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(54) **TENSION-BASED NON-PNEUMATIC TIRE**

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which is a continuation of application No. 12/055,675, filed on Mar. 26, 2008, now Pat. No. 8,109,308, which is a continuation-in-part of application No. 11/691,968, filed on Mar. 27, 2007, now Pat. No. 8,104,524.

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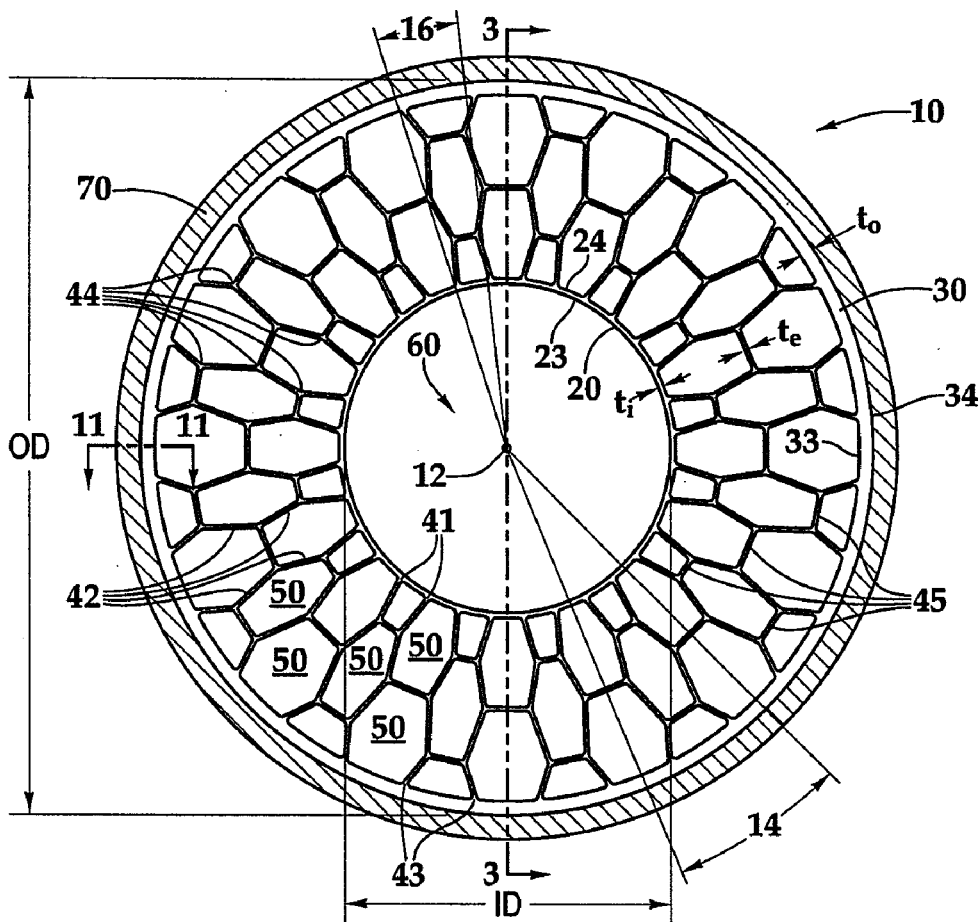
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(63) Continuation-in-part of application No. 13/333,721, filed on Dec. 21, 2011, now Pat. No. 10,086,654,

(57) **ABSTRACT**

A non-pneumatic tire and hub assembly includes an inner ring having an axis of rotation, a deformable outer ring, and a flexible web extending between the inner ring and the deformable outer ring. The assembly further includes a hollow, metal cylinder coupled to the inner ring. The hollow, metal cylinder has a flanged portion extending towards an interior portion of the hollow, metal cylinder.



