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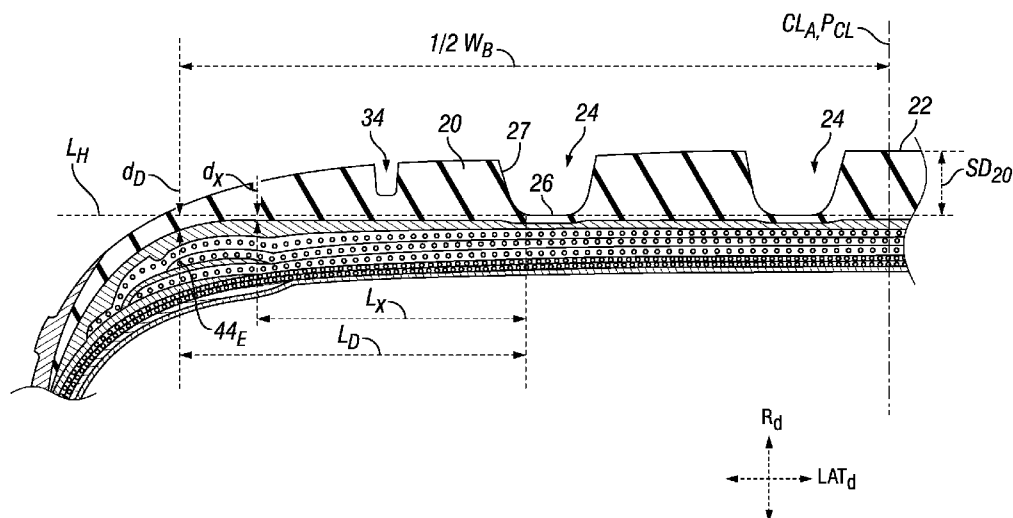


FIG. 5

(57) Abstract: Embodiments of the disclosure include a pneumatic tire having improved high speed limits while generally maintaining wear, traction, and handling performance. Said tires include a cap ply extending substantially across a full width of at least one of the belt plies and being arranged at least partially within each shoulder, the cap ply forming a layer of elastomeric material reinforced with a plurality of elongate reinforcements spaced apart in an array, the cap ply being characterized as having a rupture force greater than 210 N per 15 mm of the cap ply width. In each shoulder area of said tires, the tread is characterized as being flatter and having a greater tread thickness.

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DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN,
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TIRE WITH IMPROVED HANDLING PERFORMANCE AND SPEED DURABILITY

Field

[0001] Embodiments of this disclosure relate generally to pneumatic tires.

BACKGROUND

[0002] In the design of pneumatic tires, it is desirous to achieve any of a variety of performance parameters. It is often the case that to achieve certain performance goals, other performance measures are sacrificed. In particular instances, when attempting to improve high speed durability, maintenance of desired tread thicknesses in the shoulder areas has been sacrificed. By virtue of employing thinner tread thickness in the shoulder areas, not only is the available wear life reduced shallower grooves are provided, thereby reducing wet and snow performance. Additionally, to improve high speed durability, the lateral tread profile in the shoulder has been further rounded. By rounding the shoulder areas, as compared to a flatter tread profile, available tread contact area is reduced resulting in a reduction in traction and wear performance. Accordingly, there is a need to provide improved high speed durability performance without reducing wear, hydroplaning, and snow traction performance.

SUMMARY

[0003] Embodiments of the disclosure include a pneumatic tire. In particular embodiments, the tire comprises: a pair of annular bead areas spaced apart axially along a rotational axis of the tire; a pair of sidewalls spaced apart axially along the rotational axis of the tire, each sidewall of the pair of sidewalls extending outwardly in a radial direction from one bead area of the pair of bead areas relative to the rotational axis; and, a crown portion arranged widthwise between the pair of sidewalls and extending annularly around the tire. The crown portion includes a tread arranged annularly around the crown portion and forming an outer, ground-engaging side upon which the tire is intended to roll upon, the tread having a thickness extending radially and a width extending axially, the tread forming a wearing portion the tire. The crown portion further includes one or more belt plies each forming a layer of elastomeric material reinforced with a plurality of elongate reinforcements spaced apart in an array. The crown portion further including a pair of shoulders, each shoulder forming a portion of the crown arranged adjacent to each sidewall. The crown portion further includes a cap ply arranged radially outward from the one or more belt plies and between the tread and the one or more belt plies, the cap ply extending substantially across a full width of

at least one of the belt plies and being arranged at least partially within each shoulder, the cap ply forming a layer of elastomeric material reinforced with a plurality of elongate reinforcements spaced apart in an array, the cap ply being characterized as having a rupture force greater than 210 N per 15 mm of the cap ply width. The tread includes a plurality of tread features including grooves extending a depth within the tread thickness which includes. The tread features extend into the tread thickness substantially to a depth defining a skid depth of the tread, the skid depth being the thickness of the tread intended to be worn during the intended life of the tire tread. At each widthwise extent of the radially outermost belt ply, each widthwise extent defined by the center of the laterally outermost reinforcement at its most laterally outward location, the tread thickness extending in a direction perpendicular to the outer, ground-engaging side by is greater than 61% of the skid depth at the equatorial plane. At each widthwise extent of the rolling width, the tread thickness extending in a direction perpendicular to the outer, ground-engaging side is greater than 52% of the skid depth at the equatorial plane. At each widthwise extent of the radially outermost belt layer, as defined by the center of the laterally outermost reinforcement at its most laterally outward location, the tread thickness extends a radial distance from a horizontal line, the horizontal line extending from the skid depth at the equatorial plane, the radial distance extending to a bottom of the skid depth and equaling 50% to 80% of the skid depth at the corresponding widthwise extent of the radially outermost belt layer, where for a taper equation of $d_x = d_D(L_x/L_D)^P$, P is less than 3. It is appreciated that other variations of the tire may vary by incorporating more or less features as described hereinafter in any combination or by varying the present features as described hereinafter.

[0004] The foregoing and other objects, features, and advantages will be apparent from the following more detailed descriptions of particular embodiments, as illustrated in the accompanying drawings wherein like reference numbers represent like parts of particular embodiments.

