density after compaction is complete to thereby minimize potential movement or positioning of the aggregate that would normally occur after compaction and upon initial phases of the "in service" loadings.

SUMMARY

In an aspect, the present disclosure refers to an expanded multilayer integral geogrid for interlocking with and reinforcing aggregate comprising:

a plurality of oriented strands interconnected by partially oriented junctions and having an array of openings therebetween,

said integral geogrid having a plurality of layers each of a polymeric material,

with at least one inner layer of said plurality of layers having an expanded structure containing a distribution of voids therein to improve the initial compatibility between the aggregate and the integral geogrid to maximize an aggregate density after compaction of the aggregate and geogrid.

In an aspect, the present disclosure refers to a starting material for making an expanded multilayer integral geogrid having a plurality of layers each of a polymeric material, with at least one inner layer of said plurality of layers capable of forming an expanded structure containing a distribution of voids therein, said starting material comprising a multilayer polymer sheet having holes or depressions therein that provide openings when the sheet is biaxially stretched.

In an aspect, the present disclosure refers to a soil construction comprising a mass of particulate material strengthened by embedding therein an expanded multilayer integral geogrid of the above aspect.

In an aspect, the present disclosure refers to a method of strengthening a mass of particulate material, comprising embedding in the mass of particulate material the expanded multilayer integral geogrid of the above aspect.

In an aspect, the present disclosure refers to a method of making an expanded multilayer integral geogrid, comprising:

providing a multilayer polymer sheet having a plurality of layers each of a polymeric material, with at least one inner layer of said plurality of layers capable of forming an expanded structure containing a distribution of voids therein;

providing a patterned plurality of holes or depressions in the multilayer polymer sheet; and

orienting the multilayer polymer sheet having the patterned plurality of holes or depressions therein to provide a plurality of oriented strands interconnected by partially oriented junctions and to configure the holes or depressions as grid openings,

said at least one inner layer having the expanded structure containing the distribution of voids in the multilayer integral geogrid.

In an aspect, the present disclosure refers to a method of providing an expanded multilayer integral geogrid construction, comprising:

uniaxially or biaxially stretching a starting material that is a multilayer polymer sheet having a patterned plurality of holes or depressions therein to provide an expanded multilayer integral geogrid having a plurality of oriented strands interconnected by partially oriented junctions and a plurality of grid openings; and

embedding the integral geogrid in a mass of particulate material.

In an aspect, the present disclosure refers to a expanded multilayer integral geogrid comprising:

a plurality of interconnected oriented strands and partially oriented junctions forming a repeating pattern of outer hexagons having an array of openings therein;

each of said outer hexagons supporting and surrounding a smaller inner hexagon having oriented strands,

said oriented strands and said partially oriented junctions of said outer hexagon forming a plurality of linear strands that extend continuously throughout the entirety of the expanded multilayer integral geogrid,

said integral geogrid having a plurality of layers each of a polymeric material extending throughout said geogrid, and

at least one inner layer of said plurality of layers having an expanded structure containing a distribution of voids therein.

An example of the instant disclosure, therefore, is to deliver improved functional performance from multiaxial integral geogrids by enhancing certain physical, mechanical, and geometrical properties of the multiaxial integral geogrid structure that improves functional performance, such as by modifying and/or incorporating other new physical, mechanical, and geometrical properties. By careful physical positioning and manipulating of the amount of different polymeric materials that have the desired mechanical and physical properties in specific locations of integral geogrid structures, and by optimizing all other physical parameters of the geogrid structure, significant performance improvements can be achieved.

More specifically, subsequent to the filing of the '960 application, it has been surprisingly discovered that significantly improved initial compatibility between the aggregate and the expanded multilayer integral geogrid can be achieved if certain parameters for the foamed or expanded layer are included in the geogrid, as disclosed herein. These parameters include the following:

1. the total height or vertical thickness of the strand (or rib) of the multilayer integral geogrid at the thinnest height of the strand (likely the midpoint of the strand) is, for a foamed middle layer, from 1 mm to 4 mm, and, for an expanded middle layer,

from 1 mm to 5 mm, and preferably, for a foamed middle layer, from 1.874 mm to 3.095 mm, and, for an expanded middle layer, from 1.97 mm to 3.36 mm;

2. the voids of the foamed or expanded middle layer comprise from 5% to 60% by volume of the foamed or expanded layer, and preferably, from 20% to 40%;