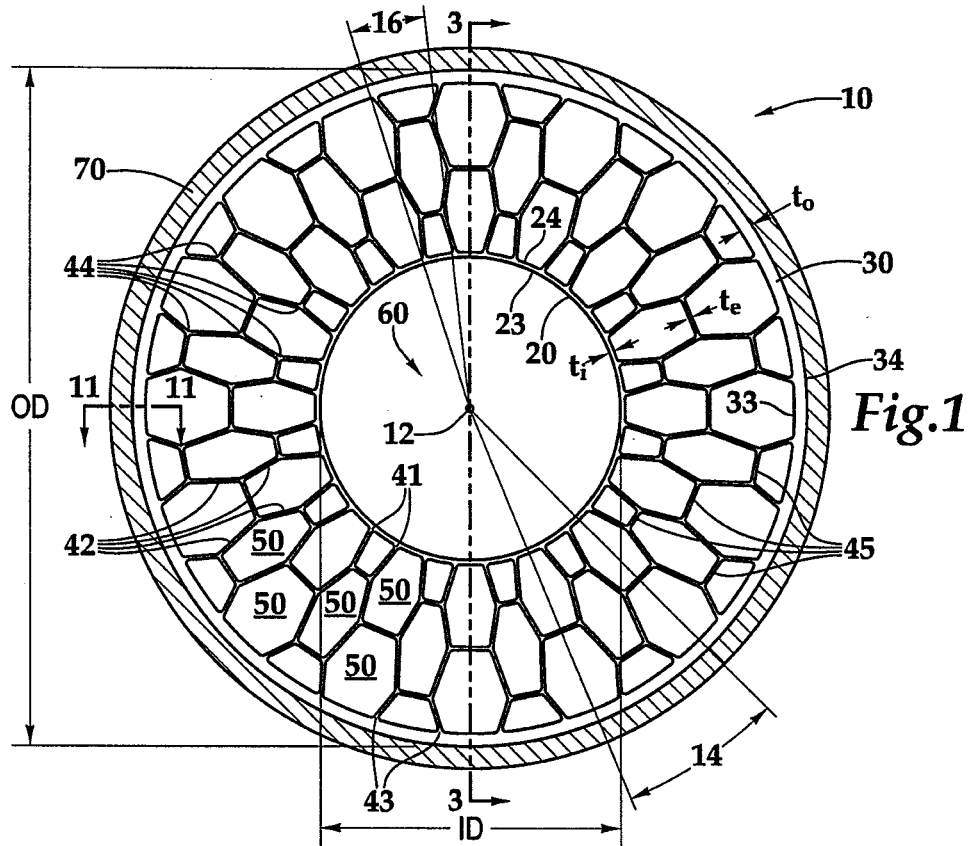


Fig. 1

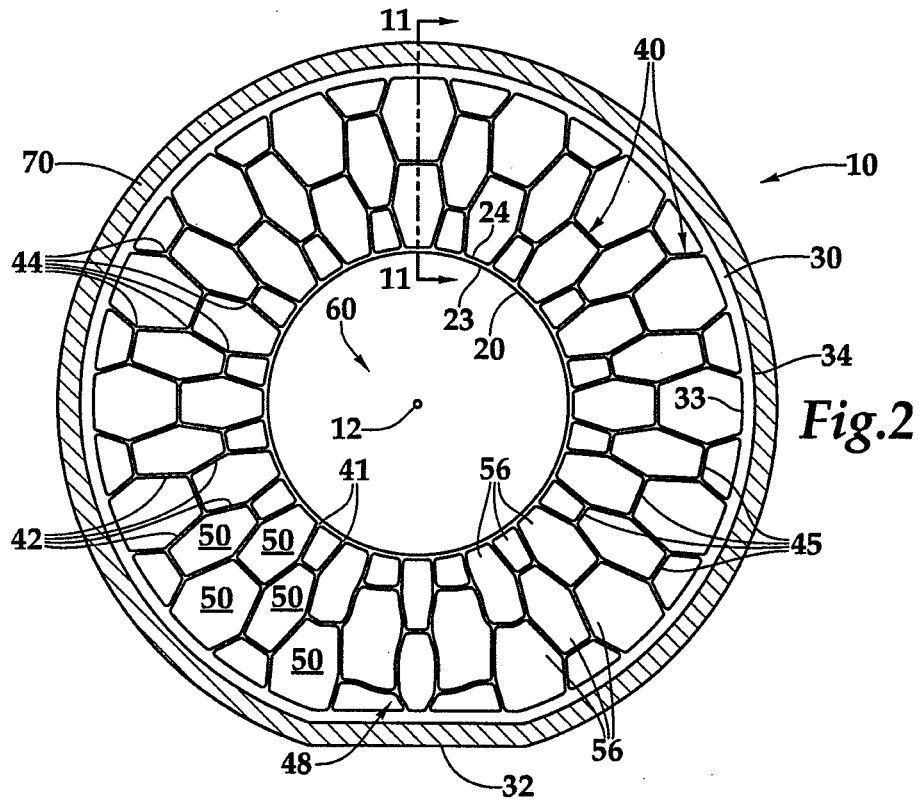


Fig. 2

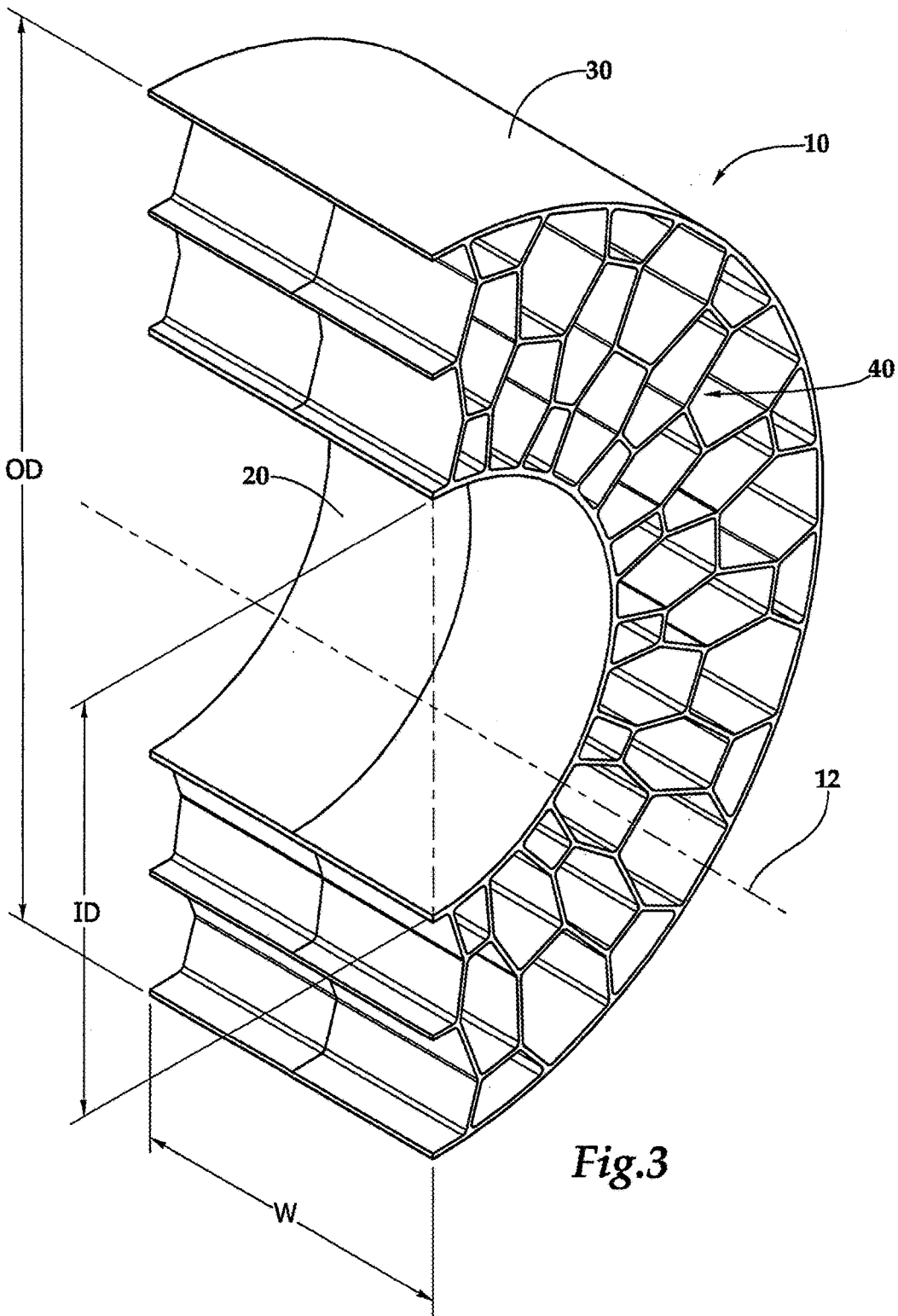


Fig.3

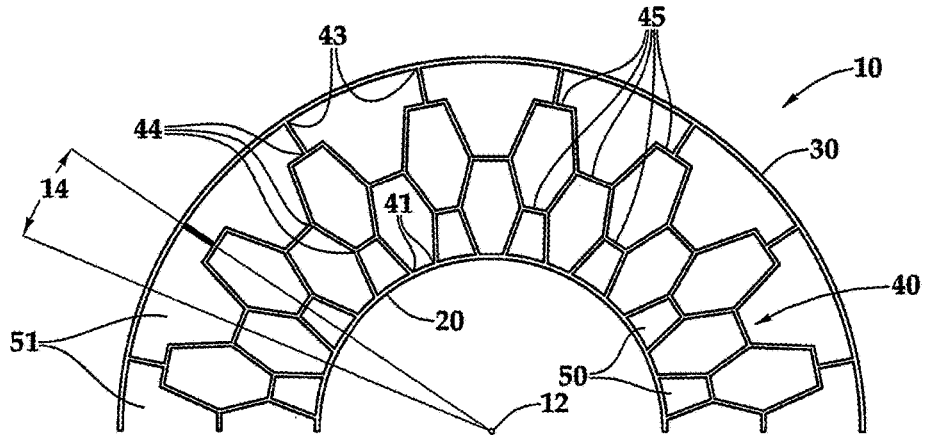


Fig. 4

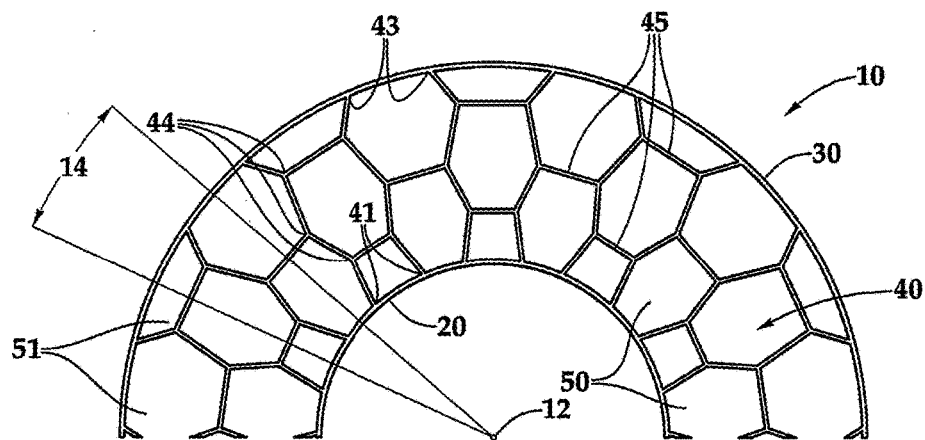


Fig. 5

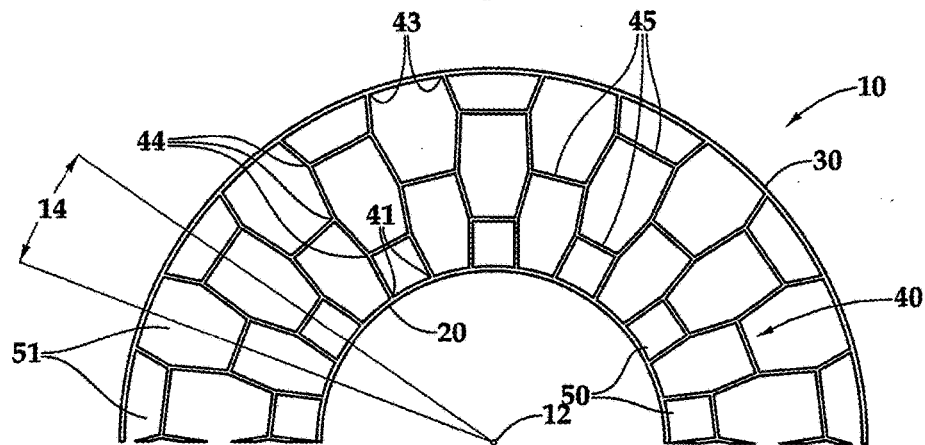
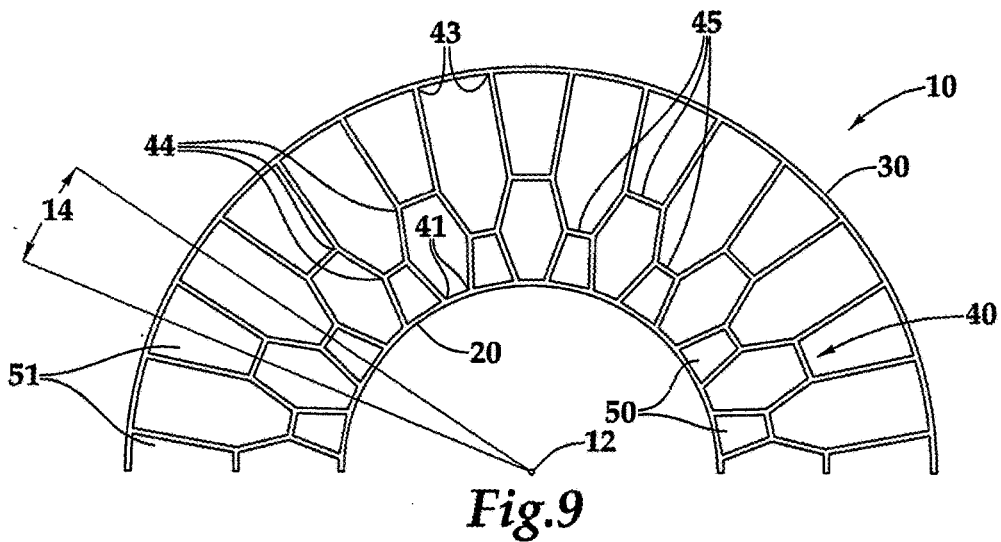
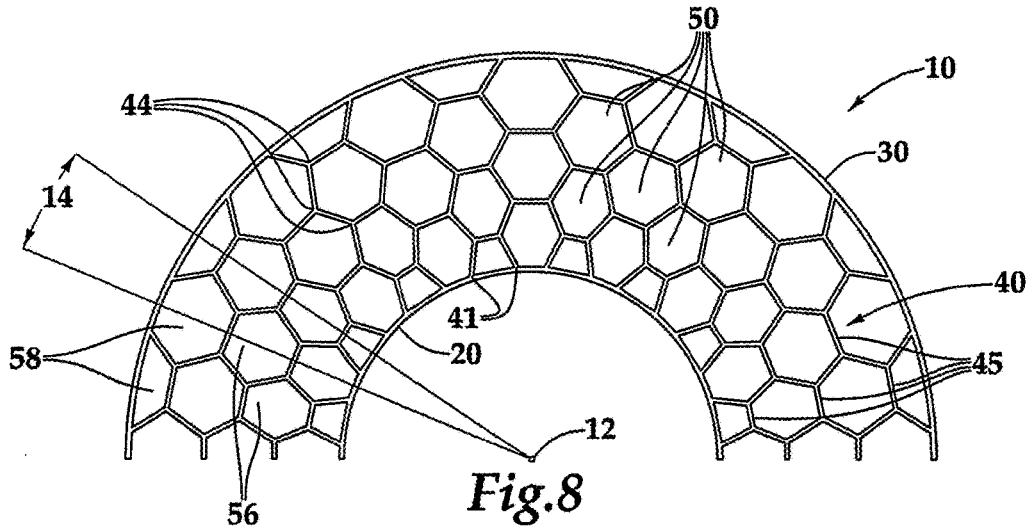
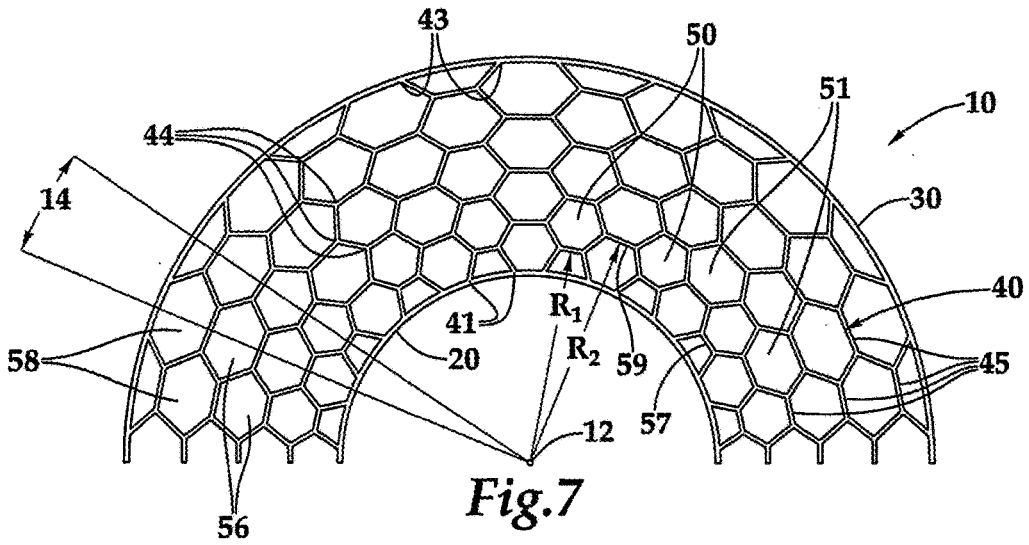


Fig. 6





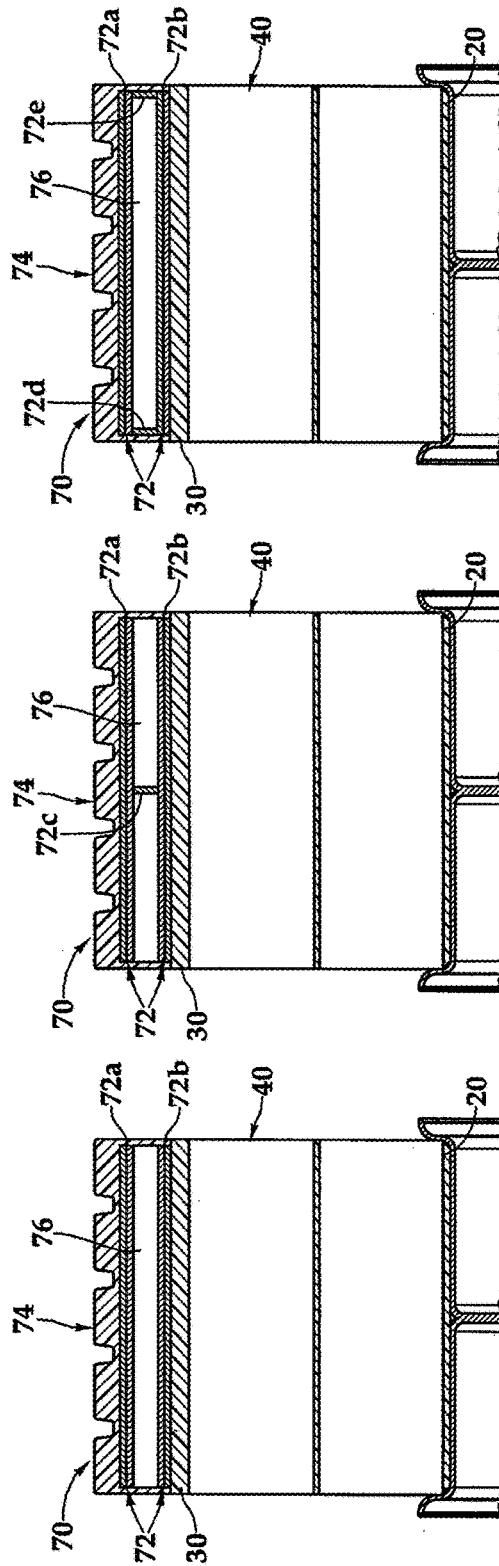
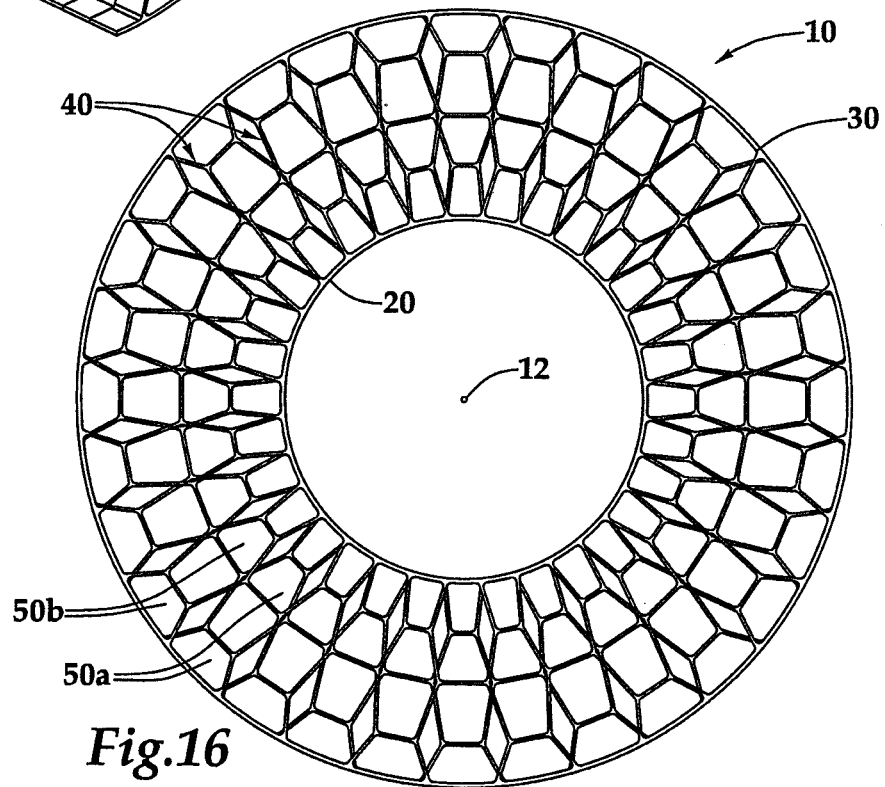
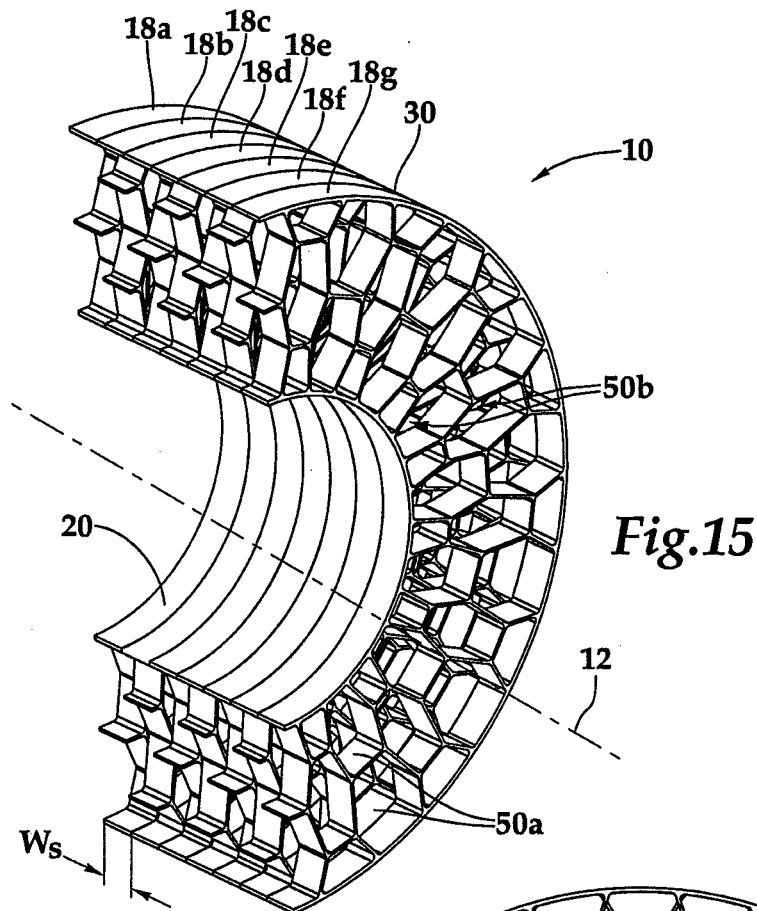