DETAILED DESCRIPTION OF THE DRAWINGS

[0005] FIG. 1 is a sectional view of a tire taken along a plane extending in both a radial direction and an axial direction, the plane extending through the rotational axis, in accordance with an exemplary embodiment;

[0006] FIG. 2 is a top view of a portion of the tire tread shown in FIG. 1, in accordance with an exemplary embodiment;

[0007] FIG. 3 is a sectional view of the tire shown in FIG. 1, showing how to measure rolling width;

[0008] FIG. 4 is a sectional view of the tire shown in FIG. 1, showing how to measure droop in a particular embodiment; and,

[0009] FIG. 5 is a sectional view of the tire shown in FIG. 1, showing how to measure taper in a particular embodiment.

DETAILED DESCRIPTION OF PARTICULAR EMBODIMENTS

[0010] While reducing the tread thickness in the shoulder areas of a tire and providing a rounder tread profile in the shoulder areas generally improves high speed tire durability, doing so also reduces wear performance, wet performance, and traction through the reduction in tread depths, groove depths, and available contact surface area. The present disclosure provides tires characterized as having increased tread thickness in the shoulder areas, which thereby increases groove depths in the shoulder areas, as well as having wet performance and traction, which has not been achieved previously, such as with passenger high performance tires.

[0011] For purposes of describing the invention, reference will now be made to particular exemplary embodiments, one or more examples of which are illustrated in particular figures, or in association with particular figures. Each example is provided by way of explanation of the invention, not limitation of the invention. In fact, it will be apparent to those skilled in the art that various modifications and variations can be made in the present invention without departing from the scope or spirit of the invention. For instance, features or steps illustrated or described as part of one embodiment, can be used with the features or steps of another embodiment to yield other embodiments or methods. Thus, it is intended that the present invention covers such modifications and variations as come within the scope of the appended claims and their equivalents.

[0012] The following terms are defined as follows for this disclosure:

[0013] “Axial direction” or the letter “**A_d**” in the figures refers to a direction parallel to the axis of rotation **A** of the tire or tire carcass, and its components, such as the outer band and inner hub, when rolling along a ground surface. “Lateral direction” or “widthwise direction” or the letter **LAT_d** is synonymous with axial direction **A_d**.

[0014] “Radial direction” or the letter “**R_d**” in the figures refers to a direction that is orthogonal to the axial direction and extends in the same direction as any radius that extends orthogonally from the axial direction. “Radially inward” means in the radial direction **R_d** towards rotational axis **A**. “Radially outward” means in the radial direction **R_d** away from rotational axis **A**.

[0015] “Circumferential direction,” or the letter “**C_d**” in the figures, refers to a direction that is orthogonal to the axial direction and orthogonal to a radial direction. The circumferential direction is the direction of the tire along which it rolls or rotates and that is perpendicular to the axis of rotation of the tire. The circumferential direction is also referred to as a longitudinal direction **LONG_d**.

[0016] A “groove” is any elongate void or channel arranged within the tread having a pair of opposing sidewalls extending depthwise into the tread and that which are spaced apart greater than 1.6 mm or, in other variations, by at least 2.0 mm or otherwise by an average distance as measured between the sidewalls for the entire depth of the groove that is greater than 1.6 mm or by 2.0 mm or more. A groove is designed to have a width, based upon the depth of the groove, to remain open as the tread rolls into, through, and out of a contact patch. A “lateral groove” is a groove that extends in a direction oblique to the longitudinal direction (the circumferential direction). A “longitudinal groove” is a groove that extends substantially in the longitudinal direction. A “circumferential groove” is synonymous with a longitudinal groove, each of which extends annularly around the tire.

[0017] A “sipe” is any elongate void or incision arranged within the tread having a pair of opposing sidewalls extending depthwise into the tread and that which are spaced apart by less than 2.0 mm or 1.6 mm or less in other variations or otherwise by an average distance as measured between the sidewalls for the entire depth of the groove that is less than 2.0 mm or 1.6 mm or less. Sidewalls of the sipe come into contact from time to time as the tread rolls into and out of the contact patch of the tire as the tire rolls on the ground. By lateral sipe, it is meant a sipe that extends in a direction that is oblique to the longitudinal direction.

[0018] A “tread element” is portion of the tread defined by one or more grooves and/or sipes arranged along the outer, ground-engaging side of the tread. Examples of tread elements include tread blocks and ribs.

[0019] A “rib” is a tread element that runs substantially in the longitudinal direction **L_d** of the tire and that is bounded by a pair of longitudinal grooves or by a longitudinal groove and any

of the pair of lateral sides defining a width of the tread. A rib may include any lateral features, which includes any lateral grooves and lateral sipes, as well as any arrangement of tread blocks.

[0020] A “tread block” is a tread element having a perimeter that is defined by one or more grooves with or without a lateral side of the tread, thereby creating an isolated structure in the tread. A sipe does not define any portion of a tread block perimeter.

[0021] A “contact patch” is the total area contained within a perimeter defining an area of contact, the area of the contact patch including the area of contact contained within the perimeter and any void arranged within the area of contact.

[0022] “Elastic material” or “elastomer” as used herein refers to a polymer exhibiting rubber-like elasticity, such as a material comprising rubber, whether natural, synthetic, or a blend of both natural and synthetic rubbers.

[0023] “Elastomeric” as used herein refers to a material comprising an elastic material or elastomer, such as a material comprising rubber.

[0024] “Modulus of elongation” (MPa) was measured at 10% strain (MA10), at 100% strain (MA100), or at 300% strain (MA300) at a temperature of 23 °C based on ASTM Standard D412 on dumb bell test pieces. The measurements were taken in the second elongation; i.e., after an accommodation cycle. These measurements are secant moduli in MPa, based on the original cross section of the test piece.

[0025] Hysteresis or hysteretic loss is denoted as P60 and is measured as a percentage rebound at the sixth rebound at 60° C, in accordance with the following equation:

$$HL(\%)=100 \times ((W0-W1)/W1),$$

in which W0 is the energy supplied and W1 is the energy returned. P60 is obtained through a P8 test that employs a pendulum that is permitted to repeatedly strike and rebound from a test sample.

[0026] “Resilient” as used herein means configured to bend and flex elastically without plastic or permanent deformation under intended operating conditions.