3. the foamed or expanded middle layer has a minimum compressibility or "crushability" or height reduction after compaction is complete of from 5% up to as much as 75%, with a preferred compressibility range of 20% to 60%, and a more preferred compressibility range of 30% to 50%;

4. the foamed or expanded middle layer has an aspect ratio such that its height, i.e., vertical thickness, is from 1.0:1 to 3.5:1 to the height or vertical thickness of the thinnest outer layer, and preferably, for a foamed middle layer, is from 1.0:1 to 1.16:1, and for an expanded middle layer, is from 1.7:1 to 2.46:1; and

5. the foamed or expanded middle layer has a height or vertical thickness that is at least forty percent (40%) of the overall height of the final integral geogrid, and preferably at least seventy percent (70%).

By including the above physical properties in the expanded multilayer integral geogrid in accordance with the present disclosure, the initial compatibility between the aggregate and the geogrid is maximized after compaction is complete. And, by maximizing the initial compatibility, any possible remaining aggregate movement or repositioning that would normally occur after compaction in the initial phases of "in service" loading is minimized. Thus, the roadway other transporting surface is better stabilized and reinforced for future traffic thereon.

Another example of the present disclosure is to provide economic benefits for use of an integral geogrid having the expanded multilayer structure. If an integral geogrid having strands with a higher aspect ratio is desired, the expanded layer according to the present disclosure can provide that higher aspect ratio while using the same overall polymer content (i.e., "amount" of polymer) as a similarly configured integral geogrid not having an expanded layer. Or, if an integral geogrid having strands with a same aspect ratio as a similarly configured integral geogrid is desired, the expanded layer according to the present disclosure can provide that same aspect ratio while using less overall polymer content (i.e., "amount" of polymer). Accordingly, the expanded multilayer integral geogrids of the present disclosure, in addition to the structural and performance enhancements associated therewith, can provide significant economic benefits, i.e., achieving a higher aspect ratio at a same cost, or achieving a same aspect ratio at a lower cost.

Accordingly, to attain the aforementioned example, the present disclosure is directed to integral geogrids having a multilayer construction, with at least one layer thereof having a structure that is expanded relative to at least one other layer of the multiple layers. These multilayer geogrids are often referred to herein as integral geogrids having at least one layer thereof with a structure that is expanded relative to at least one other layer of the multiple layers, or, more simply, an "expanded multilayer integral geogrid" or "expanded multilayer integral geogrids." By virtue of the expanded layer structure, the expanded multilayer integral geogrids of the present disclosure provide for increased layer compressibility under load, and other desirable characteristics.

More specifically, the layer having the expanded structure contains a distribution of voids therein. The voids may be associated with a foamed construction of the

layer, or may be associated with a particulate filler that is distributed throughout the layer in order to create the expansion of the layer.

Further, the multilayer construction of the expanded multilayer integral geogrids may include layers that are coextruded, or layers that are laminated. The expansion of the expanded layer may occur during extrusion/lamination or stretching/orientation, or both.

And, the resulting expanded multilayer integral geogrids having the plurality of oriented multilayer strands interconnected by the partially oriented multilayer junctions and having an array of openings therebetween may be configured in any of a variety of repeating geometric patterns, such as described herein.

According to the present disclosure, a starting material for making expanded multilayer integral geogrids includes a multilayer polymer starting sheet having holes or depressions therein that provide an array of shaped openings when the starting material is biaxially stretched. The multilayer polymer starting sheet includes an expandable inner layer having a foamed construction or having a particulate filler dispersed therein to create the expansion of the layer. According to preferred examples, the layers of the multilayer polymer starting sheet may be coextruded, or may be laminated to one another.

According to specific examples of the present disclosure, the expanded multilayer integral geogrids include a plurality of oriented multilayer strands interconnected by partially oriented multilayer oriented junctions and having an array of openings therebetween that has at least one expanded layer interposed between two non-expanded layers. According to one example, the expanded multilayer integral geogrid is a rectangular geogrid having a repeating geometric pattern of partially oriented junctions interconnecting oriented strands which define rectangular openings. According to another

example, the expanded multilayer integral geogrid is a triaxial geogrid having a repeating hexagonal geometric pattern of partially oriented junctions interconnecting oriented strands which define triangular openings. And, according to yet another example, the expanded multilayer integral geogrid is a geogrid having a repeating geometric pattern of partially oriented junctions interconnecting oriented strands which form outer hexagons, each of which outer hexagons surrounds and supports six inner interconnected oriented strands formed into the shape of an inner hexagon and defining a smaller hexagonal opening, referred to herein as a "repeating floating hexagon within a hexagon pattern."