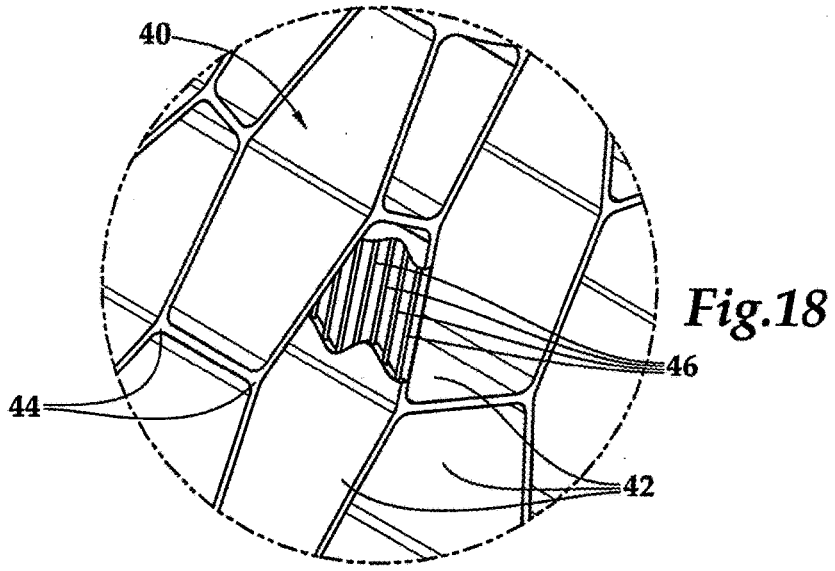
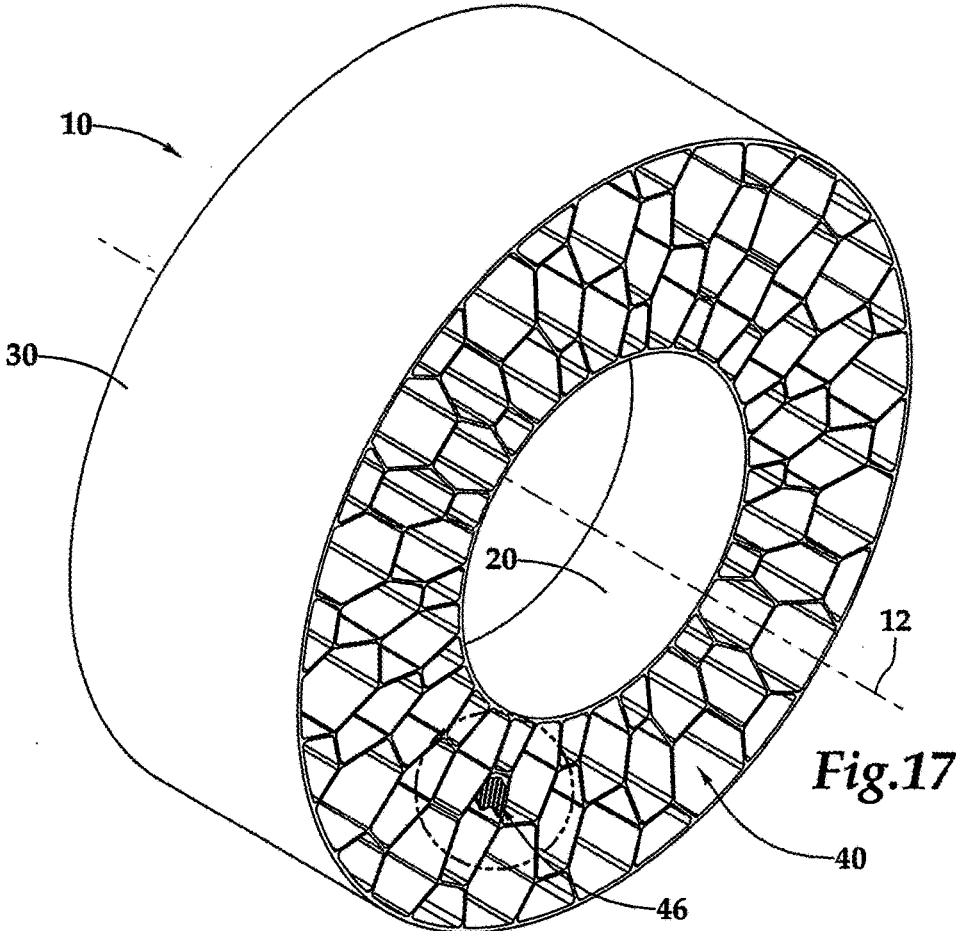
Fig.13