[0027] “Rigid” as used herein means generally unable to elastically or plastically bend or be forced out of shape under intended operating conditions, as opposed to being resilient.

[0028] Cords are said to be inextensible when the said cords under a tensile force equal to 10% of the rupture force, exhibit a strain of at most 0.2%. Cords are said to be elastic when the said cords are under a tensile force equal to the rupture load exhibit a strain of at least 3% with a maximum tangent modulus of less than 150 GPa (gigapascals). As far as the metal cords or threads are concerned, the “rupture force” (maximum load in N (Newtons)), rupture strength (in MPa (megapascals)) and elongation at break (total elongation in %) measurements are taken under tensile load in accordance with standard ISO 6892, 1984 at a temperature of 23 °C.

[0029] “Rolling width,” with reference to FIG. 3, refers to a width W_{RW} of the tread 20 that defines a width of the outer, ground-engaging side 22 of the tread 20. This width W_{RW} is defined in accordance with FIG. 3, whereby a distance W_B is measured along the radially outermost belt ply 40₂ to the center of the last elongate reinforcement 44 in said ply 40₂ at each widthwise extent of said outermost belt ply 40₂. In this instance, $\frac{1}{2}$ of W_B is shown. Upon obtaining this dimension, an additional 3 mm (millimeters) is added to each widthwise extent of W_B (6 mm in total) along the same curvilinear path along which W_B extends, where the 3 mm addition is represented by W_+ . An imaginary line L_N extending normal to the curvilinear path along which W_{B+} extends at each widthwise extent of W_{B+} intersects the outer, ground-engaging side 22 at point P_{22} . At each lateral side of the tread, opposing points P_{22} as measured in the lateral direction LAT_d define the rolling width W_{RW} of the tread 20 and outer, ground-engaging side 22, where in FIG. 3 one half ($\frac{1}{2}$) of W_{RW} is shown.

[0030] “Skid depth” or SD_{20} is defined as the thickness of the tread extending from the outer, ground-engaging side of the tread to the deepest “tread feature” (that is, any longitudinal or lateral groove or sipe) extending into the tread. Any thickness of the tread extending radially inward from the skid depth is referred to as the undertread thickness. In particular instances, with reference to FIG. 1, the skid depth SD_{20} extends along a curvilinear path laterally across the tread and between adjacent longitudinal grooves 24, intersecting each longitudinal groove bottom 26 and extending further along an arcuate path into each shoulder rib 32_{S1}, 32_{S2} at the depth of the deepest lateral groove or sipe, where the skid depth SD_{20} may or may not be arranged substantially the same distance from the radially outermost cap ply 50 or, if no cap ply is present, the radially outermost belt ply 40 for distance W_B . The skid depth defines the useful thickness of the tread intended to be worn during the life of the tire.

[0031] “Droop” means the amount of drop d from the skid depth SD_{20} at the widthwise extent of the belt relative to the skid depth at the equatorial axis of the tire, the droop being measured in the radial direction R_d . With reference to FIG. 4, for example, horizontal line L_H extends axially outward (in direction of A_d) from the skid depth SD_{20} at equatorial plane P_{CL} . Droop or drop d is the distance from line L_H to the skid depth SD_{20} measured in the radial direction R_d (normal to line L_H) along a line that intersects the center of the last elongate reinforcement 44_E of the radially outermost belt layer 40_2 , which is the location of the widthwise extent of distance W_B .

[0032] “Taper” defines amount of deviation between the skid depth SD_{20} and the horizontal line L_H extending axially outward (in direction of A_d) from the skid depth SD_{20} at equatorial plane P_{CL} as the skid depth SD_{20} extends laterally outward toward a shoulder 18 from a bottom 26 of the axially outermost longitudinal groove 24 . With reference to FIG. 5, taper can be described by the following equation:

$$d_x = d_D (L_x / L_D)^P,$$

where distance L_x is any distance extending laterally from the laterally outermost longitudinal groove bottom 26 up to distance L_D , where distance L_D terminates at a radial line that intersects the center of the last elongate reinforcement 44_E of the radially outermost belt layer 40_2 , or, to the widthwise extent of W_B . Distances L_x and L_D extend in the lateral direction LAT_d (that is, axial direction A_d) and while droop d_x is the droop at any corresponding lateral location L_x and droop L_D is the droop at distance L_D . P is referred to as the taper power.

[0033] “Longitudinal contact surface ratio” (longitudinal CSR) is the contact surface ratio of the longitudinal grooves. This is the total area contained within a contact patch (A_c) minus the total projected void area of the longitudinal grooves (A_{long}) as located along the outer, ground-engaging side of the tire tread, which extends annularly around the tire and laterally along the rolling width of the outer, ground-engaging side divided by the total area of the contact patch (A_c) that which includes the total projected void area of the longitudinal grooves (A_{long}). Both areas are measured in mm^2 . This relationship can be expressed in terms of the following equation: Longitudinal CSR = $(A_c - A_{long}) / A_c$, where the equation yields a dimensionless number.

[0034] The “maximum tan delta” dynamic properties for the elastomeric compositions were measured at 23° C. on a Metravib Model VA400 ViscoAnalyzer Test System in accordance with ASTM D5992-96. The response of a sample of vulcanized material (double shear

geometry with each of the two 10 mm diameter cylindrical samples being 2 mm thick) was recorded as it was being subjected to an alternating single sinusoidal shearing stress at a frequency of 10 Hz under a controlled temperature of 23° C. Scanning was effected at an amplitude of deformation of 0.05 to 50% (outward cycle) and then of 50% to 0.05% (return cycle). The maximum value of the tangent of the loss angle $\tan \delta$ (max $\tan \delta$) was determined during the return cycle.

[0035] Dynamic properties “Tg” and “G*” for the elastomeric compositions were measured on a Metravib Model VA400 ViscoAnalyzer Test System in accordance with ASTM D5992-96. The response of a sample of vulcanized material (double shear geometry with each of the two 10 mm diameter cylindrical samples being 2 mm thick) was recorded as it was being subjected to an alternating single sinusoidal shearing stress of a constant 0.7 MPa and at a frequency of 10 Hz over a temperature sweep from – 60° C to 100° C. with the temperature increasing at a rate of 1.5° C/min. The dynamic shear modulus G* at 60° C. was captured and the temperature at which the max $\tan \delta$ occurred was recorded as the glass transition temperature, Tg.

