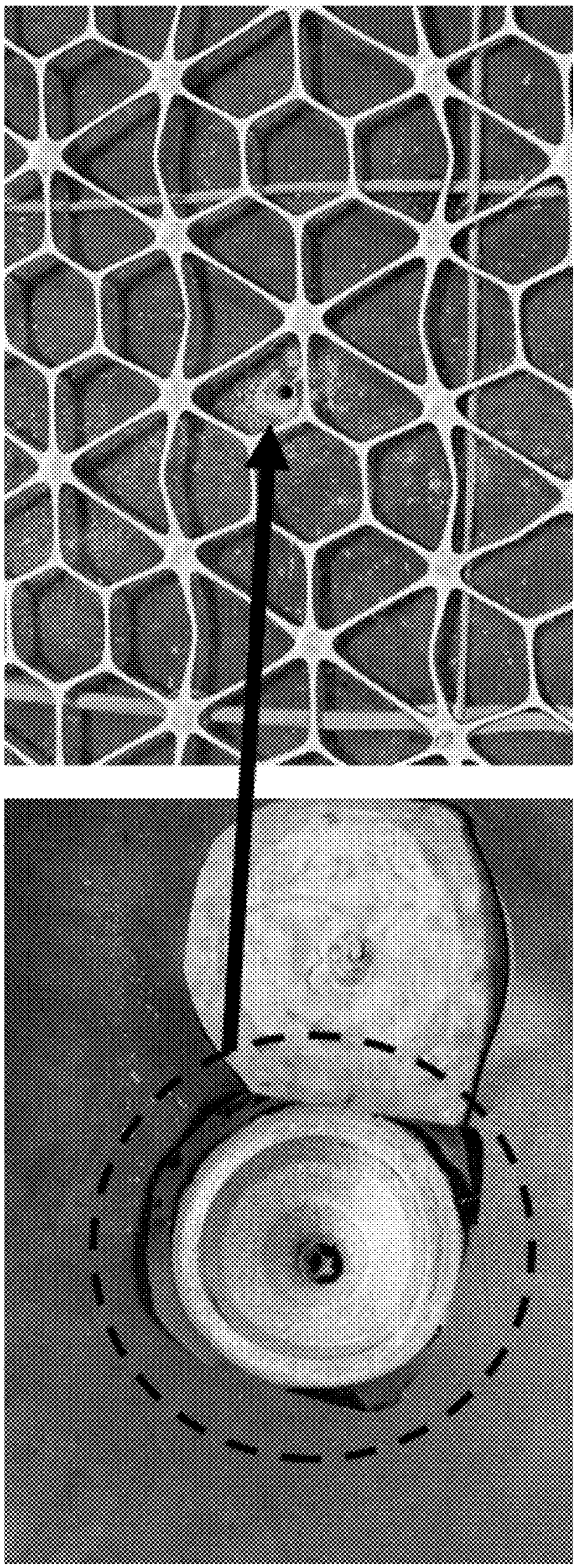


Figure 7a

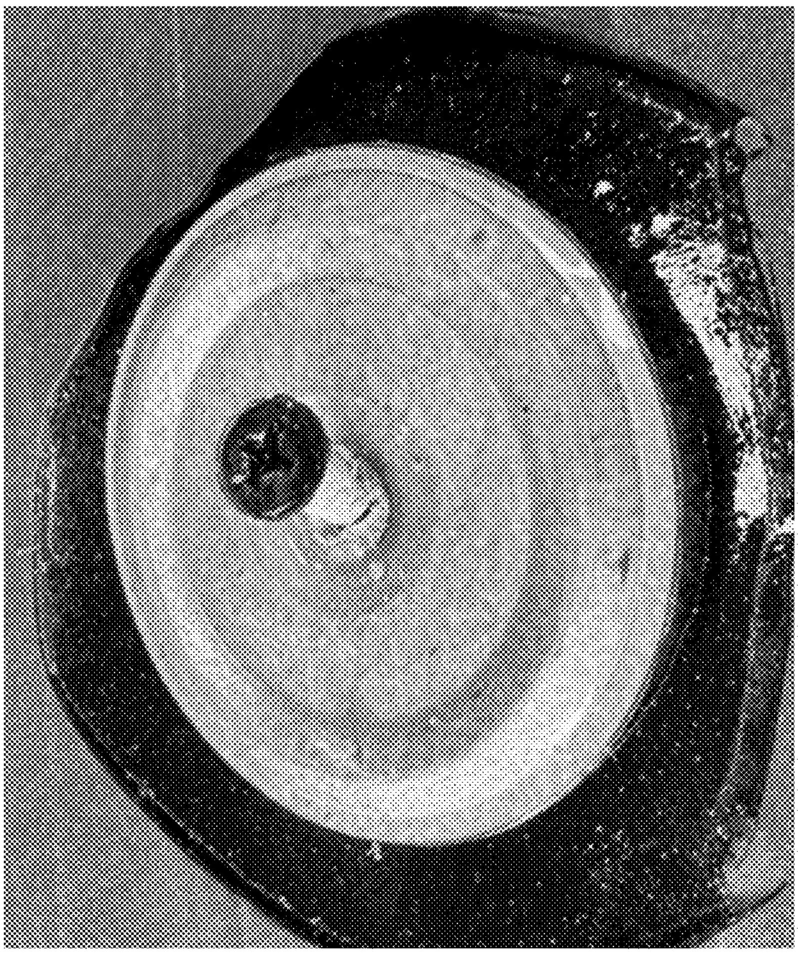