Fig.12

Fig.11







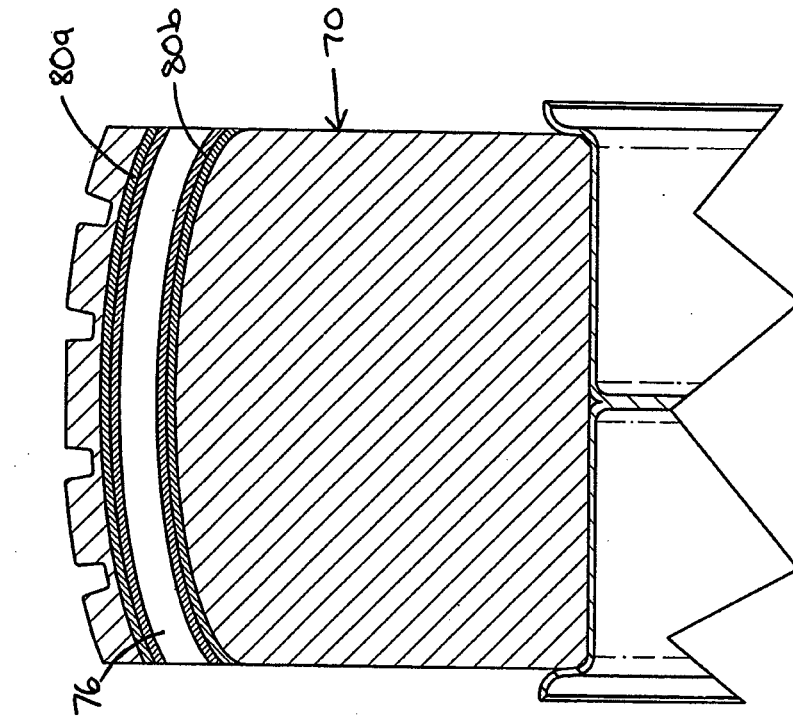


FIG. 19

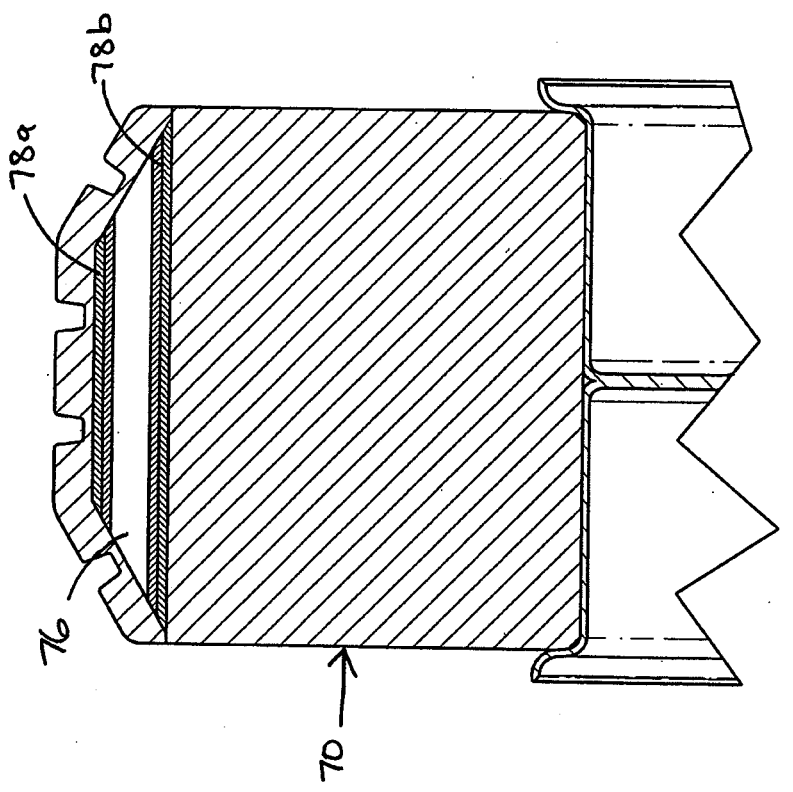


FIG. 20

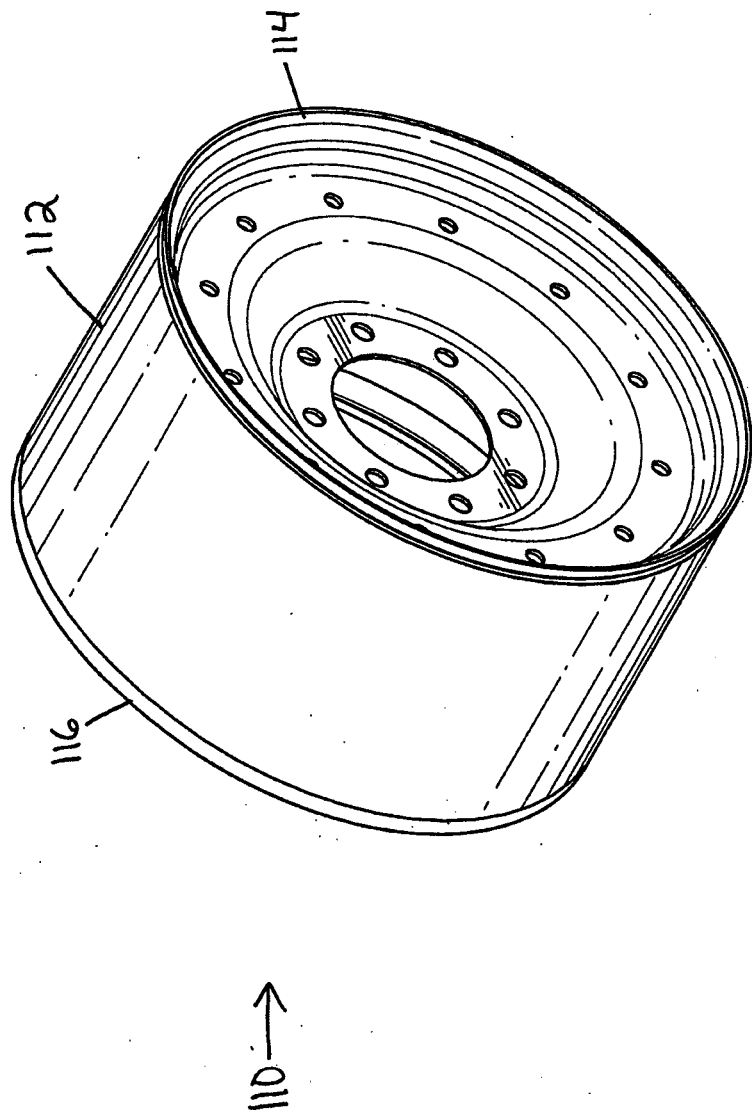


FIG. 21

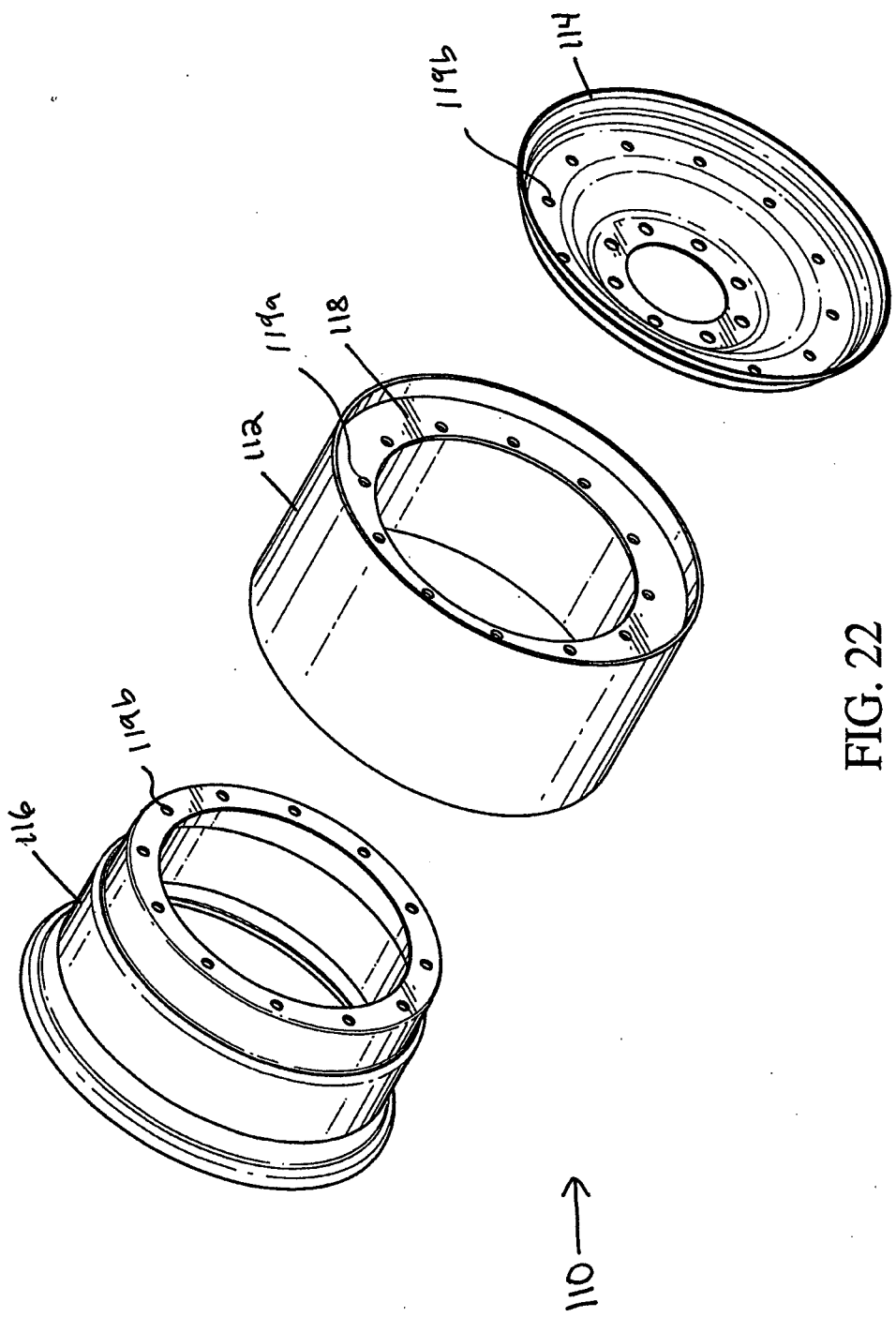


FIG. 22

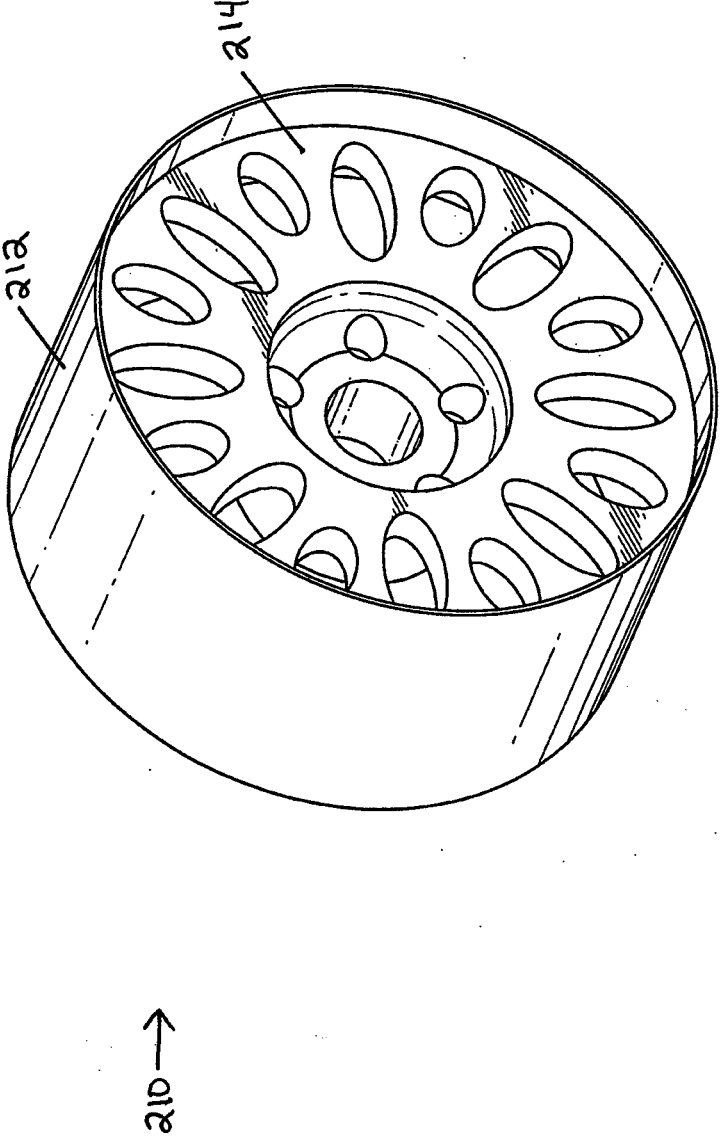


FIG. 23

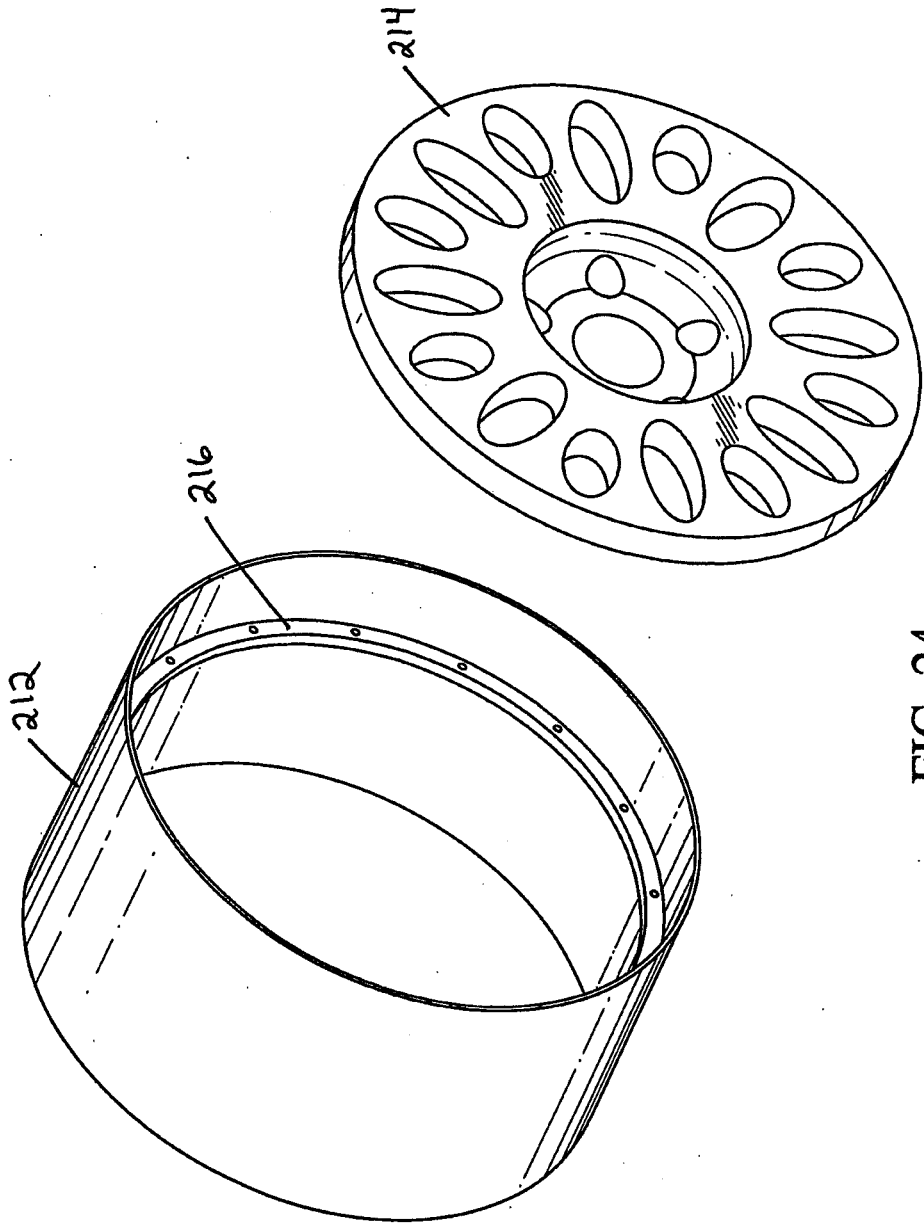


FIG. 24

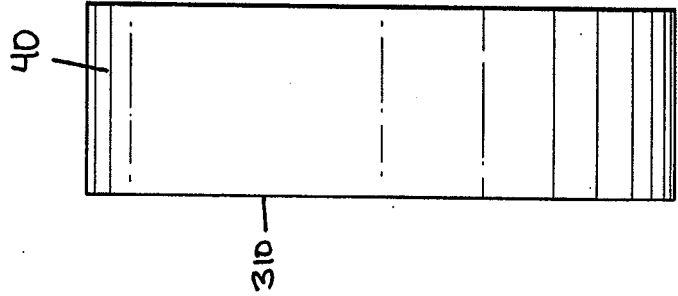


FIG. 25

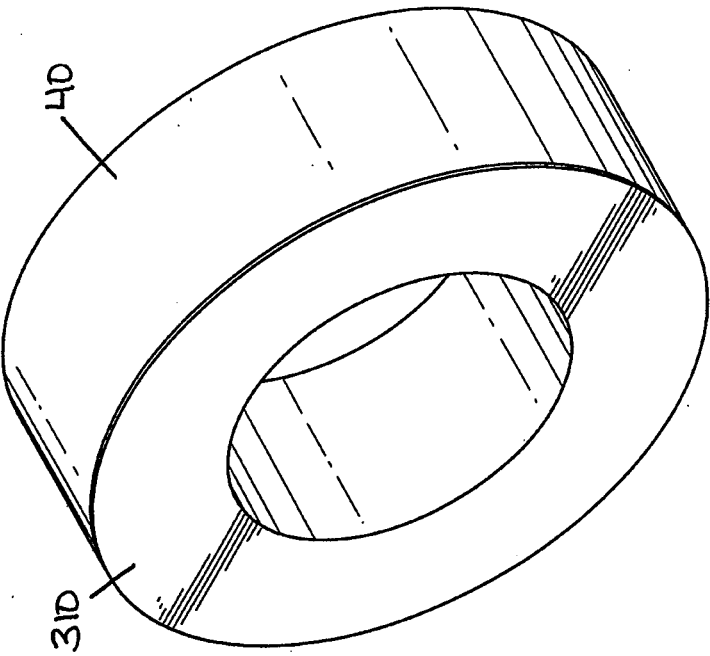


FIG. 26

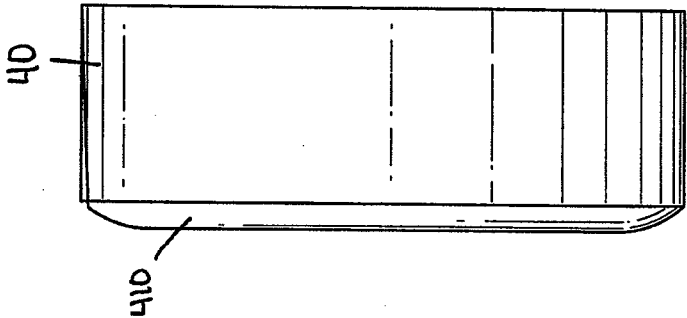


FIG. 28

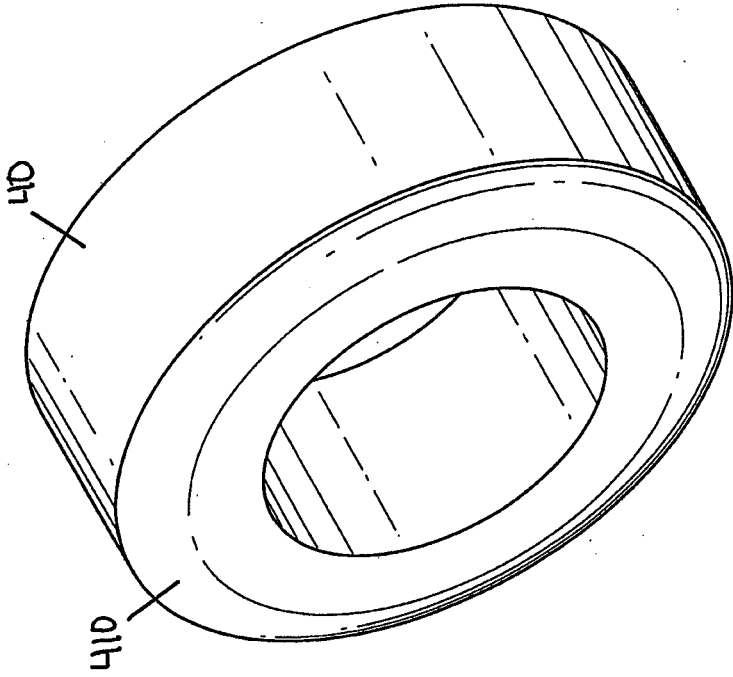


FIG. 27



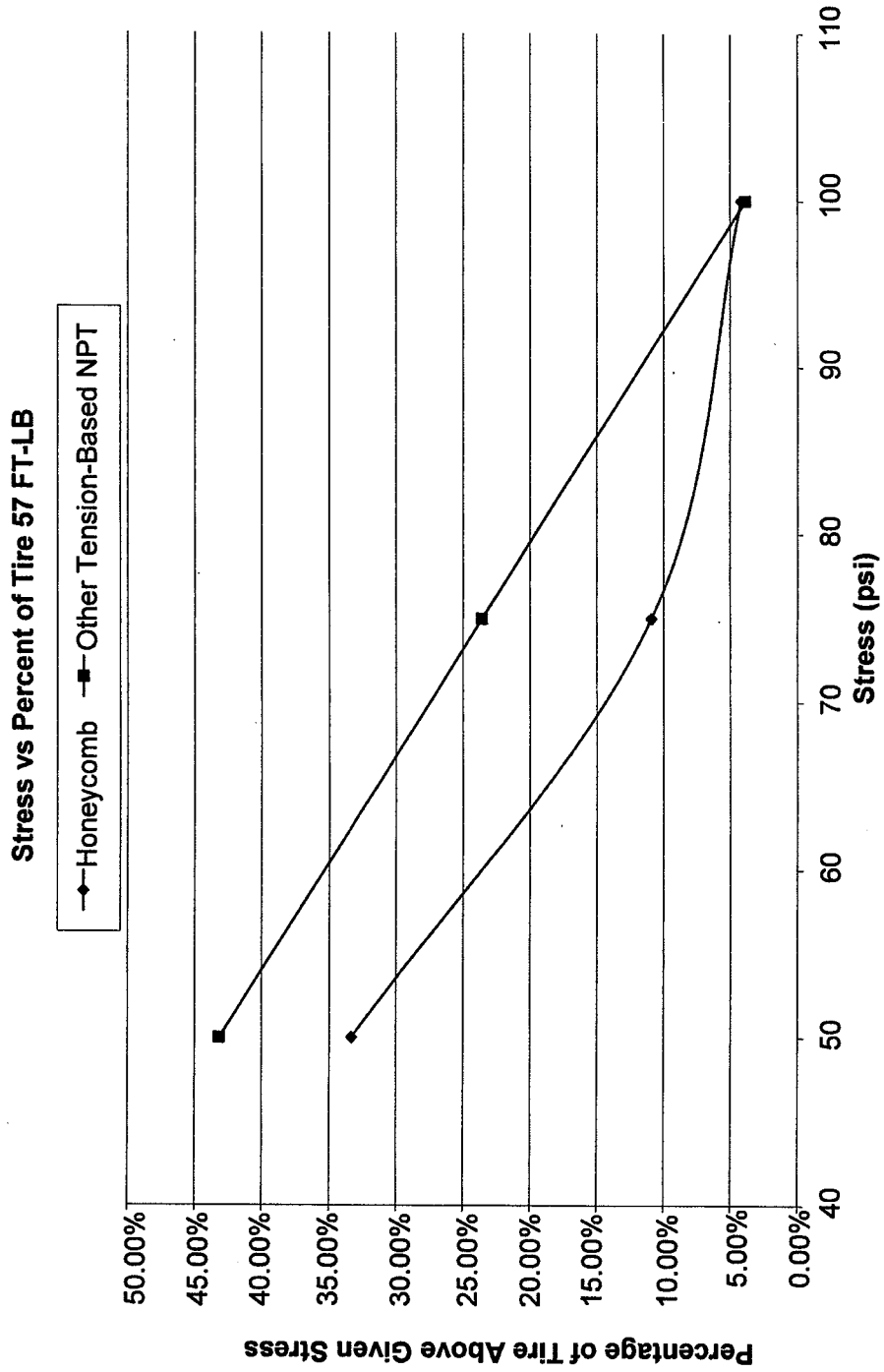
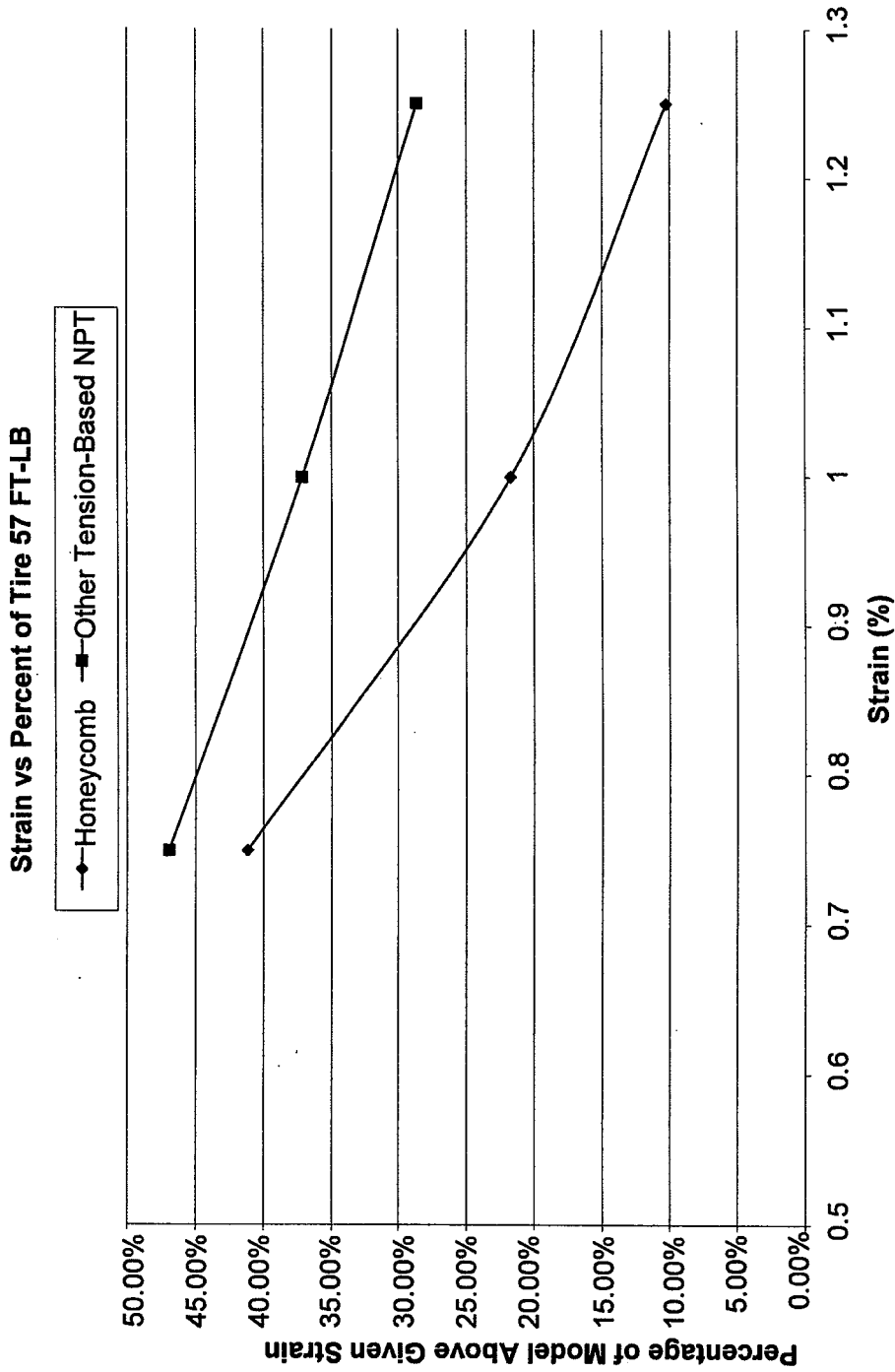