[0036] Use is made of an oscillating consistometer as described in Standard ASTM D1646 (1999). The “Mooney plasticity” or “Mooney viscosity” measurement is carried out according to the following principle: the sample, analyzed in the uncured state (i.e., before curing) is molded in a cylindrical chamber heated to a given temperature (for example 100° C). After preheating for one minute, the rotor rotates within the test specimen at 2 revolutions/minute and the working torque for maintaining this movement is measured after rotating for 4 minutes. Mooney viscosity (ML 1+4) is expressed in “Mooney unit” (MU, with 1 MU=0.83 newton-meter N-m). For greater readability, the results will be shown in base 100, the value 100 being assigned to the control. A result of less than 100 will indicate a decrease in the value concerned and, conversely, a result of greater than 100 will indicate an increase in the value concerned.

[0037] To measure the “cornering stiffness,” each tire is run at a constant speed of 80 km/h on an appropriate automatic machine (machine of the “flat track” rolling road type marketed by the company MTS), by varying the load denoted “Z”, which is a vertical or radial load. under a drift angle of 1 degree, and the drift thrust was measured continuously to identify the drift thrust or cornering stiffness denoted “D” (corrected for the drift thrust at zero drift

angle), by using sensors to record the transverse load on the wheel as a function of this load “Z”; this then gives the drift thrust or cornering stiffness.

[0038] With reference to FIG. 1, a pneumatic tire **10** is shown to generally comprise a pair of annular bead areas **12** spaced apart axially (that is, in axial direction A_d) along a rotational axis **A** of the tire **10**, a pair of sidewalls **14** spaced apart axially along the rotational axis **A** of the tire **10**, and a crown portion **16** arranged widthwise between the pair of sidewalls **14** and extending annularly around the tire **10**. Each sidewall **14** extends outwardly in a radial direction R_d from one bead area **12** of the pair of bead areas **12** relative to the rotational axis **A**. In extending widthwise between the pair of sidewalls **14**, it is a width W_{16} of the crown portion **16** extending between the sidewalls. Rolling width W_{RW} of the tread **20** and outer, ground-engaging side **22** is also shown. Shoulder area is generally designated as **18**, and includes shoulder ribs 32_{S1} , 32_{S2} .

[0039] With continued reference to FIG. 1, the crown portion **16** includes a tread **20** arranged annularly around the crown portion **16** and forming an outer, ground-engaging side **22** upon which the tire **10** is intended to roll upon. The tread **20** has a thickness t_{20} extending in a direction perpendicular to the outer, ground-engaging side **22** and in a direction toward the rotational axis **A** of the tire. Tread thickness t_{20} extends from the outer, ground-engaging side **22** to a skid depth SD_{20} of the tread to define a thickness of the tread intended to be worn during the lifetime of the tire (that is, a wearing depth or thickness of the tire tread). The skid depth SD_{20} is commonly, but not necessarily, arranged at a depth corresponding to the bottom **26** of the deepest longitudinal groove **24**. While not necessary, it is commonly the case, such as is shown, where the bottom **26** of all circumferential (longitudinal) grooves **24** is arranged at the skid depth SD_{20} . In such instances, while each circumferential (longitudinal) groove depth D_{24} may or may not be of the same depth D_{24} , in the exemplary embodiment shown, all circumferential grooves **24** are of equal depth D_{24} and extend to and terminate at the skid depth SD_{20} . In certain instances, the average depth D_{24} for all circumferential grooves **24** is 8.5 mm. This average is calculated over the full circumference of the tire **10**. In particular instances, the skid depth SD_{20} is measured at a widthwise (axial) centerline CL_A of the tread **10**, the centerline CL_A extending along an equatorial plane P_{CL} , where at this location the skid depth SD_{20} is 8.5 mm, but may remain the same or vary across the width of the tread. For example, in the FIG. 1 the skid depth SD_{20} remains generally constant until reaching each shoulder **18**, while in FIGS. 4 and 5 the skid depth SD_{20} gradually decreases as the tread extends laterally along its width.

[0040] It is noted that the tread thickness t_{20} may generally extend radially inward deeper to the tread beyond the skid depth SD_{20} , such as is generally shown in FIG. 1. Tread 20 defines a wearing layer configured and intended to engage a ground surface by way of the outer, ground-engaging side 22 throughout the intended worn life of the tread 20, and may be formed of a single elastomeric material formulation or may comprise a plurality of sub layers formed of different elastomeric material formulations. With reference now to FIG. 4, an optional inner layer 21 is arranged below tread 20, where tread 20 extends to the skid depth SD_{20} and optionally beyond radially inward. Inner layer 21 is arranged radially inward (in direction R_a) of the skid depth SD_{20} (starting at or below skid depth SD_{20}) and is configured and intended to be a non-wearing layer of the tire, such that it is not intended to form a portion of the outer, ground-engaging side 22 during the intended worn life of the tread 20. Inner layer 21 is arranged radially outward (in direction R_a) from belt plies 40 and cap ply 50. Inner layer 21 does not include any elongate reinforcements. In particular embodiments, inner layer 21 may form 15% to 35% of the total volume of elastomeric material forming tread 20. In particular instances, inner layer 21 may have a thickness t_{21} as thin as 1 to 2 mm, and which may be greater as desired up to SD_{20} . In certain embodiments, the inner layer thickness t_{21} may extend up to 4 mm or otherwise to maximize the volume between the skid depth SD_{20} and the radially outermost reinforced ply, such as any cap ply 50 or belt ply 40, to achieve the desired improvements in rolling resistance. Accordingly, other inner layer thicknesses may be employed in other variations. Inner layer 21 does not form any gum layer or adhesive that may be used to attach a tread to a tire, but rather forms a sub layer to tread 20 having a volume as desired to achieve the material properties desirous to form a tire that achieves the intended tire performance parameters (rolling resistance performance). It is appreciated that inner layer 21 may be formed separate from tread 20 or may be formed therewith, such as when coextruding both tread 20 and inner layer 21 together. In other variations, inner layer 21 is not present, where the tread may partially or full fill the volume otherwise consumed by the inner layer 21.