Figure 7b

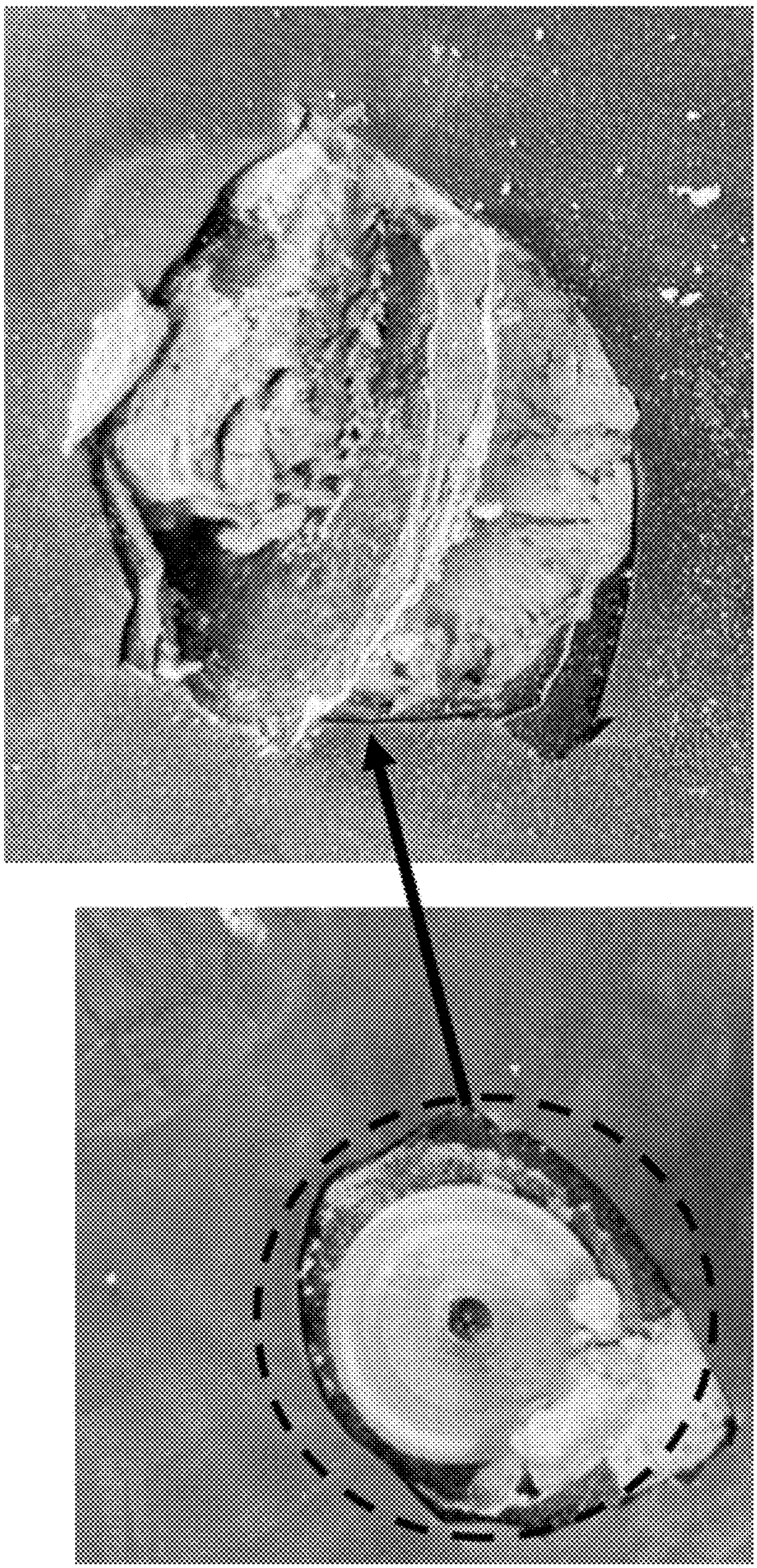


Figure 8a (reference roof)