According to still another example of the present disclosure, a soil construction includes a mass of particulate material strengthened and stabilized by embedding therein an expanded multilayer integral geogrid having a repeating geometric pattern and having an expanded inner layer.

According to yet another example of the present disclosure, a method of making a starting material for an expanded multilayer integral geogrid includes providing a multilayer polymer starting sheet having an expandable inner layer, and providing holes or depressions therein that provide a repeating geometric pattern of partially oriented junctions interconnecting oriented strands, and defining openings when the starting material is biaxially stretched.

According to another example of the present disclosure, a method of making an expanded multilayer integral geogrid includes providing a multilayer polymer starting sheet having an expandable inner layer, providing holes or depressions therein, and biaxially stretching the expandable layer multilayer polymer sheet having the holes or depressions therein so as to provide a repeating geometric pattern of partially oriented junctions interconnecting oriented strands, and defining openings therein.

And, according to yet another example of the present disclosure, a method of strengthening a mass of particulate material includes embedding in the mass of particulate material an expanded multilayer integral geogrid having a repeating geometric pattern of partially oriented junctions interconnecting oriented strands defining openings and having an expanded inner layer.

Accordingly, it is an example of the present disclosure to provide a multilayer integral geogrid with at least one inner layer thereof having a structure that is expanded relative to at least one other layer of the multiple layers, so as to provide an integral geogrid having increased layer compressibility under load.

Thus, another example of the present disclosure to provide a starting material for making an expanded multilayer integral geogrid. The starting material includes a multilayer polymer starting sheet having an expandable inner layer and holes or depressions therein that provide an array of shaped openings when the starting material is biaxially stretched. The expandable layer of the multilayer polymer starting sheet includes having a foamed construction or having a particulate filler dispersed therein to create expansion of the inner layer, and the layers of the multilayer polymer starting sheet may be coextruded, or may be laminated to one another.

Another example of the present disclosure is to provide expanded multilayer integral geogrids having a plurality of oriented multilayer strands interconnected by partially oriented multilayer junctions and having an array of openings therebetween that is produced from a multilayer polymer starting sheet having an expandable inner layer. The expanded multilayer integral geogrid may be a rectangular geogrid having a repeating geometric pattern of partially oriented junctions interconnecting oriented strands defining rectangular openings, a triaxial geogrid having a repeating geometric pattern of partially oriented junctions

interconnecting oriented strands defining triangular openings, or a geogrid having a repeating geometric pattern of partially oriented junctions interconnecting oriented strands defining outer hexagons, each of which surrounds and supports an inner oriented hexagon, i.e., the "repeating floating hexagon within a hexagon pattern."

An associated example of the present disclosure is to provide a geometry that can engage with and stabilize a greater variety and range of quality of aggregates than geometries associated with prior geogrid structures, while at the same time providing an enhanced compressibility, and other desirable characteristics.

Still another example of the present disclosure is to provide a soil construction that includes a mass of particulate material strengthened and stabilized by embedding therein an expanded multilayer integral geogrid having a repeating geometric pattern and having an expanded inner layer.

Yet another example of the present disclosure is to provide a method of making a starting material for expanded multilayer integral geogrids that includes providing a multilayer polymer starting sheet having an expandable inner layer, and providing holes or depressions therein that provide a repeating geometric pattern of partially oriented junctions interconnecting oriented strands, and openings when the starting material is biaxially stretched. The expandable inner layer may be produced by providing a foamed construction, or by dispersing a particulate filler therein. The multilayer polymer starting sheet may be produced by coextruding the plurality of layers, or by laminating the plurality of layers to one another.