Fig. 29



*Fig. 30*

## TENSION-BASED NON-PNEUMATIC TIRE

### CROSS-REFERENCE TO RELATED APPLICATIONS

**[0001]** The present application is a continuation-in-part of U.S. patent application Ser. No. 13/333,721, filed Dec. 21, 2011 and presently pending, which is a continuation of U.S. patent application Ser. No. 12/055,675, filed Mar. 26, 2008 and now U.S. Pat. No. 8,109,308, which is a continuation-in-part of U.S. patent application Ser. No. 11/691,968, filed Mar. 27, 2007 and now U.S. Pat. No. 8,104,524. The entire contents of these disclosures are hereby expressly incorporated by reference in their entirety.

**[0002]** This invention was made, in part, with United States government support awarded by the United States Army Research Laboratory under contract numbers W911NF-06-2-0021 and W911QX-08-C-0034. Accordingly, the United States may have certain rights in this invention.

### BACKGROUND OF THE INVENTION

#### Field of the Invention

**[0003]** The present application is directed to a tire, and more particularly, to a non-pneumatic tire.

#### Description of the Related Art

**[0004]** Non-pneumatic, or airless, tires (NPT) have historically been comprised largely of an entirely solid substance. These solid tires made the ride rather uncomfortable for passengers and caused greater damage to the suspension of a vehicle, which had to compensate for the lack of “give” in a solid tire. Eventually, it was found that putting pressurized air in tires created a more comfortable ride. However, along with their advantages, pneumatic tires still possess some drawbacks.

**[0005]** The material that encloses standard pneumatic tires is susceptible to leaking the pressurized air it tries to withhold. This occurs both via leakage around the wheel rim, and on a smaller scale, when the rubber of the tire absorbs the oxygen. As a result, loss of pressure causes the tire to flatten in the area where the load is applied, subjecting a larger portion of the tire to the load with every revolution, and leading to quicker degradation of the tire. Furthermore, a tire reliant upon pressurized air is susceptible to being punctured leading to rapid release of the pressurized air.

**[0006]** Focusing on fuel efficiency, safety and ride comfort, several attempts have been made to address the problems associated with pneumatic tires while retaining their advantages over solid non-pneumatic tires. By way of example, U.S. Published Application 2006/0113016 by Cron, et al., and assigned to Michelin, discloses a non-pneumatic tire that it commercially refers to as the Tweel™. In the Tweel™, the tire combines with the wheel. It is made up of four parts that are eventually bonded together: the wheel, a spoke section, a reinforced annular band that surrounds the spoke section, and a rubber tread portion that contacts the ground.

**[0007]** Other alternatives to standard pneumatic tires have been attempted, including making solid tires out of polyurethane instead of rubber and suspending reinforcement materials within the polyurethane during molding. Another alternative is to use internal ribs made of a thermoplastic that

are subsequently reinforced with glass fibers. A third alternative is to use an electroactive polymer that is capable of changing shape when an electrical current is applied. This allows the tire to change shape or size based upon road conditions by using the automobile’s electrical system.

### SUMMARY OF THE INVENTION

**[0008]** In one embodiment, a non-pneumatic tire and hub assembly includes an inner ring having an axis of rotation, a deformable outer ring, and a flexible web extending between the inner ring and the deformable outer ring. The assembly further includes a hollow, metal cylinder coupled to the inner ring. The hollow, metal cylinder has a flanged portion extending towards an interior portion of the hollow, metal cylinder.

**[0009]** In another embodiment, a method of making a tire and hub assembly includes providing a hollow cylinder, placing the hollow cylinder in a mold, and connecting an inner ring of a non-pneumatic tire to the hollow cylinder.

**[0010]** In yet another embodiment, a method of making a non-pneumatic tire and hub assembly includes providing a hollow cylinder, and providing a non-pneumatic tire having an inner ring, an outer ring, and a web connecting the inner ring to the outer ring. The method further includes applying an adhesive to at least one of an outer surface of the hollow cylinder and an inner surface of the inner ring of the non-pneumatic tire. The method also includes connecting the inner surface of the inner ring of the non-pneumatic tire to the outer surface of the hollow cylinder.

### BRIEF DESCRIPTION OF THE DRAWINGS

**[0011]** These and other features of the present embodiments will become more apparent upon reading the following detailed description and with reference to the accompanying drawings of the embodiments, in which:

**[0012]** FIG. 1 is a front view of an undeformed non-pneumatic tire.

**[0013]** FIG. 2 is a front view of the non-pneumatic tire of FIG. 1 being deformed when subjected to a load.

**[0014]** FIG. 3 is a sectional perspective view of the undeformed non-pneumatic tire taken along line 3-3 in FIG. 1.

**[0015]** FIG. 4 is a front view of another embodiment of an undeformed non-pneumatic tire.

**[0016]** FIG. 5 is a front view of still another embodiment of an undeformed non-pneumatic tire.

**[0017]** FIG. 6 is a front view of a further embodiment of an undeformed non-pneumatic tire.

**[0018]** FIG. 7 is a front view of yet another embodiment of an undeformed non-pneumatic tire.

**[0019]** FIG. 8 is a front view of another embodiment of an undeformed non-pneumatic tire.

**[0020]** FIG. 9 is a front view of still another embodiment of an undeformed non-pneumatic tire.

**[0021]** FIG. 10 is a front view of a further embodiment of an undeformed non-pneumatic tire.

**[0022]** FIG. 11 is a sectional view of a prior art tread carrying portion attached to a non-pneumatic tire taken along line 11-11 in FIG. 2.

**[0023]** FIG. 12 is a sectional view of another tread carrying portion attached to a non-pneumatic tire taken along line 11-11 in FIG. 2.

[0024] FIG. 13 is a sectional view of still another tread carrying portion attached to a non-pneumatic tire taken along line 11-11 in FIG. 2.

[0025] FIG. 14 is a perspective view of an embodiment of an undeformed non-pneumatic tire with circumferentially offset segments.

[0026] FIG. 15 is a sectional perspective view of the undeformed non-pneumatic tire taken along line 15-15 in FIG. 14.

[0027] FIG. 16 is a front view of the undeformed non-pneumatic tire as viewed from the line 16-16 in FIG. 14.

[0028] FIG. 17 is a perspective view of the non-pneumatic tire of FIG. 1.

[0029] FIG. 18 is an enlarged, cutaway view of the interconnected web of the non-pneumatic tire of FIG. 17.

[0030] FIG. 19 is a cross sectional view of an embodiment of the shear layer of a non-pneumatic tire.

[0031] FIG. 20 is a cross sectional view of an embodiment of the shear layer of a non-pneumatic tire.

[0032] FIG. 21 is a perspective view of an embodiment of a non-pneumatic tire incorporating a cylinder and two wheel components.

[0033] FIG. 22 is an exploded view of the embodiment of FIG. 21.

[0034] FIG. 23 is a perspective view of an embodiment of a non-pneumatic tire incorporating a cylinder and wheel plate.

[0035] FIG. 24 is an exploded view of the embodiment of FIG. 23.

[0036] FIG. 25 is a perspective view of an embodiment of a non-pneumatic tire, including a sidewall integrated with the interconnected web.

[0037] FIG. 26 is a left side view of the sidewall in FIG. 25.

[0038] FIG. 27 is a perspective view of an embodiment of a non-pneumatic tire, including a sidewall integrated with the interconnected web.

[0039] FIG. 28 is a left side view of the sidewall in FIG. 27.

[0040] FIG. 29 is a graphical comparison of the relative stresses in the tension-based non-pneumatic tire vs. the percentage of the tire experiencing that stress compared to another tension-based non-pneumatic tire.

[0041] FIG. 30 is a graphical comparison of the relative strains in the tension-based non-pneumatic tire vs. the percentage of the tire experiencing that strain compared to another tension-based non-pneumatic tire.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0042] FIGS. 1, 2 and 3 illustrate an embodiment of a non-pneumatic tire 10 having certain features and advantages according to an embodiment of the present invention. In the illustrated embodiment, the non-pneumatic tire 10 comprises a generally annular inner ring 20 that engages a wheel 60 to which tire 10 is mounted. The wheel 60 has an axis of rotation 12 about which tire 10 spins. The generally annular inner ring 20 comprises an internal surface 23 and an external surface 24 and can be made of cross-linked or uncross-linked polymers. In one embodiment, the generally annular inner ring 20 can be made of a thermoplastic material such as a thermoplastic elastomer, a thermoplastic urethane or a thermoplastic vulcanizate. In another embodiment, the generally annular inner ring 20 can be made of

rubber, polyurethane, and/or other suitable material. In this application, the term “polymer” means cross-linked or uncross-linked polymers.

[0043] For smaller applied loads, L, the generally annular inner ring 20 can be adhesively engaged with wheel 60 or can undergo some chemical structure change allowing it to bond to the wheel 60. For larger applied loads, L, the generally annular inner ring 20 can be engaged to the wheel 60 via some form of a mechanical connection such as a mating fit, although a mechanical connection can be used for supporting smaller loads as well. The mechanical engagement can provide both the wheel 60 and the generally annular inner ring 20 with extra strength to support the larger applied load, L. In addition, a mechanical connection has the added benefit of ease of interchangeability. For example, if the non-pneumatic tire 10 needs to be replaced, generally annular inner ring 20 can be detached from wheel 60 and replaced. The wheel 60 can then be remounted to the axle of the vehicle, allowing the wheel 60 to be reusable. In another embodiment, the inner ring 20 can be connected to the wheel 60 by a combination of a mechanical and adhesive connection.

[0044] With continued reference to FIGS. 1, 2 and 3, the non-pneumatic tire 10 further comprises a generally annular outer ring 30 surrounding an interconnected web 40 (discussed below). The outer ring 30 can be configured to deform in an area around and including a footprint region 32 (see FIG. 2), which decreases vibration and increases ride comfort. However, since in some embodiments the non-pneumatic tire 10 does not have a sidewall, the generally annular outer ring 30, combined with the interconnected web 40, can also add lateral stiffness to the tire 10 so that the tire 10 does not unacceptably deform in portions away from the footprint region 32.

[0045] In one embodiment, the generally annular inner ring 20 and a generally annular outer ring 30 are made of the same material as interconnected web 40. The generally annular inner ring 20 and the generally annular outer ring 30 and the interconnected web 40 can be made by injection or compression molding, castable polymer, or any other method generally known in the art and can be formed at the same time so that their attachment is formed by the material comprising the inner ring 20, the outer ring 30 and the interconnected web 40 cooling and setting.

[0046] As shown in FIGS. 1, 2 and 3, the interconnected web 40 of non-pneumatic tire 10 connects the generally annular inner ring 20 to the generally annular outer ring 30. In the illustrated embodiment, the interconnected web 40 comprises at least two radially adjacent layers 56, 58 of web elements 42 that define a plurality of generally polygonal openings 50. In other words, with at least two adjacent layers 56, 58, a slice through any radial portion of the non-pneumatic tire 10 extending from the axis of the rotation 12 to the generally annular outer ring 30 passes through or traverses at least two generally polygonal openings 50. The polygonal openings 50 can form various shapes, some of which are shown in FIGS. 4-10. In many embodiments, a majority of generally polygonal openings 50 can be generally hexagonal shape with six sides. However, it is possible that each one of the plurality of generally polygonal openings 50 has at least three sides. In one embodiment, the plurality of generally polygonal openings 50 are either generally hexagonal in shape or hexagonal in shape circumferentially separated by openings that are generally trapezoidal.

dal in shape, as can be seen in FIG. 1, giving interconnected web 40 a shape that can resemble a honeycomb.