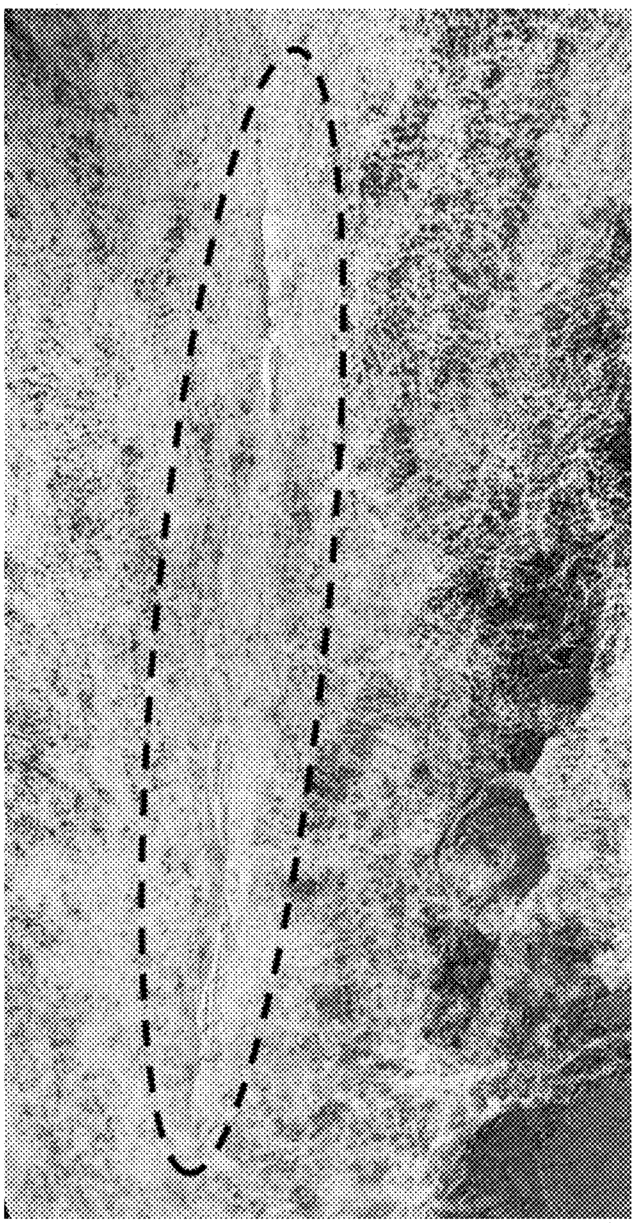


Figure 8b (reference roof)

# LOW-SLOPE ROOFING SYSTEM

## CROSS REFERENCE TO RELATED APPLICATIONS

**[0001]** The present application claims the benefit under 35 USC § 119(e) to U.S. Provisional Patent Application No. 63/471,830, filed Jun. 8, 2023; the entire disclosure of that application is incorporated herein by reference.

## TECHNICAL FIELD

**[0002]** The present disclosure relates to improved low-slope roofing membrane systems and methods to reduce and/or distribute evenly wind uplift pressure over a larger area, avoiding the problems inherent in fastening methods and roof membrane systems of the prior art.

## BACKGROUND OF THE INVENTION

**[0003]** A roof is an integral part of the building envelope that provides a physical separation between the indoor and outdoor environments. Its role is essential for protecting the indoor environment from natural phenomena such as wind, rain, snow, temperature gradients, solar radiation, etc. Roofs can be classified as either low- or steep-slope. Low-slope roofs are often installed in commercial and industrial buildings such as warehouses and factories, while residential buildings mostly have steep-slope roofs.

**[0004]** Referring to the example diagram in FIG. **1**, a typical commercial low-slope roof system **100** usually contains several components, from bottom to top: the roof deck **110**, a vapor or air barrier membrane **120**, insulation **130**, cover board **140**, and finally a waterproof membrane or one or more membrane components **151**, **152**. These components are integrated to form a compact roof system using various attachment methods. Based on attachment method, low-slope roofs can be grouped as: adhesive-applied roofing systems (AARS), mechanically attached roofing systems (MARS), fully bonded roofing systems (FBRS), and ballasted roofing systems (BRS).

**[0005]** The present disclosure relates to AARS applications, where at least two of the layers of the roof system (e.g., from among the several components noted above and potentially others) are attached to each other with adhesive. (See, e.g., **160** in FIG. **1**.) Broadly defined, an AARS may have some other mechanical attachments between layers, which may be designed as additional strength points or to hold the layers in place as the adhesive sets. AARS systems, and indeed roofing systems in general, should have a considerable degree of durability, retaining water resistance and physical integrity in the face of solar-, moisture- and temperature-related weathering, as well as from the physical loading and variable stresses caused by snow loads, hail, foot traffic and especially high wind events.

**[0006]** During the last decade, cover boards have become an essential component in low-slope membrane roofs. Cover boards may be made of various materials, such as plywood, etc., but nowadays are often comprised of a gypsum core with embedded glass mat facers on the top and bottom of the board. Cover boards aid in improving roof resistance to foot traffic and hail damage, as well as resist deterioration, warping, and job site damage. In addition, gypsum-based, glass-mat faced boards in particular can reduce the potential for mold growth and mildew.

**[0007]** However, many wind-uplift experiments and post-wind events investigations have observed brittle fracture of gypsum cover boards. These types of failure occur due to the relatively low inherent flexural strength of the gypsum material under wind uplift pressures. Further, mechanical fasteners are commonly used to hold these boards with other components to the steel deck, but these can weaken the boards by allowing cracks to initiate in a parallel pattern with the fastener line (See, e.g., FIG. **2**, showing a brittle fracture crack along the fastener line on the cover boards in FIG. **2***b*, hidden by the waterproof membrane prior to inspection, FIG. **2***a*)

**[0008]** To solve the problems inherent in use of gypsum-based cover boards, we have developed a novel roofing membrane system and method of reducing and/or distributing evenly over a larger area uplift pressure concentrations over cover boards, avoiding the problems inherent in fastening methods and roof membrane systems of the prior art.