[0041] The purpose of inner layer 21 is to provide elastomeric material characterized as having a hysteresis (P60) lower than the elastomeric material forming tread 20, which assists in reducing rolling resistance and controlling tire operating temperatures (so that the tires run cooler). In particular embodiments, the inner layer 21 is characterized as having a dynamic shear modulus (G^*) ranging from 58% to 68% of the dynamic shear modulus (G^*) of the tread 20, a modulus of elongation (MA10) ranging from 40% to 60% or substantially 50% of

the modulus of elongation (MA10) of the tread **20**, and for a maximum tan delta from 60% to 75% of the maximum tan delta of the tread **20**.

[0042] Because it is often desired to maximize traction by way of the tread through the selection of elastomeric material, tire treads are commonly formed of elastomeric material formulated for elevated traction (grip) performance. Such traction formulations, however, increase rolling resistance and thereby reduce rolling resistance performance. By substituting at least a portion of the tread thickness t_{20} below the skid depth SD_{20} otherwise formulated for elevated traction with elastomeric material having low hysteresis by way of the inner layer **21**, an overall reduction in rolling resistance is achieved without sacrificing traction, since higher traction tread **20** remains. Therefore, while prior art treads may employ a single layer of elastomeric material, the tread herein includes an inner layer **21** having improved hysteretic properties (lower) relative to the elastomeric material(s) forming the skid depth SD_{20} of the tread **20**. As a result, use of lower hysteretic the inner layer **21** provides improved rolling resistance performance while maintaining traction benefits associated with tread **20**.

[0043] With reference to FIGS. 1 and 2, the tire tread **20** includes a plurality of features extending a depth within the tread thickness that include longitudinal (circumferential) grooves **24**, lateral grooves **28**, and lateral sipes **30**. These features are arranged along the outer, ground-engaging side **22**, although any such feature may be submerged below the outer, ground-engaging side **22** to be later exposed after a particular depth of the tread **20** has been worn away. In the embodiment shown, the longitudinal grooves **24** are arranged to form a plurality of ribs **32**, each rib extending annularly around the tread such that adjacent ribs are separated by one of the longitudinal grooves **24**. The plurality of ribs include a first shoulder rib 32_{S1} , a second shoulder rib 32_{S2} , and a plurality of central ribs 32_C . Each of the first and second shoulder ribs 32_{S1} , 32_{S2} are arranged along one of opposing widthwise extents of the outer, ground-engaging side **22**, where the plurality of central ribs 32_C are arranged axially (laterally) between the first and second shoulder ribs 32_{S1} , 32_{S2} . Generally, in combination with the different embodiments contemplated herein, each of the ribs 32_{S1} , 32_{S2} , 32_C may be characterized as having any desired width, where the rib widths W_{32} may be the same or different between the ribs 32_{S1} , 32_{S2} , 32_C . In particular instances, each of the first and second shoulder ribs have a width W_{32} equal to 24% to 29% of the tread width. Further, in certain instances, the width W_{32} of each first and second shoulder rib 32_{S1} , 32_{S2} has a width W_{32} equal to 150% to 170% of an average width of the central ribs 32_C , 32_{S2} . The width W_{32}

of each shoulder rib is measured from the adjacent, widthwise extent of the rolling width W_{RW} of the tire as described herein. While the average width W_{32} of each central rib 32_C may be different than any one or more of the other central ribs 32_C , in particular instances the average width W_{32} of each central rib is substantially the same. It is appreciated that while any number of ribs may be employed, in certain embodiments the tread has 5 ribs (shown) or 6 ribs (not shown). In the embodiment shown, the tire tread features form an asymmetrical, non-directional tire tread pattern design, where non-directional means that the tire may be mounted in to rotate in either of opposing circumferential directions. It is appreciated, however, that a directional tread pattern design may also be employed.

[0044] With continued reference to FIG. 1, it is also noted that longitudinal grooves 24 each has a width W_{24} defined by a pair of opposing groove sidewalls 27 . It is appreciated that each of the longitudinal grooves 24 may have the same or different widths W_{24} , and in particular embodiments the longitudinal groove widths W_{24} are selected to provide the longitudinal contact surface ratios discussed elsewhere herein. While each groove sidewall 27 may extend into the tread thickness t_{20} at any angle α relative to a direction perpendicular to the outer, ground-engaging side 22 , in particular exemplary instances each groove sidewall 27 extends at an angle α measuring 2° to 12° relative to a direction perpendicular to the outer, ground-engaging side 22 . As noted previously, each longitudinal groove 24 has a depth D_{24} extending into the tread thickness to a bottom 26 , where all of the longitudinal grooves may be of the same or different depth D_{24} . With reference to FIG. 2, it is noted as well that tread 20 includes lateral grooves 28 and lateral sipes 30 , all of which together are referred to as lateral features. While the depths of the lateral grooves 28 and lateral sipes 30 may vary, in particular embodiments, the lateral grooves 28 and lateral sipes 30 extend substantially the full skid depth SD_{20} of the tread 20 .

[0045] With reference to FIG. 4, it is noted that at each widthwise extent of the radially outermost belt layer 40_2 , as defined by the center of the laterally outermost reinforcement 44_E at its most laterally outward location, the tread thickness t_{20} extends a radial distance d (droop or drop) from a horizontal line L_H to a bottom of the skid depth at the corresponding widthwise extent of the outermost belt layer 40_2 , the radial distance (droop) d equals substantially 65% of the total skid depth SD_{20} measured in the radial direction R_d at the same lateral location. In other instances, the droop d is less than 78% or ranges from 50% to 80% of the skid depth at that laterally outward location of the tire. Horizontal line L_H extends axially outward (in direction of A_d) from the skid depth SD_{20} at equatorial plane P_{CL} .

[0046] With reference now to FIG. 5, in particular embodiments, the taper of the droop **d** in any instance contemplated above, as defined by the equation $d_x = d_D(L_x/L_D)^P$, is characterized as having a taper power **P** that is less than 3 or, in other variations, ranges from 2 to 2.7. In the prior art tires described herein, the droop is 78% or greater and has a taper characterized by the prior equation having a taper power **P** equal to or greater than 3.