[0047] A preferred range of angles between any two interconnected web elements (moving radially from the tread portion of the tire to the wheel) can be between 80 and 180 degrees (see, for example, the web elements of FIG. 1). Other ranges are also possible.

[0048] With continued reference to the illustrated embodiment of FIGS. 1-3, the interconnected web 40 can be arranged such that one web element 42 connects to the generally annular inner ring 20 at any given point or line along the generally annular inner ring 20 such that there are a first set of connections 41 along the generally annular inner ring 20. Likewise, one web element 42 can connect to the generally annular outer ring 30 at any given point or line along an internal surface 33 of the generally annular outer ring 30 such that there are a second set of connections 43 along the generally annular outer ring 30. However, more than one web element 42 can connect to either the generally annular inner ring 20 or to the generally annular outer ring 30 at any given point or line.

[0049] As shown in FIGS. 4-10, the interconnected web 40 can further comprise intersections 44 between web elements 42 in order to distribute applied load, L, throughout the interconnected web 40. In these illustrated embodiments, each intersection 44 joins at least three web elements 42. However, in other embodiments, the intersections 44 can join more than three web elements 42, which can assist in further distributing the stresses and strains experienced by web elements 42.

[0050] With continued reference to FIGS. 4-10, the web elements 42 can be angled relative to a radial plane 16 containing the axis of rotation 12 that also passes through web element 42. By angling the web elements 42, applied load, L, which is generally applied perpendicular to the axis of rotation 12, can be eccentrically applied to the web elements 42. This can create a rotational or bending component of an applied load on each web element 42, facilitating buckling of those web elements 42 subjected to a compressive load. Similarly situated web elements 42 can all be angled by about the same amount and in the same direction relative to radial planes 16. Preferably, however, the circumferentially consecutive web elements 42, excluding tangential web elements 45, of a layer of plurality of generally polygonal openings 50 are angled by about the same magnitude but measured in opposite directions about radial planes such that web elements 42 are generally mirror images about radial plane 16 of one another.

[0051] Each of the openings within the plurality of generally polygonal tubular openings 50 can, but is not required, to be similar in shape. FIG. 7, for example shows a first plurality of generally polygonal openings 50 that is different in shape from a second plurality of generally polygonal openings 51. In this embodiment, at least one opening of the first plurality of general polygonal openings 50 can be smaller than at least one opening of the second plurality of generally polygonal openings 51. FIG. 7 also shows that each generally polygonal opening in the first plurality of generally polygonal openings 50 has an inner boundary 57 spaced a radial distance,  $R_1$ , from axis of rotation 12 and each generally polygonal opening in the second plurality of generally polygonal openings 51, has a second inner boundary 59 spaced a radial distance,  $R_2$ , which can be greater than  $R_1$ , from axis of rotation 12.

[0052] The number of openings 50 within the interconnected web 40 can vary. For example, the interconnected web 40 can have five differently sized openings patterned 16 times for a total of 80 cells, such as in FIG. 1. In yet other embodiments, other numbers of openings 50 can be used other than 16. For example, in preferred embodiments the interconnected web 40 could include between 12-64 patterns of cells. Other numbers outside of this range are also possible.

[0053] As shown in FIGS. 7 and 8, openings in a radially inner layer 56 can be similarly shaped as compared to those in a radially outer layer 58 but can be sized differently from those openings such that the generally polygonal openings 50 increase in size when moving from opening to opening in a radially outward direction. However, turning to FIG. 10, a second plurality of generally polygonal openings 51 in a radially outer layer 58 can also be smaller than those in a first plurality of generally polygonal openings 50 in a radially inner layer 56. In addition, the second plurality of generally polygonal openings can be either circumferentially separated from each other by a third plurality of generally polygonal openings 53 or can be greater in number than the first plurality of generally polygonal openings 50, or it can be both.

[0054] As noted above, FIGS. 1-9 show several variations of a plurality of generally polygonal openings 50 that are generally hexagonally shaped. As shown, these openings can be symmetrical in one direction or in two directions, or, in another embodiment, they are not symmetrical. For example, in FIG. 1, radial symmetry planes 14 bisect several of the plurality of generally polygonal openings 50. Those openings are generally symmetrical about radial symmetry planes 14. However, interconnected web 40 of tire 10 can also be generally symmetrical as a whole about radial symmetry planes. In comparison, a second plurality of generally polygonal openings 51 can be generally symmetrical about similar radial symmetry planes 14. In addition, as shown in FIGS. 7-8, a second plurality of generally polygonal openings can be generally symmetrical about lines tangent to a cylinder commonly centered with axis of rotation 12, providing a second degree of symmetry.

[0055] The web elements 42 can have significantly varying lengths from one embodiment to another or within the same embodiment. For example, the interconnected web 40 in FIG. 7 comprises web elements 42 that are generally shorter than web elements of the interconnected web shown in FIG. 6. As a result, interconnected web 42 can appear denser in FIG. 7, with more web elements 42 and more generally polygonal openings 50 in a given arc of tire 10. In comparison, FIGS. 9 and 10 both show interconnected webs 40 which web elements 42 substantially vary in length within the same interconnected web. In FIG. 9, radially inward web elements 42 are generally shorter than web elements 42 located comparatively radially outward. However, FIG. 10 shows radially inward web elements 42 that are substantially longer than its radially outward web elements 42. As a result, interconnected web 40 of FIG. 9 appears more inwardly dense than interconnected web 42 of FIG. 10.

[0056] Remaining with FIG. 10, an interconnected web 40 is shown such that web elements 42 define a radially inner layer 56 of generally polygonal openings 50 that is significantly larger than a radially outer layer 58 of generally polygonal openings 50. Radially inner layer 56 can comprise

alternating wedge-shaped openings **55** that may or may not be similarly shaped. As shown, second plurality of generally polygonal openings **51** can be separated from first plurality of generally polygonal openings **50** by a generally continuous web element **42** of interconnected web **40** spaced at a generally constant radial distance from axis of rotation **12**. The generally continuous, generally constant web element **42** can assist in providing further stiffness to non-pneumatic tire **10** in regions that are resistant to deformation.

**[0057]** With reference back to FIG. 2, the combination of the geometry of interconnected web **40** and the material chosen in interconnected web **40** can enable an applied load,  $L$ , to be distributed throughout the web elements **42**. Because the web elements **42** are preferably relatively thin and can be made of a material that is relatively weak in compression, those elements **42** that are subjected to compressive forces may have a tendency to buckle. These elements are generally between the applied load,  $L$ , that generally passes through axis of rotation **12** and footprint region **32** and are represented as buckled section **48** in FIG. 2.

**[0058]** In one embodiment, some or all of the web elements **42** can be provided with weakened (e.g., previously bent) or thinned sections such that the web elements **42** preferentially bend and/or are biased to bend in a certain direction. For example, in one embodiment, the web elements are biased such that they bend generally in an outwardly direction. In this manner, web elements do not contact or rub against each as they buckle. In addition, the position of the weakened or thinned portion can be used to control the location of the bending or buckling to avoid such contact.

**[0059]** When buckling occurs, the remaining web elements **42** may experience a tensile force. It is these web elements **42** that support the applied load  $L$ . Although relatively thin, because web elements **42** can have a high tensile modulus,  $E$ , they can have a smaller tendency to deform but instead can help maintain the shape of the tread carrying layer **70**. In this manner, the tread carrying layer **70** can support the applied load  $L$  on the tire **10** as the applied load  $L$  is transmitted by tension through the web elements **42**. The tread carrying layer **70**, in turn, acts as an arch and provides support. Accordingly, the tread carrying layer **70** is preferably sufficiently stiff to support the web elements **42** that are in tension and supporting the load  $L$ . Preferably a substantial amount of said applied load  $L$  is supported by the plurality of said web elements working in tension. For example, in one embodiment, at least 75% of the load is supported in tension, in another embodiment at least 85% of the load is supported in tension and in another embodiment at least 95% of the load is supported in tension. In other embodiments, less than 75% of the load can be supported in tension.

**[0060]** Although the generally annular inner ring **20**, the generally annular outer ring **30**, and the interconnected web **40** can be comprised of the same material; they can all have different thicknesses. That is, the generally annular inner ring can have a first thickness,  $t_1$ , the generally annular outer ring can have a second thickness  $t_2$ , and the interconnected web can have a third thickness,  $t_3$ . As shown in FIG. 1, in one embodiment, the first thickness  $t_1$  can be less than the second thickness  $t_2$ . However, the third thickness,  $t_3$ , can be less than either first thickness, or the second thickness,  $t_2$ . This illustrated arrangement is presently preferred as a thinner

web element **42** buckles more easily when subjected to a compressive force whereas a relatively thicker generally annular inner ring **20** and the generally annular outer ring **30** can advantageously help maintain lateral stiffness of non-pneumatic tire **10** in an unbuckled region by better resisting deformation.

**[0061]** The thickness,  $t_e$ , of web elements **42** can vary, depending on predetermined load capability requirements. For example, as the applied load,  $L$ , increases, the web elements **42** can increase in thickness,  $t_e$ , to provide increased tensile strength, reducing the size of the openings in the plurality of generally polygonal openings **50**. However, the thickness,  $t_e$ , should not increase too much so as to inhibit buckling of those web elements **42** subject to a compressive load. As with choice of material, the thickness,  $t_e$ , can increase significantly with increases in the applied load  $L$ . For example, in certain non-limiting embodiments, each web element **42** of interconnected web **40** can have a thickness,  $t_e$  between about 0.04 inch and 0.1 inch thick for tire loads of about 0-1000 lbs, between about 0.1 and 0.25 inch thick for loads of about 500-5000 lbs, and between 0.25 and 0.5 inch thick for loads of about 2000 lbs or greater. Those of skill in the art will recognize that these thicknesses can be decreased or increased in modified embodiments.

**[0062]** In addition to the web elements **42** that are generally angled relative to radial planes **16** passing through axis of rotation **12**, the interconnected web **40** can also include tangential web elements **45**, as shown in FIGS. 1-9. The tangential web elements **45** can be oriented such that they are generally aligned with tangents to cylinders or circles centered at axis of rotation **12**. The tangential web elements **45** are preferred because they assist in distributing applied load  $L$ . For example, when the applied load  $L$ , is applied, the web elements **42** in a region above axis of rotation **12** are subjected to a tensile force. Without the tangential web elements **45**, interconnected web **40** may try to deform by having the other web elements **42** straighten out, orienting themselves in a generally radial direction, resulting in stress concentrations in localized areas. However, by being oriented in a generally tangential direction, the tangential web elements **45** distribute the applied load,  $L$  throughout the rest of interconnected web **40**, thereby minimizing stress concentrations.

**[0063]** Staying with FIGS. 1-9 the plurality of generally polygonal openings **50** are shown wherein each one of said plurality of generally polygonal openings **50** is radially oriented. As noted above, the generally polygonal openings **50** can be oriented such that they are symmetrical about radial symmetry planes **14** that pass through axis of rotation **12**. This arrangement can facilitate installation by allowing tire **10** to still function properly even if it is installed backwards because it should behave in the same manner regardless of its installed orientation.

**[0064]** As shown in FIG. 1, the generally annular outer ring **30** can have a radially external surface **34** to which a tread carrying layer **70** is attached. Attachment can be done adhesively or using other methods commonly available in the art. In addition, as seen in FIG. 11-13, the tread carrying layer **70** can comprise embedded reinforcing belts **72** to add increased overall stiffness to the non-pneumatic tire **10** wherein the embedding of the reinforcing belts **72** is accomplished according to methods commonly available in the art. Reinforcing belts **72** can be made of steel or other strengthening materials.

**[0065]** FIGS. 11-13 show several possible examples of the arrangement of the reinforcing belts 72 in tread carrying layer 70. FIG. 11 is a version showing a tread 74 at a radial outermost portion of the tire 10. Moving radially inwardly are a plurality of reinforcing belts 72a, a layer of support material 76, which forms a shear layer, and a second plurality of reinforcing belts 72b. In this embodiment, the reinforcing belts 72a, 72b are arranged so that each belt is a generally constant radial distance from axis of rotation 12.

**[0066]** Turning to the embodiment of FIG. 12, a tread carrying layer 70 similar to that of FIG. 11 is shown. However, the embodiment of FIG. 12 shows the layer of support material 76 being approximately bisected in a generally radial direction by at least one transverse reinforcing belt 72c. Support material 76 can be a rubber, polyurethane or similar compound. As a footprint is formed by the tire, the support material 76 between the reinforcing belts 72 is subjected to a shear force. Thus, the support layer 76 provides the tread carrying layer 70 with increased stiffness.

**[0067]** The tread carrying layer 70 of FIG. 13 resembles that of FIG. 11 but comprises two additional groupings of reinforcing belts 72. In addition to the generally radially constant plurality of reinforcing belts 72a, 72b, the tread carrying layer 70 in FIG. 13 includes transverse reinforcing belts 72d, 72e. The transverse reinforcing belts 72d, 72e include at least one reinforcing belt 72d proximate a longitudinally inner surface and at least one reinforcing belt 72e proximate a longitudinally outer surface, such that reinforcing belts 72a, 72b, 72d, 72e generally enclose layer of support material 76 in a generally rectangular box shape.

**[0068]** The reinforcing belts 72 and the support material 76 as described above generally form a shear layer. As a footprint is formed by the tire, the support material 76 between the reinforcing belts is subjected to a shear force. Thus, the support layer 75 provides the tread carrying layer with increased stiffness.

**[0069]** In one embodiment, the shear layer (support material) 76 has a thickness that is in the range from about 0 inches (i.e., no shear layer) to about 1 inch thick (as measured along a radius extending from the axis of rotation). In other heavy load applications, the shear layer 76 can have a thickness greater than 1 inch.

**[0070]** The interconnected web 40, the generally annular inner ring 20 and the generally annular outer ring 30 can be molded all at once to yield a product that has a width or depth of the finished non-pneumatic tire. However, the interconnected web 40, the generally annular inner ring 20 and the generally annular outer ring 30 can be manufactured in steps and then assembled as seen in the embodiments of FIGS. 14-16. In these figures, each segment 18 has an interconnected web 40 having the same pattern as the non-pneumatic tire 10 of FIG. 1.