## SUMMARY OF THE INVENTION

**[0009]** Embodiments of the present invention may include a low-slope roofing system, the system comprising a geogrid layer, and a first coverboard layer, wherein the geogrid layer is attached to the first coverboard layer. In other embodiments, the geogrid layer is attached to the first coverboard layer with adhesive. In others, the geogrid layer is attached to the first coverboard layer with fasteners, or with both fasteners and adhesive. In some embodiments, the fasteners are plate fasteners, and may extend through the geogrid and one or more adjacent layers.

**[0010]** In yet other embodiments, the system further comprises a second coverboard layer, which in some embodiments, may be water-resistant.

**[0011]** In some embodiments, the geogrid layer has a thickness of between about 3.25-4.5 mm.

**[0012]** Aspects of the present invention may include a method of assembling a low-slope roofing system, comprising attaching a first coverboard layer, and attaching a geogrid layer to the first coverboard layer. In other aspects, the geogrid layer is attached to the first coverboard layer with adhesive. In others, the geogrid layer is attached to the first coverboard layer with fasteners, or with both fasteners and adhesive. In some aspects, the fasteners are plate fasteners, and may extend through the geogrid and one or more adjacent layers.

**[0013]** In yet other aspects, the method further comprises attaching a second coverboard layer, which in some embodiments, may be water-resistant.

**[0014]** In some aspects, the geogrid layer has a thickness of between about 3.25-4.5 mm.

**[0015]** Other features and advantages of the present invention will become apparent from the following detailed description, including the drawings. It should be understood, however, that the detailed description and the specific examples, while indicating preferred embodiments, are provided for illustration only, because various changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art from the detailed description.

## DESCRIPTION OF THE DRAWINGS

**[0016]** FIG. **1** is a graphical representation of a typical adhesive-applied roofing system (AARS) of the prior art;

**[0017]** FIG. **2** is a graphical representation of a common failure mode after uplift pressure in roofing systems of the prior art, (a) prior to inspection, (b) after inspection, underneath the waterproof membrane;

**[0018]** FIG. **3** diagrams the lateral shear force-displacing effect caused by an example embodiment of the present invention;

**[0019]** FIG. **4** shows the composition of a reference specimen designed for a low-slope roof of the prior art;

**[0020]** FIG. **5** depicts an example embodiment of the present invention;

**[0021]** FIG. **6** depicts the incremental pressure increase protocol in a static loading pressure test;

**[0022]** FIGS. **7**(*a*)-(*b*) depicts two types of minor damage after a static loading pressure test for an example embodiment of the present disclosure;

**[0023]** FIGS. **8**(*a*)-(*b*) show two types of significant damage to a reference roof of the prior art under the same conditions as in FIG. **7**.

## DESCRIPTION OF THE INVENTION

**[0024]** Definitions. The terms used in this specification generally have their ordinary meanings in the art, within the context of this subject matter and in the specific context where each term is used. Certain terms are defined below to provide additional guidance in describing the compositions and methods of the disclosed subject matter and how to make and use them.

**[0025]** As used in the specification and the appended claims, the singular forms "a," "an," and "the" include plural referents unless the context clearly dictates otherwise. Thus, for example, reference to "a compound" includes mixtures of compounds.

**[0026]** The term "about" or "approximately" means within an acceptable error range for the particular value as determined by one of ordinary skill in the art, which will depend in part on how the value is measured or determined, i.e., the limitations of the measurement system. For example, "about" can mean within three or more than three standard deviations, per the practice in the art. Alternatively, "about" can mean a range of up to 20%, preferably up to 10%, more preferably up to 5%, and more preferably still up to 1% of a given value. Also, particularly with respect to systems or processes, the term can mean within an order of magnitude, preferably within five-fold, and more preferably within two-fold, of a value.

**[0027]** The terms "interior", "bottom", "under" and "exterior", "top", "above" refer, for descriptive purposes only, to the orientation of roof components under normal use (but do not limit the invention to standard roof usages), where an "interior" or "bottom" component or a first component orientated "interior of" "to the bottom of" or "under" a second component, for example, refers to a first component closer to the interior of the building than the second component, when attached to the building under normal usage. Similarly, an "exterior" or "top" component or a first component orientated "exterior of" "to the top of" or "above" a second component, for example, refers to a first component closer to the interior of the building than the second component, when attached to the building under normal usage.

**[0028]** "Geogrid" refers to any plastic or other material (metal, etc.) known in the art that can act to reinforce or stiffen an overall structure and tie adjacent layers and materials together. In some embodiments and aspects, the geogrid has a stiffness that acts to inherently stabilize (e.g., resisting deformation forces) the material it is a part of; in some embodiments, the geogrid material is capable of distributing loads laterally or otherwise to further transfer and minimize deformation forces.

**[0029]** It should be appreciated by those skilled in the art that the conception and specific embodiment disclosed may be readily utilized as a basis for modifying or designing other structures for carrying out the same purposes of the present application. It should also be realized by those skilled in the art that such equivalent constructions do not depart from the spirit and scope of the application as set forth in the appended claims.