Another example of the present disclosure is to provide a method of making expanded multilayer integral geogrids, which includes providing a multilayer polymer starting sheet having an expandable inner layer, providing holes or depressions therein, and

biaxially stretching the multilayer polymer starting sheet so as to provide a repeating geometric pattern of partially oriented junctions interconnecting oriented strands, and openings. The method of making the above-described rectangular opening or triangular opening integral geogrids can employ known geogrid fabrication methods, such as those described in the aforementioned U.S. Patent Nos. 4,374,798, 4,590,029, 4,743,486, 5,419,659, 7,001,112, 9,556,580, 10,024,002, and 10,501,896 as well as in other patents. The method of making the above-described integral geogrid having a repeating geometric pattern of partially oriented junctions interconnecting oriented strands, and defining outer hexagons, each of which surrounds and supports an oriented inner hexagon, can employ a fabrication method as described hereinafter.

More specifically, it is an example of the present disclosure to provide a method of making expanded multilayer integral geogrids in which the expanded inner layer is produced by first providing a foamed construction in a layer of the multilayer polymer starting sheet, and then biaxially orienting the multilayer polymer starting sheet so as to stretch the foamed material and create a distribution of voids of the foam.

Correspondingly, it is another example of the present disclosure to provide a method of making expanded multilayer integral geogrids in which the expanded inner layer is produced by first dispersing a particulate filler in a layer of the multilayer polymer starting sheet, and then biaxially orienting the multilayer polymer starting sheet so as to stretch the dispersion of particulate filler and create a distribution of voids as the particulate filler partially separates from the polymeric layer material.

And, still another example of the present disclosure is to provide a method of strengthening a mass of particulate material that includes embedding in the mass of particulate material an expanded multilayer integral geogrid having a repeating geometric

pattern of partially oriented junctions interconnecting oriented strands and openings and having an expanded inner layer.

And, yet another example of the present disclosure, in addition to the structural and performance enhancements associated therewith, is to provide significant economic benefits for using the inventive multilayer integral geogrids, i.e., by achieving a higher aspect ratio at a same cost, or by achieving a same aspect ratio at a lower cost. The numerous advantages associated with the expanded multilayer integral geogrid according to the present disclosure are varied in nature.

By virtue of the expanded multilayer integral geogrids of the present disclosure having not only a multilayer construction, but with at least one inner layer thereof having a structure that is expanded relative to at least one other layer of the multiple layers as a result of the distribution of voids therein, the geogrids provide for increased layer compressibility under load.

Further, the multilayer nature of the expanded multilayer integral geogrids of the present disclosure impart overall greater stiffness to the integral geogrid relative to that of prior monolayer integral geogrids. In addition, by virtue of the expanded inner layer, the expanded multilayer integral geogrids of the present disclosure are characterized by a compliant, i.e., initial give or flexibility, that leads to better compaction and higher density, yet with a final horizontal aggregate geogrid composite stiffness that is greater as a result of the initial give.

In addition, the expanded multilayer integral geogrids of the present disclosure provide higher aspect ratios on all strands compared to those of prior integral geogrids. Because the high aspect ratio of the integral geogrids of the present disclosure increases

aggregate interlock, the expanded multilayer integral geogrids of the present disclosure can better accommodate the varying aspect ratios of aggregate.

Even more specifically, with regard to the higher aspect ratio achievable with the expanded multilayer integral geogrids of the present disclosure, the higher aspect ratio provides at least the following distinct and important benefits. First, if an integral geogrid having strands with a higher aspect ratio is desired, the expanded layer according to the present disclosure can provide that higher aspect ratio while using the same overall polymer content (i.e., "amount" of polymer) as a similarly configured integral geogrid not having an expanded layer. Second, if an integral geogrid having strands with a same aspect ratio as a similarly configured integral geogrid is desired, the expanded layer according to the present disclosure can provide that same aspect ratio while using less overall polymer content (i.e., "amount" of polymer). Accordingly, the expanded multilayer integral geogrids of the present disclosure, in addition to the structural and performance enhancements associated therewith, can provide significant economic benefits, i.e., achieving a higher aspect ratio at a same cost, or achieving a same aspect ratio at a lower cost.

In summary, by virtue of the void-containing expanded inner layer, the expanded multilayer integral geogrids of the present disclosure provide for both increased layer compressibility under load and increased strength as an aggregate reinforcement, while also providing economic benefits for their use based solely on the amount of polymer used.

These together with other objects and advantages which will become subsequently apparent reside in the details of construction and operation as more fully hereinafter described, reference being had to the accompanying drawings forming a part hereof, wherein like reference numbers refer to like parts throughout. The accompanying drawings are intended to illustrate the invention, but are not necessarily to scale.