**[0071]** FIG. 14 shows a perspective view of an embodiment where the tire 10 comprises a plurality of segments 18. Each segment 18 can have a generally uniform width,  $W_s$ , but they can also have different widths in modified embodiments. The segments 18 can be made from the same mold so as to yield generally identical interconnected webs 40, but they can also be made from different molds to yield varying patterns of interconnected webs 40. In addition, as seen in FIGS. 14, 15 and 16, segments 18 can be circumferentially offset from one another so that a plurality of generally polygonal openings 50a of one segment 18 is not generally aligned with a plurality of similarly-shaped generally

polygonal openings 50b of a radially adjacent segment 19. The segments can alternate so that every other segment 18 is generally aligned. In another embodiment, the segments do no alternate. FIG. 15 shows an embodiment having seven segments 18, where the first, third, fifth and seventh segments 18a, 18c, 18e and 18g are generally aligned with each other, the second, fourth and six segments 18b, 18d, and 18f are generally aligned with each other, but the two groups of segments are not generally aligned as a whole. In addition, FIG. 15 is a cutaway view showing two radially adjacent segments 18, 19 that are not generally aligned. This stacking orientation can help with buckling around the footprint region 32, can decrease vibration and noise, and can provide greater torsional stiffness to non-pneumatic tire 10.

**[0072]** The choice of materials used for interconnected web 40 may be an important consideration. In one embodiment, the material that is used will buckle easily in compression, but be capable of supporting the required load in tension. Preferably, the interconnected web 40 is made of a cross-linked or uncross-linked polymer, such as a thermoplastic elastomer, a thermoplastic urethane, or a thermoplastic vulcanizate. More generally, in one embodiment, the interconnected web 40 can preferably be made of a relatively hard material having a Durometer measurement of about 80 A-95 A, and in one embodiment 92 A (40D) with a high tensile modulus, E, of about 21 MPa or about 3050 psi or in other embodiments between about 3000 psi to about 8000 psi. However, tensile modulus can vary significantly for rubber or other elastomeric materials, so this is a very general approximation. In addition, Durometer and tensile modulus requirements can vary greatly with load capability requirements.

**[0073]** The polymer materials discussed above for the interconnected web 40, the inner ring 20, and/or the outer ring 30 can additionally include additives configured to enhance the performance of the tire 10. For example, in one embodiment, the polymer materials can include one or more of the following: antioxidants, light stabilizers, plasticizers, acid scavengers, lubricants, polymer processing aids, anti-blocking additives, antistatic additives, antimicrobials, chemical blowing agents, peroxides, colorants, optical brighteners, fillers and reinforcements, nucleating agents, and/or additives for recycling purposes.

**[0074]** Other advantages can be obtained when using a polymer material such as polyurethane to make non-pneumatic tire 10 instead of the rubber of traditional tires. A manufacturer of the illustrated embodiments can only need a fraction of the square footage of work space and capital investment required to make rubber tires. The amount of skilled labor necessary can be significantly less than that of a rubber tire plant. In addition, waste produced by manufacturing components from a polyurethane material can be substantially less than when using rubber. This is also reflected in the comparative cleanliness of polyurethane plants, allowing them to be built in cities without the need for isolation, so shipping costs can be cut down. Furthermore, products made of polyurethane can be more easily recyclable.

**[0075]** Cross-linked and uncross-linked polymers, including polyurethane and other similar non-rubber elastomeric materials can operate at cooler temperatures, resulting in less wear and an extended fatigue life of tire 10. In addition, the choice of materials for interconnected web 40 and outer ring 30 can significantly decrease rolling resistance, leading to

about a 10% decrease in fuel consumption. Polyurethane has better abrasion resistance and, therefore, better tread wear than a traditional rubber tire and, unlike rubber, it is inert, making it resistant to oxidization or reaction with other materials that make rubber harden or even crack.

**[0076]** In another embodiment shown in FIGS. 17 and 18, the interconnected web 40 comprises web elements 42 that also contain strengthening components 46 such as carbon fibers, KEVLAR®, or some additional strengthening material to provide additional tensile strength to the interconnected web 40. Properties of the strengthening components 46 for certain embodiments can include high strength in tension, low strength in compression, light weight, good fatigue life and an ability to bond to the material comprising interconnected web 40.

**[0077]** With reference back to the tread and shear layers, in the embodiments shown in FIGS. 19 and 20, a crowned (FIG. 19) or rounded configuration (FIG. 20) of the components of the tread layer 70 can be utilized to prevent or reduce excessive drag on the edges of the tread and shear layer 70 during steering or cornering of the vehicle. By giving the tread layer a curved or crowned geometry, such as that shown in FIGS. 19 and 20, the tread along the outer edges of the tire will not wear down as quickly, and the life of the tire can be extended.

**[0078]** Thus, for example, and with reference to FIG. 19, in at least one embodiment the tread carrying layer 70 can comprise inner belt layers 78a and 78b. The belt layer 78a can have a larger width than the belt layer 78b, giving the tread carrying layer 70 a generally crowned or rounded shape. A layer of support material 76 can be placed between the belt layers 78a and 78b.

**[0079]** With reference to FIG. 20, in at least another embodiment the tread carrying layer 70 can comprise belt layers 80a and 80b. Both belt layers 80a and 80b can be curved in order to give the tread carrying layer 70 a generally crowned or rounded shape. Again, a layer of support material 76 can be placed between belt layers 80a and 80b.

**[0080]** The tread carrying layer 70 of FIGS. 11-13, 19, and 20 described above can be manufactured similar to pneumatic tires. For example, in one embodiment, each layer of the tread carrying layer can be manufactured separately in rolls. The thicknesses of the rolls can vary. In at least one embodiment, some of the rolls can be rubber, while other rolls can comprise a steel belting that is coated in a rubber compound and configured for a particular belt angle for a particular tire. Each of the rolls can be brought to a tire building machine, and wrapped onto the machine in a particular order. The last layer can generally comprise a thick layer of rubber to be used as the exterior tread for the tire.

**[0081]** After wrapping each layer, the entire assembly can be brought to a mold. The outer diameter of the mold can have the reverse pattern of the tread engraved in it. The mold can be heated to a temperature that allows the rubber to easily deform and/or flow. The assembly can be set in the mold, and pressure can be applied from the inside to force the tread against the outer wall of the mold, which converts the thick outer layer into a patterned tread. The assembly can sit within the mold under heat and pressure for a specified period of time, allowing the rubber layers to vulcanize and generally transform from several individual layers into one solid layer.

**[0082]** Once a tread carrying layer has been manufactured as described above, the tread carrying layer 70 can be connected to the interconnected web 40. Various methods can be used. For example, at least one arrangement comprises overmolding the interconnected web 40 directly onto the radially inwardly facing surface of the tread carrying layer 70. An adhesive can be sprayed onto the inside diameter of the tread carrying layer 70 and outside diameter of the tire's wheel 60. In one embodiment, a mold can then be filled with liquid urethane. The adhesive on the tread layer 70 and wheel 60 of the tire 10 can form a bond with the urethane. Once the urethane cures and stiffens, the interconnected web 40 will be molded to both the tread carrying layer 74 and tire wheel 60.

**[0083]** In another embodiment, the interconnected web 40 can first be made separately in its own mold. The outside diameter of the interconnected web 40, or the generally annular outer ring 30, can be formed so that it is slightly larger than the inside diameter of the tread carrying layer 70. An adhesive can be applied to the outside diameter of the interconnected web 40. The interconnected web 40 can then be temporarily compressed so that it can be placed into the tread carrying layer 70. Once the interconnected web is positioned correctly, the compression on the interconnected web 40 can be removed. The interconnected web 40 can then spread out and contact the tread carrying layer 70. This method can reduce the residual tension (caused by shrinking of the web material as it cures) that might occur by molding the interconnected web 40 and attaching it to the tread carrying layer 70 at the same time as discussed above.

**[0084]** As mentioned above, the tire 10 can be coupled to the wheel 60 of a vehicle. In at least one embodiment, a generally cylindrical component can fasten to the non-pneumatic tire's wheel 60. For example, with reference to FIGS. 21 and 22, an embodiment of a non-pneumatic tire 110 can comprise a hollow metal (or other material) cylinder 112 configured for attachment to an existing High Mobility Multipurpose Wheeled Vehicle ("HMMWV") or other vehicle's wheel components 114, 116. The wheel components 114, 116 may be configured for use with a specific vehicle. The wheel components 114, 116 may also include a faceplate identified with a specific vehicle or manufacturer. Alternatively, the wheel components 114, 116 may be configured to receive a faceplate identified with a specific vehicle or manufacturer.

**[0085]** The cylinder 112 can include a flanged portion 118 extending towards the interior hollow portion of the cylinder 112. The flange 118 can have holes 119a which align with holes 119b in the wheel components 114, 116, thereby facilitating attachment of the cylinder 112 and wheel 114, 116 by bolts or other fasteners (not shown). While the embodiment shown discloses a flange 118 that extends circumferentially around the interior of the cylinder 112, in other embodiments the flange 118 can extend around only a portion of the interior of the cylinder 112. In yet other embodiments, there can be a plurality of flanges spaced apart around the interior of the cylinder 112.

**[0086]** At least a portion of cylinder 112 can be coupled to the generally annular inner ring 20 as described above. Thus, an interconnected web 40 and a generally annular outer ring 30, such as any of those shown in FIGS. 1-18, can be attached to the exterior, or radially outwardly facing surface, of cylinder 112 via molding, adhesion, or other methods of attachment. In one example of a molding method of attach-



ment, the cylinder **112** is placed inside of an injection mold (not shown). The interconnected web **40** is then built on the cylinder **112** during an injection molding process. Alternatively, a green interconnected web may be built on a cylinder **112**, and then the web and cylinder assembly are placed in a vulcanization mold. The interconnected web **40** may bond to the cylinder **112** during a curing process.

**[0087]** In yet another embodiment, the parts are formed of cured thermoset urethane. The urethane parts may be produced by an open mold casting, spin casting, or liquid injection molding (LIM) process. In an open mold casting process, a mold with an open top is used and the mixed urethane, still in its liquid state, is either pumped into the open cavity through ports in the base of the mold (bottom-fill) or poured in from the top (top-fill or gravity-fill). In a spin casting process, a closed mold is rotated while the mixed, liquid urethane is pumped into the mold. The rotation of the mold forces the liquid outward from the center of rotation, allowing for more unique geometries to be molded when compared the open mold method. In an LIM process, a liquid mixing and pumping mechanism is used. The mixed, liquid urethane is then pumped or injected into the mold.

**[0088]** In one embodiment, an intermediate material is disposed about the cylinder **112** to facilitate bonding between the cylinder **112** and the interconnected web **40**. Exemplary intermediate materials include sheets of fabric or polymeric material, and an adhesive or cement. In an alternative embodiment, the interconnected web is built directly onto the cylinder **112**. The cylinder **112**, the interconnected web **40**, the inner ring **20**, and the generally annular outer ring **30** can then be attached to the wheel **114**, **116**.

**[0089]** The tire configuration of FIGS. **21** and **22** provides an advantage in tire servicing and replacement. For example, the cylinder **112** and wheel components **114**, **116** can easily be removed from one another by removing the bolts or other fasteners. Once the bolts are removed, the tire **10** can quickly be serviced, and/or parts of the tire **10** can quickly and easily be replaced.

**[0090]** With reference to FIGS. **23** and **24**, another embodiment of a non-pneumatic tire **210** can comprise a metal (or other material) cylinder **212**. Cylinder **212**, much like cylinder **112** of the preceding embodiment, can include a flange **216** with holes configured for attaching cylinder **212** with wheel plate **214**. Just as with cylinder **112**, the inner ring **20**, the interconnected web **40** and the generally annular outer ring **30**, such as any of those shown in FIGS. **1-18**, can be attached to the radially outwardly facing surface of cylinder **212** via molding, adhesion, or other methods of attachment. In one example of a molding method of attachment, the cylinder **212** is placed inside of an injection mold (not shown). The interconnected web **40** is then built on the cylinder **212** during an injection molding process. Alternatively, a green interconnected web may be built on a cylinder **212**, and then the web and cylinder assembly are placed in a vulcanization mold. The interconnected web **40** may bond to the cylinder **212** during a curing process.

**[0091]** In one embodiment, an intermediate material is disposed about the cylinder **212** to facilitate bonding between the cylinder **212** and the interconnected web **40**. Exemplary intermediate materials include sheets of fabric or polymeric material, and an adhesive or cement. In an alternative embodiment, the interconnected web is built directly onto the cylinder **212**. The single metal wheel plate

**214** can quickly and easily be removed from the rest of the tire in order to service the tire or replace parts.

**[0092]** In yet another embodiment, the interconnected web and the generally annular outer ring, such as any of those shown in FIGS. **1-18**, can be directly attached to an existing wheel rim (not shown) without use of a cylinder such as cylinder **112** or **212**. Thus, instead of removing any bolts and replacing or servicing different parts of the tire, the tire can simply be discarded when it has worn down.

**[0093]** Additionally, in yet another embodiment, an interconnected web can be directly engaged by a wheel, tread carrying layer, or both. For example, a wheel and tread carrying layer can either or both comprise dovetail joints. The wheel and tread carrying layer can then be inserted into a mold with the material comprising the interconnected web filling the joints. In this case, the generally radially outwardly facing surfaces of the wheel comprise the generally annular inner surface of the tire, and the generally radially inwardly facing internal surface of the tread carrying layer comprises the generally annular outer ring. Therefore, when the interconnected web sets, the interconnected web is directly engaged, obviating the need to bond or otherwise affix the interconnected web to the generally annular outer ring.

**[0094]** Non-pneumatic tires, including those that use an interconnected web as discussed above, can also incorporate the use of a sidewall or some other structure capable of covering and protecting the interconnected web **40** and tire **10**. Use of a sidewall helps to ensure that debris, water, or other material does not enter the tire, including the interconnected web area, and interfere with the tire's functionality and performance. The sidewall can also help prevent damage to the web from projectiles or other debris.

**[0095]** With reference to FIGS. **25** and **26**, a sidewall **310** can be attached to or integrated with an interconnected web **40**. In at least one embodiment, the sidewall **310** can be adhered directly to at least one side of the interconnected web **40**. The sidewall **310** can be entirely flat when viewed from its side, as illustrated in FIG. **26**, such that it can be bonded directly to the edges of each or some of the interconnected web element **42** exposed along the outside of the tire **10**. The sidewall **310** can be manufactured separately as one piece and then adhered to the interconnected web **40**, or the sidewall can be integrated directly into the interconnected web's molding during production of the web **40**.

**[0096]** With continued reference to FIGS. **25** and **26**, the sidewall **310** can cover all, or only a portion of, the side of the interconnected web **40**. By attaching or integrating a sidewall **310** onto at least a portion of the interconnected web **40**, debris or other material can be prevented from entering the interconnected web area of the tire **10** and interfering with the web elements **42**.