[0047] It is noted that at each widthwise extent of the radially outermost belt ply **40₂**, as defined by the center of the laterally outermost reinforcement **44** at its most laterally outward location, the tread thickness **t₂₀** or skid depth **SD₂₀** extending in a direction perpendicular to the outer, ground-engaging side **22** is greater than 61%, or in other variations, 68% to 70% of the skid depth **SD₂₀** at the equatorial plane **P_{CL}**. It is also noted that at each widthwise extent of the rolling width **W_{RW}**, the tread thickness extending in a direction perpendicular to the outer, ground-engaging side **22** is greater than 52% or, in other variations, 62% to 64% of the skid depth **SD₂₀** at the equatorial plane **P_{CL}**. In certain instances, the tread depth **t₂₀** or skid depth **SD₂₀** at a shoulder as described above is 3.1 mm to 8.2 mm.

[0048] With reference to FIG. 3 regarding the total thickness **t₁₀** of the tire at each widthwise extent of the rolling width **W_{RW}**, the total thickness **t₁₀** of the tire extending from an interior side **S_{10i}** to the outer, ground-engaging side **22** in a direction perpendicular to the outer, ground-engaging side **22** is less than 480% of the skid depth **SD₂₀** at the equatorial plane **P_{CL}**, or in other variations 400% to 450% or substantially 425% of the skid depth **SD₂₀** at the equatorial plane **P_{CL}**.

[0049] In any embodiment contemplated herein, the tread **20** is formed of elastomeric material, such as any natural or synthetic rubber, or any blend thereof. In particular instances, the tread is substantially formed of an elastomeric material to provide elevated traction (grip) and which is characterized as having a glass transition temperature (T_g) of -25 °C to -10 °C, a maximum tan delta of 0.4 to 0.6, a dynamic shear modulus (G*) of 1.0 to 1.4 MPa, a Mooney viscosity of 80 to 120, and a modulus of elongation (MA10) of 5.75 to 9.5. An elastomeric material so characterized may be formed using any of a variety of formulations. In particular instances, the so characterized elastomeric material is a mixture including an elastomer, a filler, and a plasticizer. In this formulation, the elastomer ranges from an SBR/BR blend containing at least 70% SBR to 100% SBR, or in other variations a 70/30 or 85/15 blend of SBR and BR, respectively. "SBR" means styrene-butadiene rubber while "BR" means butadiene rubber. SBR is a functionalized elastomer. The filler in this formation comprises silica and carbon black, silica forming 23.5% to 25.9% and the carbon

black forming 1% of the total elastomeric material mixture. The plasticizer in this formation forms 25% to 30% of the total elastomeric material mixture and comprising high Tg resin that forms 12% to 23% of the total elastomeric material mixture and highly oleic sunflower oil that forms the balance of the plasticizer (2% to 18%). It is appreciated that other formations may be employed to achieve the desired characteristics and properties.

[0050] The elastomers useful for forming the elastomeric material compositions disclosed herein, such as for the tread **20**, may have any microstructure, such microstructure being a function of the polymerization conditions used, in particular of the presence or absence of a modifying and/or randomizing agent and the quantities of modifying and/or randomizing agent used. The elastomers may, for example, be block, random, sequential or micro-sequential elastomers, and may be prepared in dispersion or in solution; they may be coupled and/or starred or alternatively functionalized with a coupling and/or starring or functionalizing agent.

[0051] Functionalized rubbers, *i.e.*, those appended with active moieties, are well known in the industry. The backbone or the branch ends of the elastomers may be functionalized by attaching these active moieties to the ends of the chains or to the backbone or mid-chains of the polymer. Exemplary functionalizing agents that could be included with the diene elastomers include, but are not limited to, metal halides, metalloid halides, alkoxysilanes, imine-containing compounds, esters, ester-carboxylate metal complexes, alkyl ester carboxylate metal complexes, aldehydes or ketones, amides, isocyanates, isothiocyanates and imines – all of these being well-known in the art. Particular embodiments may include functionalized diene elastomers while other embodiments may be limited to including no functionalized elastomers.

[0052] Particular embodiments include at least 80 phr of a functionalized elastomer or alternatively at least 90 phr or 100 phr of a functionalized elastomer wherein the functional moiety interacts with the silica filler. Examples known in the art include silanol functional groups or polysiloxane functional groups having a silanol end (such as described, for example, in FR 2 740 778 or U.S. Pat. No. 6,013,718), alkoxysilane groups (such as described, for example, in FR 2 765 882 or U.S. Pat. No. 5,977,238), carboxyl groups (such as described, for example, in WO 01/92402 or U.S. Pat. No. 6,815,473, WO 2004/096865 or US 2006/0089445) or else polyether groups (such as described, for example, in EP 1 127 909

or U.S. Pat. No. 6,503,973), wherein each of these mentioned documents are hereby incorporated herein by reference.

[0053] Particular embodiments of the rubber compositions disclosed herein are limited to those having at least 80 phr of the rubber components being highly unsaturated diene elastomers. Other embodiments are limited to having at least 90 phr or 100 phr of the highly unsaturated diene elastomer components.

[0054] Examples of suitable highly unsaturated diene elastomers include, but are not necessarily limited to natural rubber (NR) and synthetic rubbers such as polybutadienes (BR), polyisoprenes (IR), butadiene copolymers, isoprene copolymers and mixtures of these elastomers. Such copolymers include butadiene/styrene copolymers (SBR), isoprene/butadiene copolymers (BIR), isoprene/styrene copolymers (SIR) and isoprene/butadiene/styrene terpolymers (SBIR). Any of these examples or mixtures of these examples are suitable for particular embodiments of the rubber compositions disclosed herein.

[0055] In particular embodiments, useful SBR elastomers may have a bound styrene content of between 1 mol% and 45 mol% or alternatively between 15 mol% and 40 mol% or between 20 mol% and 30 mol%. Particular embodiments of the rubber compositions disclosed herein include an SBR that is functionalized with a moiety that interacts with the silica filler.