**[0030]** As noted above, a typical commercial low-slope roof system usually contains several components, from bottom to top: the roof deck, a vapor or air barrier membrane, insulation, cover board, and finally a waterproof membrane. (E.g., FIG. **1**.) The present disclosure relates to AARS applications, where at least two of the layers of the roof system (e.g., from among the components noted above and potentially others) are attached to each other with adhesive. An AARS may have some other mechanical attachments between layers, which may be designed as additional strength points or to hold the layers in place as the adhesive sets.

**[0031]** The cover board is an important component, as it aids in improving roof resistance to foot traffic and hail damage, as well as resist deterioration, warping, and job site damage. Types of cover boards include gypsum, gypsum fiber (with fiberglass mat reinforcement), wood fiber, cement, polyisocyanurate (often with a fiberglass facing), stone (e.g., low-weight stones such as perlite and others), asphalt, mineral fiber, and plywood. Gypsum board are similar to dry wall construction, and have an advantage of low cost and fire and mold resistance.

**[0032]** The failure of gypsum cover boards commonly used in constructing low-slope roofs occurs under high wind uplift pressures due to the minimum inherent flexural strength of the gypsum material. Mechanical fasteners are commonly used to hold these boards with other components to the steel deck and can weaken the boards by allowing cracks to initiate in a parallel pattern with the fastener lines. Wind uplift pressures create a lateral shear flow beside the vertical flow at the top surface. The lateral shear flow is maximum at the edges of the roof; this is evidenced by fracture of the cover boards observed close to the edges in failure studies. (E.g., FIG. **2**)

**[0033]** Geogrids can be categorized as geosynthetic materials that are used in the construction industry in the form of reinforcing materials. For instance, geogrids are used in roadways to deliver in-service stress transfer from the aggregate to the geogrid, reducing differential settlement, lessening the impact of heavy loads, and reducing installation and maintenance costs. Therefore, reducing vertical load impacts by laterally distributing it became a proposed application to minimize the adverse vertical pressure on the cover boards. FIG. **3** diagrams the force displacement in an example embodiment **300** of the present invention, with an upper layer (membrane and/or green board and/or insulation) **310**, geogrid **320**, and coverboard **330**. Wind uplift force **350** is converted into lateral shear flow **360**, but laterally resisted (represented by arrows **370**) due to adhesion between the geogrid **320** and the coverboards **330**. In embodiments and aspects of the present disclosure, the geogrid layer is adhered to the cover boards, such that the geogrid can possess sufficient frictional resistance that opposes lateral movement. Reduction of outward stresses means inward stresses are formed, which is thought to be why uplift capacity increases.

**[0034]** Geogrids usually are made of rigid plastic and consist of an open grid of various geometries (e.g., hexagons, rectangles squares or other shapes or a mixture thereof). The open grid allows layers above and below to contact each other, as well as the large surface area of the grid itself, which reinforces the stability of the overall structure or material (usually soils in the prior art). The polymer may be polyester, polyvinyl alcohol, polyethylene or polypropylene, or any other suitable polymer, natural polymer, or other material with the requisite properties. Aspects and embodiments of the present disclosure are not limited to geogrids, but any suitable reinforcing material may be used, with sufficient rigidity, flexibility, resistance to low and high temperature extremes and the like, for durability in roofing applications and having ability to dissipate and transfer uplift and other forces.

**[0035]** The geogrid may be attached to adjacent layers in several ways, depending on geogrid composition, identity of the roof layers adjacent to it, use, or ease of application. In some instances, the geogrid may be placed directly on top of a layer below (e.g., on top of the cover board) without adhesive, and the geogrid attached to the layer below by fasteners extending through layers above (e.g., a second cover board) through the geogrid, into layers below the geogrid. In some aspects, the geogrid may be directly attached to a layer below via fasteners attached to the geogrid and layers below, and/or via adhesive. In some embodiments, occasional fasteners may be used to attach the geogrid layer to the layer below while the adhesive sets. Similarly, the geogrid layer may be attached to layers above the geogrid layer via fasteners or adhesive; the fasteners may extend through the geogrid layer through one or more, or multiple layers above and/or below the geogrid layer.

**[0036]** In some embodiments and aspects, the geogrid layer may be deployed separately onto the roof as part of the low-slope roof assembly. Geogrid may be transported to the roof in rolls, or flat sheets. In some embodiments and aspects, coverboards or a flat surface layer similar in properties to a coverboard may be pre-attached to either the top or bottom surfaces (or both) of a geogrid layer prior to roof assembly (e.g. in a pre-assembled or integral geogrid/coverboard product).

**[0037]** In some embodiments and aspects, the geogrid can be attached to the bottom of the cover board layer. In other embodiments, the geogrid layer can be attached above the cover board layer. In other embodiments, the geogrid layer may be attached to another layer (i.e., such a vapor or air barrier membrane, or insulation), which is then attached to the cover board, such that an additional layer is present between the cover board and geogrid. In other embodiments, the geogrid may be attached to the cover board and also attached to another layer adjacent to the geogrid, such as (i.e., such as the roof deck, vapor or air barrier membrane, or insulation). In many embodiments, individual geogrid sheets will overlap seams or junctions between cover boards in order to transfer lateral forces across individual cover board sheets. In some embodiments, the geogrid will run across one or more fastener lines holding roof elements (coverboards, insulating layers, etc.) to the roof and/or seams or junctions between cover boards.