**[0097]** The sidewall **310** can be made from the same material as that of the interconnected web **40**, or the material can be different, such as rubber. In some embodiments, the material for both the interconnected web **40** and sidewall **310** is cast polyurethane. Additionally, in some embodiments the sidewall **310** can have a lower stiffness than that of the interconnected web elements **42**. By having a lower stiffness, the sidewall **310** as illustrated in FIGS. **25** and **26** will generally not support any of the loads acting on the tire **10**. Instead, the sidewall **310** can bend or flex during loading in the areas between the interconnected web elements **42**, allowing the interconnected web elements **42** to continue

supporting the loads acting on the tire **10**. In other embodiments, the sidewall **310** can support a load.

**[0098]** In an additional embodiment, and with continued reference to FIGS. **25** and **26**, the sidewall **310** can be adhered to or integrated with the interconnected web **40** only near the generally annular inner ring **20** and the generally annular outer ring **30**. In such embodiments, the sidewall **310** is not adhered to or integrated with some of the interconnected web elements **42** located between the generally annular inner ring **20** and generally annular outer surface **30**. This allows sidewall **310** the freedom to flex and bend in the region between the generally annular inner **20** and the generally annular outer rings **30**, instead of only in those areas between the interconnected web elements **42**.

**[0099]** With reference to FIGS. **27** and **28**, an additional embodiment of a sidewall **410** can have a generally “domed” or flexed shape, as opposed to the flat shape of sidewall **410** as shown in FIG. **26**. In this embodiment, the sidewall **410** can be adhered to or integrated with the interconnected web **40** as discussed above near both the generally annular inner ring **20** and the generally annular outer ring **30**. The “domed” shape of the sidewall **410**, as illustrated in FIG. **28**, biases the sidewall **410** to deform in a prescribed direction (i.e., away from the web **40**), as opposed to buckling or deforming in towards the web **40** and interconnected web elements **42**. Just as with the previous embodiments, the sidewall **410** and interconnected web **40** can be made of the same material, or different materials. In some embodiments, the interconnected web material **40** is cast polyurethane, and the sidewall **410** rubber.

**[0100]** In yet additional embodiments, the sidewalls **310**, **410** described above can be made separate from the interconnected web, and be removable from the tire for servicing and/or replacement. For example, the sidewall **310**, **410** can be held in place adjacent the interconnected web **40** by a flange or flanges encircling the tire **10**. The flanges (not shown) can be made from material having low stiffness so as to prevent the flanges from interfering with the functionality and performance of the interconnected web elements **42**. The flanges can be adhered to or integrated with the interconnected web **40** or other portions of the tire **10**. In at least some embodiments, the sidewall can slide out from the grip of the flanges. In yet other embodiments, the flanges can bend or flex, allowing the sidewall to be inserted or removed. In yet other embodiments, the sidewall can be flexible enough to bend and to be inserted into the stationary flanges.

**[0101]** In yet additional embodiments, instead of an actual wall along the side(s) of the interconnected web **40**, the interconnected web **40** can be filled partially or wholly with filler, for example, a foam material. In at least one embodiment, the foam can comprise polyurethane foam. By filling the interconnected web **40** with foam or similar material, debris can be prevented from entering the areas between the interconnected web elements **42**, which can substantially interfere with the tire’s functionality and performance. At the same time, the foam can be flexible. Thus, the foam itself generally will not support any loads on the tire, instead allowing the tire’s interconnected web elements to continue supporting the loads. In addition, in other modified embodiments, the filler can be used to support some of the load. As mentioned above, non-foam materials can also be used.

**[0102]** In yet additional embodiments, non-pneumatic tires can incorporate sidewalls similar to pneumatic tires.

The sidewalls can be vulcanized to the tread portion of the generally annular outer ring and additionally mounted to the rim of the wheel after the interconnected web has been formed.

**[0103]** Sidewall thicknesses can vary, depending on factors including, but not limited to, the expected applied loads the tire will experience during use, as well as material strength and flexibility. For example, in at least one embodiment, a sidewall comprised of rubber can have a thickness of approximately 0.09375 inches. In at least some embodiments, the thickness of the sidewall can also vary across each individual sidewall.

**[0104]** Advantageously, the embodiments of a non-pneumatic tire described above exhibit many of the same performance characteristics as traditional pneumatic tires. For example, the non-pneumatic tire can demonstrate a general ride quality and traction similar to current pneumatic tires. The non-pneumatic tire **10** can also have costs, weight, load supporting capability and tread life similar to current pneumatic tires.

**[0105]** However, the non-pneumatic tires of the embodiments described herein demonstrate several advantages over standard pneumatic tires. For example, in addition to virtually eliminating blowouts and flat tires, the ability of the generally annular outer ring **30** and the interconnected web **40** to deform in an area around footprint region **32** as shown in FIG. **2** reduces the stresses placed on wheel **60** when hitting a bump, pothole, or similar obstacle, thereby making non-pneumatic tire **10** and wheel **60** less susceptible to damage. Without relying on air pressure to maintain its functionality, interconnected web **40** of non-pneumatic tire **10** can also be better able to withstand damage caused by projectiles. If a portion of interconnected web **40** is damaged, the applied load **L**, which is generally applied perpendicular to axis of rotation **12**, can be transferred to the remaining elements so that a vehicle relying on non-pneumatic tires **10** is not immediately disabled. In addition, because non-pneumatic tire **10** cannot be over- or under-inflated, footprint region **32** can remain generally constant, improving fuel efficiency as compared to traditional pneumatic tires.

**[0106]** The generally annular outer ring **30** combined with interconnected web **40** can display higher lateral stiffness compared to standard pneumatic tires, especially in the embodiment in which the tread carrying layer **70** is attached. Therefore, while general ride quality can be similar to standard pneumatic tires, non-pneumatic tire **10** can achieve improved cornering ability. The non-pneumatic tire **10** can also require less maintenance by obviating the need to check and maintain air pressure.

**[0107]** Additionally, a major advantage of using a non-pneumatic tire compared to a standard tire is eliminating flat tires. If a portion of the web is compromised, the load will be redistributed through other elements of the web by virtue of the fact that the web is interconnected, prolonging the life of the tire. In addition, by not carrying any significant load along a footprint region where the tire contacts a surface, a smoother ride results since the non-pneumatic tire is less susceptible to shock and vibration.

**[0108]** Besides its benefits over traditional pneumatic tires, non-pneumatic tire **10** can exhibit multiple advantages over other non-pneumatic tires. Most of these other tires have solid rim and a solid tire section and are in production for low-speed applications. In comparison to these tires, the

non-pneumatic tire **10** can be significantly lighter. The interconnected web **40** can allow non-pneumatic tire **10** to absorb impacts significantly better, resulting in a more comfortable ride. In addition, other non-pneumatic tires are not usable at high speeds due to the amount of vibration that is generated. Some conventional non-pneumatic tires work by placing the portion of the tire that is between the applied load  $L$  and the contact surface in compression. This causes that section of the tire and its internal structure to deform under the load. When the body to which the tire is attached is not in motion, this portion of the tire remains deformed under the static load. Over time, this can lead to semi-permanent deformation of the tire causing decreased performance, increased noise vibration and worse fuel efficiency, among other things. In contrast, buckled section **48** carries very little, if any, load so the tire can remain statically deformed for a while and not experience any appreciable semi-permanent deformation.

[0109] In comparison to other tension-based non-pneumatic tires, tire **10** can demonstrate even further benefits. Non-pneumatic tire **10** can experience smaller stresses and strains under loading conditions than other tension-based non-pneumatic tires, as can be seen in FIGS. **29** and **30**. By allowing air to flow through the tire **10** and around web elements **42**, the design of interconnected web **40** can result in less heat generation as well as less fatigue, prolonging the life of tire **10**. The ability of interconnected web **40** to buckle around footprint region **32**, thereby causing less reactive force when passing over an obstacle, can also result in less vibration and a better ride. Despite the ability of interconnected web **40** to buckle, it can also be relatively stiff when compared to the internal structure of other tension-based non-pneumatic tires. This can result in less noise being generated, resulting in a quieter ride. It can also cause non-pneumatic tire **10** to experience better starting and stopping performance.

#### Example

[0110] In one non-limiting example embodiment, a non-pneumatic tire **10** possesses the interconnected web **40** of the configuration shown in FIGS. **1** and **2**. Tire **10** has a radius of about 9.5 inches and wheel **60** has a radius of about 4.375 inches.

[0111] In general, the force required for buckling of a column is governed by the equation:  $F_{\text{buckling}} = (KEI\pi^2)/l^2$  where  $K$  = a constant whose value depends on how the ends of the column are affixed,  $E$  = tensile modulus,  $I$  = the area moment of inertia, and  $l$  = the unsupported length of the column.

[0112] If each web element **42** of interconnected web **40** is modeled as its own thin column, the radially innermost elements will be fixed at one end and free to move laterally at another end. In this example,  $K = 1/4$ .

[0113] In this example, the interconnected web **40** and the generally annular outer ring **30** are made of a similar material having a tensile modulus,  $E$ , of about 21 MPa or 3050 psi.

[0114] Tire **10** can be about 8 inches wide. As noted above, in preferred embodiments, each web element **42** of interconnected web **40** can be between about 0.04 inch and 0.1 inch thick for tire loads of about 0-1000 lbs, between about 0.1 and 0.25 inch thick for loads of about 500-5000 lbs, and between 0.25 and 0.5 inch thick for loads of about 2000 lbs or greater. A thickness of about 0.08 inch will be used for this

example. In this case, the area moment of inertia,  $I = (w \cdot h^3)/12$  where  $w$  = the width of each web element **42**, 8 inches and  $h$  = the thickness, 0.08 inch. Therefore,  $I$  is about 0.000341 in<sup>4</sup>.

[0115] Using the tire and wheel radii mentioned above, and observing the pattern of interconnected web **40** as seen in FIGS. **1** and **2**, each web element **42** can have an approximate length of about  $(9.5 \text{ in.} - 4.375 \text{ in.})/4$ , or approximately 1.28 inch.

[0116] Based on these numbers,  $F_{\text{buckling}} = (KEI\pi^2)/l^2 =$  about 1.59 lbs. In addition, web elements **42** of interconnected web **40** are angled with respect to a radial direction to facilitate buckling, which can further decrease  $F_{\text{buckling}}$ .

[0117] In this application, non-pneumatic tire **10** is subjected to a load,  $L$ , of about 250 lbs. Load,  $L$ , is distributed throughout web elements **42** such that the entire load,  $L$ , is not borne by a single web element, **42**. However, the web elements **42** most directly aligned with the direction of load,  $L$ , should bear the greatest portion of the load. Since  $L$  is significantly larger than  $F_{\text{buckling}}$ , elements **42** of interconnected web **40** that are subjected to a compressive force will buckle and not support load,  $L$ .

[0118] While the foregoing written description of embodiments of the invention enables one of ordinary skill to make and use what is considered presently to be the best mode thereof, those of ordinary skill will understand and appreciate the existence of variations, combinations, and equivalents of the specific exemplary embodiments and methods herein. The invention should therefore not be limited by the above described embodiment and method, but by all embodiments and methods within the scope and spirit of the invention as claimed.

What is claimed is:

1. A non-pneumatic tire and hub assembly comprising:
  - an inner ring having an axis of rotation;
  - a deformable outer ring;
  - a flexible web extending between the inner ring and the deformable outer ring; and
  - a hollow, metal cylinder coupled to the inner ring, wherein the hollow, metal cylinder has a flanged portion extending towards an interior portion of the hollow, metal cylinder.
2. The non-pneumatic tire and hub assembly of claim 1, wherein the deformable outer ring has a radially innermost surface and a radially outermost surface, and wherein the deformable outer ring is constructed of a first flowable material.
3. The non-pneumatic tire and hub assembly of claim 2, wherein the flexible web includes tension members coupled to the radially innermost surface of the deformable outer ring.
4. The non-pneumatic tire and hub assembly of claim 2, further comprising a cured tread carrying layer constructed of a second flowable material and having a radially innermost surface that extends continuously in a circumferential direction of the non-pneumatic tire.
5. The non-pneumatic tire and hub assembly of claim 1, further comprising a wheel plate connected to the flanged portion of the hollow, metal cylinder.
6. The non-pneumatic tire and hub assembly of claim 1, further comprising a pair of wheel components connected to the flanged portion of the hollow, metal cylinder.

7. The non-pneumatic tire and hub assembly of claim 1, wherein the flanged portion includes a plurality of axially spaced flange portions.

8. A method of making a tire and hub assembly comprising:

- providing a hollow cylinder;
- placing the hollow cylinder in a mold; and
- connecting an inner ring of a non-pneumatic tire to the hollow cylinder.

9. The method of claim 8, wherein the mold is an injection mold.

10. The method of claim 9, wherein the step of connecting the inner ring of the non-pneumatic tire to the hollow cylinder includes injecting flowable material into the injection mold to form the inner ring of the non-pneumatic tire about the hollow cylinder.

11. The method of claim 10, further comprising injecting additional flowable material into the injection mold to form an interconnected web and an outer ring.

12. The method of claim 8, wherein the mold is a vulcanization mold.

13. The method of claim 12, wherein the step of connecting the inner ring of the non-pneumatic tire to the hollow cylinder includes providing a green non-pneumatic tire and placing the green non-pneumatic tire in the mold about the hollow cylinder.

14. The method of claim 13, further comprising placing a material between the hollow cylinder and the green non-pneumatic tire, wherein the material is selected from the

group consisting of a sheet of fabric, a sheet of polymeric material, an adhesive, and a cement.

15. The method of claim 13, further comprising curing the green non-pneumatic tire in the vulcanization mold.

16. A method of making a non-pneumatic tire and hub assembly comprising:

- providing a hollow cylinder;
- providing a non-pneumatic tire having an inner ring, an outer ring, and a web connecting the inner ring to the outer ring;

applying an adhesive to at least one of an outer surface of the hollow cylinder and an inner surface of the inner ring of the non-pneumatic tire; and

connecting the inner surface of the inner ring of the non-pneumatic tire to the outer surface of the hollow cylinder.

17. The method of claim 16, further comprising providing an intermediate material between the outer surface of the hollow cylinder and the inner surface of the inner ring of the non-pneumatic tire prior to connecting the inner surface of the inner ring of the non-pneumatic tire to the outer surface of the hollow cylinder.

18. The method of claim 17, wherein the intermediate material is selected from the group consisting of a sheet of fabric and a sheet of polymeric material.

19. The method of claim 16, further comprising connecting a wheel plate to the hollow cylinder.

20. The method of claim 16, further comprising connecting a pair of wheel components to the hollow cylinder.

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