[0056] With reference to FIG. 3, the crown portion **16** further includes one or more belt plies **40** (generally, but more specifically as first and second belt plies **40₁**, **40₂**) each forming a layer of elastomeric material **42** reinforced with a plurality of elongate reinforcements **44** spaced apart in an array, the one or more belt plies being arranged radially inward and below the tread. Together, the one or more belt plies form a “belt,” the belt also being referred to as a “belt structure” and forming an annular structure formed by all of the one or more belt plies **40**). Each elongate reinforcement **44** may be formed of metal or non-metal elongate reinforcements, where the elongate reinforcements **44** are formed of a plurality of filaments arranged lengthwise and twisted along their lengths as desired. Metal elongate reinforcements are constructed from filaments most commonly formed of steel, but may be formed any metal having desirous properties. Non-metal reinforcements are constructed from filaments formed of any fabric or textile, such as polyester, rayon, nylon, aramid, silk, and/or fiberglass. In the exemplary embodiment shown, the tire **10** includes a pair of belt plies **40** to form an annular belt structure, although any single belt ply **40** or three or more

belt plies **40** may be employed to achieve the desired properties of the annular belt structure formed by any one or more belt plies **40**.

[0057] In particular embodiments, the overall mass of each belt layer **40** is reduced in comparison to those used previously in prior art passenger tires, which thereby reduces the rolling resistance to generating an overall improvement in rolling resistance performance for tire **10**. Additionally, or in the alternative, a lower hysteretic elastomeric material **44** may be employed, which also assists in reducing rolling resistance. Each of these may also reduce the operating temperature of the tire. For example, in particular embodiments, each of the elongate reinforcements **44** form a 0.60 mm thick steel cable. The cable is formed of two (2) twisted 0.3 mm diameter steel filaments. Each such elongate reinforcement **44** is characterized as having a 470 N rupture force, where in other variations when using other elongate reinforcements may range from 420 to 520 N. The elongate reinforcements **44** are arranged to extend lengthwise greater than 24 degrees and up to 32 degrees relative to the longitudinal direction **LONG_a**, and in other instances 26 degrees to 30 degrees, or substantially 28 degrees relative to the longitudinal direction **LONG_a**. To the contrary, belt plies used for prior high performance passenger tires employed elongate reinforcements forming a steel cable formed of four (4) twisted 0.3 mm diameter steel filaments, each of which were arranged to extend lengthwise 24 degrees relative to the longitudinal direction. The plurality of elongate reinforcements **44** in each of the one or more belt plies **40** are spaced apart centerline-to-centerline by substantially 1 mm with the elastomeric material **42** of each of the one or more belt plies, which defines the pace of the elongate reinforcements **44**. The elastomeric material **42** has a thickness of 1.08 mm, and is characterized as having a modulus of elongation of less than 10.5 and loss due to hysteresis (P60) at 60 degrees of less than 26.5 as measured as a result of conducting a P8 pendulum test. Together with the elastomeric material **42**, which settles in between the spaced-apart elongate reinforcements **44**, each belt ply **40** before application to the tire in an uncured state has a thickness of 1.22 mm (where belt ply used for prior high performance passenger tire was 1.42 mm thick). In sum, the mass of each belt ply **40** is reduced 5.5% (reduced from 2.531 kg/mm² to 2.394 kg/mm²) relative to belt plies previously used in related passenger (high performance) tires. Even though more elongate reinforcements **44** are included within any give size belt ply **40** due to the reduced pace, the additional elongate reinforcements do not offset the mass reduction achieved by reducing the elongate reinforcement diameter (which also permits a reduction in elastomeric material **42**). As noted previously, a reduced hysteretic elastomeric

material **42** may be employed, which in certain exemplary instances is characterized as having a hysteresis (P60) of less than 26.5, 23.5 or less, 17.5 to 23.5, or of substantially 20.5. In particular embodiments, elastomeric material **42** is characterized as having a hysteresis (P60) of substantially 20.5 and a modulus of elongation (MA10) substantially 6 MPa, which is contrasted with elastomeric material used in belt plies of prior high performance passenger tires was characterized as having a hysteresis (P60) of substantially 26.5 and a modulus of elongation (MA10) substantially 10.5 MPa.

[0058] With continued reference to FIG. **3**, the crown portion **16** further includes a cap ply **50** arranged radially outward from the one or more belt plies **40** and from the annular belt structure formed by all belt plies contained within the tire. The cap ply **50** is provided to increase rigidity of crown portion **16** to counteract the effects of centrifugal forces generated during high speeds. The provision of the cap layer **50** described herein may be provided as a substitute to other cap layers previously employed by other tires or added to tires not previously incorporating a cap layer to control the expansion of the belt” (that is, all of the one or more belt plies **40**), as may be required to attain certain vehicle speeds. For example, in particular instances, the cap ply **50** is employed together with other features of the tire described herein to provide a tire rated for vehicle speeds upwards of 186 miles per hour (mph) (a Y speed rating) or greater. The cap ply **50** is arranged between the tread **20** and the one or more belt plies **40** (the belt). The cap ply **50** extends substantially across a full width of at least one of the belt plies **40**. In doing so, the cap ply **50** is arranged within each shoulder **18** or shoulder rib **32_{S1}**, **32_{S2}**. In other variations, the cap ply **50** may extend partially across the width of the belt, whether in width or if including spaces or gaps within the cap ply or cap layer, as may be suitable to achieve any intended high speed performance measures.

[0059] The cap ply **50** is formed of a layer of elastomeric material **52** reinforced with a plurality of elongate reinforcements **54** spaced apart in an array. The elongate reinforcements **54** are arranged to extend lengthwise substantially in a circumferential direction **C_d** of the tire, that is, in a direction substantially parallel to a plane **P_{CL}** bisecting the tire at its equatorial centerline **CL_A** and extending perpendicular to rotational axis **A**. “Substantially parallel” means that any such elongate reinforcement **54** extends by an angle of 0 to 5 degrees in absolute value (that is, spanning -5 degrees to 5 degrees) relative to the longitudinal direction **LONG_d** or plane **P_{CL}**.