**[0038]** In some embodiments, the geogrid layer may be attached to the coverboard on one side of the geogrid and a second coverboard layer on the other to give a layer of protection between the geogrid and a more-deformable layer such as a waterproof membrane or insulation. In some embodiments and aspects, the second coverboard layer may be greenboard, or another product; in some embodiments and aspects, the second coverboard layer may be water-resistant. The second coverboard layer may be less thick, more thick or the relatively the same thickness and/or rigidity as the first coverboard layer in some embodiments.

**[0039]** Suitable methods of attachment of the geogrid to the cover boards and/or adjacent layers may use any suitable means known to persons of skill in the art, such as adhesives, (such as construction glues especially formulated for outdoor use) fasteners like screws, nails, etc., although care should be taken to refrain from puncturing waterproofing membranes during installation. Fastening methods may used alone or in combination (i.e., gluing the geogrid to a surface along with fasteners.

**[0040]** Any suitable insulation product may be used in aspects and embodiments of the present disclosure, such as rigid foam boards and spray foam applications. Similarly, any waterproofing membrane (such as TPO, PVC or EPDM, for example) or other waterproofing layer (such as tar, paint, etc.)

## EXAMPLE 1

### Fabrication of Reference Roofing Section and Example Embodiment of the Present Disclosure

**[0041]** For purposes of comparison, an 8×8 ft reference specimen was constructed based on a typical construction of a low-slope membrane roof. A diagram of the reference board **400** is shown in FIG. **4**. The specimen consisted of a steel B-deck **410**, thermal insulation **430**, cover boards (recovery boards) **440**, and an EPDM (ethylene propylene diene monomer rubber) membrane **460**. As seen in FIG. **4**, the B-deck **410** is joined to thermal insulating isoboard **430** with adhesive beads **420**, then a recovery board **440** is joined to the isoboard **430** with mechanical fasteners **454** extending through the recovery board, then a waterproofing membrane **460** joined to the recovery board **440** with a single-ply adhesive **450** applied to the surface of the recovery board.

**[0042]** The reference specimen was compared with an example 8×8 ft embodiment specimen, **500**, diagrammed in FIG. **5**, which adds a geogrid layer **545** to the typical roof mode, namely at the top of the cover boards **540**. The geogrid layer was attached down by using elastomeric adhesive. Greenboards **548** were purposely installed on top of the geogrid **545** to keep it in place and add more stability and pressure for the adhesive curing, as well as a flat surface for the membrane EPDM **560** to attach to via single-ply adhesive **550**. The geogrid was additionally fastened to the recovery board and isoboard with screws **554** and plastic washers **556**. The isoboard **530** was attached to the b-deck **510** with adhesive beads **510**. The Greenboards are entirely made of recycled material and are relatively inexpensive.

**[0043]** The following tables list the properties of the reference specimen and the example embodiment of the present invention.

TABLE 1

| Reference Specimen | |
|---|---|
| **Structural Deck** | |
| Type | Profiled metal sheeting 22-gauge |
| Nominal thickness | 0.76 mm (1/32 = 0.030 in) |
| Overall depth | 38 mm (1.5 in) |
| Flute spacing, c/o | 150 mm (5.9 in) |
| Fastener pullout as per ANSI/SPRI FX-1 | 2120 N (470 lbf) |
| Manufacturer | Metal Decking ACT |
| **Thermal Insulation** | |
| Type | InsulBase Polyisocyanurate (ISO) |
| Description | Thermal insulation is a rigid roof insulation panel composed of a closed-cell polyisocyanurate foam core bonded on each side to glass-reinforced felt (GRF) |
| Dimensions | boards of size 1219 × 2438 mm (4 × 8 ft) and a total thickness of 38.1 mm (1.5 in) |
| Manufacturer | Carlisle SynTec Systems |
| **Insulation attachment details** | |
| Type | Adhesive beads thickness of 3 mm (1/8 in) |
| Beads spacing, c/o | 150 mm (5.9 in) |
| Adhesive type | Modified Polyether |
| Manufacturer | GreenLink. Inc |

TABLE 1-continued

| Reference Specimen | |
|---|---|
| **Cover board** | |
| Type | DenseDeck |
| Description | DensDeck is a roof board of gypsum core with embedded glass mat facers on the top and bottom of the board used in commercial roof systems and provides a thermal barrier, exceptional fire, moisture, and wind uplift resistance properties |
| Dimensions | 1 board of size 1219 × 2438 mm (4 × 8 ft) and a total thickness of 12.7 mm (0.5 in) |
| Manufacturer | Georgia Pacific |
| **Cover board attachment details** | |
| Type 1 | Mechanical fasteners with plates |
| Fastener details | 76.2 mm (3 in) Deckfast #15 HS |
| Plate details | 76 mm (3 in) diameter metal plate |
| Fastener row spacing, c/o | 610 mm (24 in) |
| Fastener spacing, c/o | 610 mm (24 in) |
| Type 2 | Adhesive beads thickness of 3 mm (1/8 in) |
| Adhesive details | Beads |
| Beads spacing, c/o | 150 mm (5.9 in) |

TABLE 2

| Example embodiment | |
|---|---|
| **Structural Deck** | |
| Type | Profiled metal sheeting 22-gauge |
| Nominal thickness | 0.76 mm (1/32 = 0.030 in) |
| Overall depth | 38 mm (1.5 in) |
| Flute spacing, c/o | 150 mm (5.9 in) |
| Fastener pullout, per ANSI/SPRI FX-1 | 2120 N (470 lbf) |
| Manufacturer | Metal Decking ACT |
| **Thermal Insulation** | |
| Type | InsulBase Polyisocyanurate (ISO) |
| Description | Thermal insulation is a rigid roof insulation panel composed of a closed-cell polyisocyanurate foam core bonded on each side to glass-reinforced felt (GRF) |
| Dimensions | boards of size 1219 × 2438 mm (4 × 8 ft) and a total thickness of 38.1 mm (1.5 in) |
| Compressive strength as per ASTM D1621 | 130 kPa (18.8 psi) |
| Manufacturer | Carlisle SynTec Systems |
| **Insulation attachment details** | |
| Type | Adhesive beads thickness of 3 mm (1/8 in) |
| Beads spacing, c/o | 150 mm (5.9 in) |
| Adhesive type | Modified Polyether |
| Manufacturer | GreenLink. Inc |
| **Cover board 1** | |
| Type | DenseDeck |
| Description | DensDeck is a roof board of gypsum core with embedded glass mat facers on the top and bottom of the board used in commercial roof systems and provides a thermal barrier, exceptional fire, moisture, and wind uplift resistance properties |

TABLE 2-continued

| | Example embodiment |
|---|---|
| Dimensions | One board of size 1219 × 2438 mm (4 × 8 ft) and a total thickness of 12.7 mm (0.5 in) |
| Manufacturer | Georgia Pacific |
| Cover board attachment details | |
| Type | Adhesive beads thickness of 3 mm (⅛ in) |
| Adhesive details | Beads |
| Beads spacing, c/o | 150 mm (5.9 in) |
| Adhesive type | Modified Polyether |
| Manufacturer | GreenLink. Inc |
| Geogrid sheet | |
| Type | Tensar NX750 Geogrid |
| Description | Hexagonal aperture of coextruded composite polymer sheet, |
| Geometry | 203.2 × 203.2 mm (96 × 96 in) cut out of 3.8 m (12.5 ft) × 60 m (197 ft) roll with node thickness of 4.5 mm (0.18 in) |
| Manufacturer | Tensar |
| Type | |
| Beads spacing, c/o | |
| Adhesive type | |
| Manufacturer | |
| Cover board 2 | |
| Type | Kelly Green Board |
| Description | Roof cover board is a composite panel made of 100% recycled material. The content is shredded and compressed. The board is made of a water-resistant core and surfaced with a coated fiberglass facer |
| Dimensions | 1 board of size 1219 × 2438 mm (4 × 8 ft) and a total thickness of 12.7 mm (0.5 in) |
| Manufacturer | Kelly Green |
| Cover board 2 attachment details | |
| Type | Mechanical fasteners with plates |
| Fastener details | 76.2 mm (4 in) Deckfast #15 HS |
| Plate details | 76 mm (3 in) diameter metal plate |
| Fastener row spacing, c/o | 610 mm (24 in) |
| Fastener spacing, c/o | 610 mm (24 in) |
| | Roof membrane |
| Type | EPDM, single ply |
| Description | Ethylene Propylene Diene Monomer (EPDM) is a roof membrane that has a high resistance to wind, hail, UV radiation, thermal shock, and extreme temperatures and is watertight |
| Nominal thickness | 1.14 mm (45-mil) |
| Manufacturer | Carlisle SynTec Systems |
| Membrane attachment details | |
| Type | Single-Ply EPDM Adhesive |
| Description | 100% solvent free, non-water based polyether adhesive |
| Application method | Heavy nap paint rollers |
| Quantity | 100 sq. feet/gallon |
| Manufacturer | ChemLink Inc. |

## Example Method of Construction

**[0044]** The following is an example method of building an example 8×8 ft embodiment of the present disclosure. The reference specimen followed the same procedure, but the geogrid and greenboards were not applied, and the associated steps can be ignored from the following procedure

**[0045]** Type B Roof Deck (22 Gauge) was installed with screws to 8×8 ft steel frame table. Then, beads of elastomeric adhesive (free-solvent polyether base) were applied at each flute of the steel deck. Two thermal insulation boards (4×8 ft) were laid on the adhesive beads laid in the above step, with no excessive pressure applied, so as not to squeeze out and thin the adhesive line.

**[0046]** Elastomeric adhesive beads were applied again on top of the thermal insulation boards, where extra adhesive lines were applied at the corners to ensure proper adhesion. The adhesive beads were located parallel to the steel deck flutes with a 6-inch spacing between the beads. Two cover boards of (4×8 ft) DensDeck roof board (i.e., gypsum board from Georgia Pacific) were laid on top of the thermal insulation boards with minimum applied pressure to bond properly with the adhesive beads.

**[0047]** Beads of elastomeric adhesive were applied on top of the cover boards in a biaxial pattern with 6 in spacing in both directions to increase the attachment area with the Geogrid sheet. A geogrid hexagonal sheet (8×8 ft) was placed on top of the cover boards, and a sufficient weight on top was placed atop the sheet to let it bond with the adhesive, while installing another type of recover boards (i.e., green boards).

**[0048]** Two cover boards of (4×8 ft) Greenboards were laid on top of the DensDeck boards, and then 16 #15 HS (4 in) fasteners with plates (3 in diameter) were fastened at 24 in spacing in the field and 12 in spacing at the perimeter to hold the Greenboards and other components down to the steel deck. Single-Ply EPDM adhesive was fully applied to the top boards (i.e., DensDeck in the reference specimen case and Greenboards for the Reinforced specimen case) with a heavy nap paint roller at 90-120 square feet per gallon.

**[0049]** The adhesive was allowed 10 minutes to become tacky (forming strings) when touched before setting the EPDM. After setting the EPDM in place, the bond was secured with a soft bristle floor broom. Any dry spots, if present, were coated with additional adhesive. Since this is not a "contact bond adhesive," minor bubbles can occur.

## Testing

**[0050]** Testing was conducted at graduated, increasing 15-pounds-per-square-foot increments, held at each increment for a minimum of 60 seconds. The pressure was increased to the next increment until failure, or the test suspended (see FIG. **6**, which illustrates the pressure stepping protocol). Results typically were reported as the highest-pressure level maintained for 60 seconds.

**[0051]** The specimen was inserted into the test chamber and sealed securely at the edges. A camera detection system was incorporated to track the failure and give a better understanding of specimen response.

## Results

**[0052]** The pressure rating is the pressure that the specimen has sustained for **60** seconds without failure. Failure could occur at any component, including fastener pull out, membrane detachment, board cracks, etc. The pressure rating of the example embodiment result occurred at 135 psf. In contrast, the reference specimen showed a pressure rating result of 105 psf. It can be concluded that the addition of the geogrid layer increases the wind uplift resistance by 25% relative to the reference specimen.

**[0053]** A post-test inspection was performed on the test specimens in line with the produced videos to determine the failure mode and define the failure key. The failure in the example embodiment specimen was observed in the mechanical fasteners and corresponding plates. The inspection shows that the fastener plates were deformed and bent due to the applied uplift pressure (see FIG. **7***a*), while in other locations, the fasteners were pulled out and saved the plates from deformation (see FIG. **7***b*). The cover board was inspected with no noticeable damage to it, or the geogrid.

**[0054]** In contrast, the failure mode in the reference specimen shows that the fasteners' plates were deformed and caused fracture damage to the cover board as they were connected directly (see FIG. **8***a*). At the edges of specimens, a crack path (fracture) was seen, showing shear and flexural failure (see FIG. **8***b*).

**[0055]** In terms of rebuilding a roof made from the reference specimen, more cost is required compared to the example embodiment specimen. The latter specimen only needs a new membrane, while the reference specimen requires almost the whole roof component system to be replaced.

**[0056]** The above description is considered that of the illustrated embodiments and aspects only. Modifications of the processes, materials, and structures will occur to those skilled in the art and to those who make or use low-slope roofing systems. Therefore, it is understood that the embodiments shown in the drawings and described above are merely for illustrative purposes and not intended to limit the scope of the method which is defined by the following claims as interpreted according to the principles of patent law, including the Doctrine of Equivalents.

What is claimed is:

**1**. A low-slope roofing system, the system comprising
a geogrid layer, and
a first coverboard layer, wherein the geogrid layer is attached to the first coverboard layer.

**2**. The low slope roofing system of claim **1**, wherein
the geogrid layer is attached to the first coverboard layer with adhesive.

**3**. The low slope roofing system of claim **1**, wherein the geogrid layer is attached to the first coverboard layer with fasteners.

**4**. The low slope roofing system of claim **1**, wherein the geogrid layer is attached to the first coverboard layer with fasteners and adhesive.

**5**. The low slope roofing system of claim **3**, wherein the fasteners are plate fasteners.

**6**. The low slope roofing system of claim **1**, further comprising
a second coverboard layer.

**7**. The low slope roofing system of claim **5**, wherein the second coverboard layer is water-resistant.

**8**. The low-slope roofing system of claim **1**, wherein the geogrid layer has a thickness of between about 3.25-4.5 mm.

**9**. A method of assembling a low-slope roofing system, comprising
attaching a first coverboard layer, and
attaching a geogrid layer to the first coverboard layer.

**10**. The method of claim **9**, wherein the geogrid layer is attached to the first coverboard layer with adhesive.

**11**. The method of claim **9**, wherein the geogrid layer is attached to the first coverboard layer with fasteners.

**12**. The method of claim **9**, wherein the geogrid layer is attached to the first coverboard layer with fasteners and adhesive.

**13**. The method of claim **11**, wherein the fasteners are plate fasteners.

**14**. The method of claim **9**, further comprising attaching a second coverboard layer.

**15**. The method of claim **9**, wherein the second coverboard layer is water-resistant.

**16**. The method of claim **9**, wherein the geogrid layer has a thickness of between about 3.25-4.5 mm.

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