[0060] Cap ply **50** may be applied in any desired manner. For example, in certain exemplary instances, cap ply **50** is formed using one or more sheets wound once around the tire, the sheets including the elastomeric material **52** and elongate reinforcements **54**, while in other exemplary instances the cap ply **50** is formed using one or more strips wound multiple revolutions around the tire in a helical configuration, the strips including the elastomeric material **52** and elongate reinforcements **54**. In winding into a helical configuration, each wind of the strip is arranged to abut the adjacent wind of strip, or, in other variations, may be spaced apart from or overlap an adjacent wind by as much as a 50% (providing a spacing or overlap, where, for example, a 50% overlap forms $\frac{1}{2}$ pace between winds of the strip). It is appreciated that one or more cap plies **50** may be employed. At each widthwise end of the belt, before beginning the helical wind at one end and after reaching the other end after making the plurality of helical winds, a full revolution of the cap strip is made. In doing so, the cap ply extends 4 mm to 14 mm beyond the belt, that is, beyond the widest of the one or more belt plies **40** at each widthwise extent of the belt.

[0061] Each elongate reinforcement **54** may be formed of metal or non-metal elongate reinforcements, where elongate reinforcements are formed of a plurality of filaments arranged lengthwise and twisted along their lengths as desired. Metal elongate reinforcements are constructed from filaments most commonly formed of steel, but may be formed any metal having desirous properties. Non-metal reinforcements are constructed from filaments formed of any fabric or textile, such as polyester, rayon, nylon, aramid, silk, and/or fiberglass. In certain exemplary instances, the cap ply is characterized as having a rupture force greater than 3150 N per 15 mm of cap ply width, while in other instances the cap ply is characterized as having a rupture force ranging from 4650 N to 6150 N per 15 mm of cap ply width or substantially 5400 N per 15 mm of cap ply width. In any such embodiment, the cap ply may also be characterized as having a 4% elongation per 15 mm of cap ply width with application of a 100 N tensile force, and as having a 5.5% elongation per 15 mm of cap ply width with application of a 200 N tensile force. In particular embodiments, with reference to FIG. 3, for example, cap ply **50** is formed using a strip, such as a 15 mm wide strip, wound in a helical configuration fully across and beyond a full width of each of the pair of belt plies **40**, where each wind of the strip abuts an adjacent wind of the strip and extends by a distance $\Delta 50$ of less than 15 mm beyond the full width of the widest belt ply **40** or of the annular belt structure at each widthwise extent in certain exemplary instances.

[0062] An exemplary elongate reinforcement **54** that may be employed within any such contemplated cap ply **50**, including any cap sheet or cap strip used to form such ply, is characterized as having a rupture force ranging from 310 N to 410 N. In more specific instances, each elongate reinforcement **54** is characterized as having a rupture force substantially equal to 360 N, where such elongate reinforcements **54** arranged in an array having a 1 mm pace, where pace is the centerline-to-centerline spacing between adjacent elongate reinforcements **54**. When using fifteen (15) elongate reinforcements **54** characterized as having a rupture force substantially equal to 360 N to form a 15 mm wide cap strip with a pace of 1 mm, the rupture force of the 15 mm wide strip is 5400 N and is characterized as having an elongation of 4% as measured at 100 N force and as having an elongation of 5.5% as measured at 200 N force. While other elastomeric material may be employed, in certain instances elastomeric material used to form any cap ply **50** or cap strip contemplated above may be characterized as follows in Table 1:

Table 1:

<u>Property</u>	<u>Desired Range</u>	<u>Embodiment A</u>
MA10	5.8 to 7.8 MPa	6.8 MPa
MA100	3.2 to 4.0 MPa	3.6 MPa
MA300	3.4 to 4.2 MPa	3.8 MPa
Hysteresis Loss, P60	18 to 23 %	20.5%

[0063] In any such embodiment, for any cap ply **50** or cap strip contemplated herein, each elongate reinforcement **54** is formed of a two (2) yarn twist, where an aramid 167 filament is twisted with a nylon 140 filament at a rate of 290 turns per meter. In such instances, the rupture force for each elongate reinforcement is 360 N.

[0064] For any belt or cap ply formed of elastomeric material having elongate reinforcements, the array of elongate reinforcements may be coated with the elastomeric material or skim (layers) of elastomeric may be applied to opposing sides of the array. It is appreciated, however, that any other manner may be employed for providing any such ply.

[0065] In a prior art tire, a full-width cap layer is applied to a pair of belt plies, the cap layer being formed of elongate reinforcements that are formed of nylon. These prior art elongate reinforcements are characterized as having a 210 N rupture force, and when arranged in a 15 mm wide cap ply strip having a pace of 1 mm, the strip has a rupture force of 3150 N. Also,

the cap ply is applied in a Z-configuration, where a cap ply strip is initially applied inward from an intended widthwise extent of the cap ply, the strip being wound outwardly to the nearest widthwise side, such as by two helical winds, for example, and then is wound helically in an abutting arrangement in a lateral direction across the tire to form a full width of the cap ply, and thereafter winding the strip back in towards away from the widthwise extent, such as by two helical winds, to complete the Z-configuration. As a result, the prior art cap layer is less rigid in both circumferential and in the axial directions. By employing a more rigid cap layer **50** as discussed herein, cap layer **50** overcomes the loss in rigidity provided by the more flexible and compliant tread **20** as achieved by the particular arrangement tread features. Specifically, the cap layer **50** described herein provides an increase in rigidity in the lateral (Y) direction, for improved D(Z) gain (in cornering stiffness) and for improved handling. The cap layer **50** described herein also provides an increase in rigidity in the longitudinal (X) direction, for improved wear and dry braking performance. In the prior art tire, the tire is characterized as having the droop and taper as articulated above and has the tire thickness at each widthwise extent previously articulated. It is also noted that the pair of prior art belt plies each employ elongate reinforcements each having a rupture force of 875 N and are arranged to extend lengthwise by 24 degrees relative to the longitudinal direction of the tire, where the prior art elongate reinforcements are steel cables formed of four (4) 0.30 mm diameter steel filaments twisted.

[0066] It is noted that tires formed according to this disclosure may achieve a Y speed rating, in accordance with DOT139 HSI testing method, such as any tire:

- a. having a cap ply arranged radially outward from the one or more belt plies and between the tread and the one or more belt plies, the cap ply extending substantially across a full width of at least one of the belt plies and being arranged at least partially within each shoulder, the cap ply forming a layer of elastomeric material reinforced with a plurality of elongate reinforcements spaced apart in an array, the cap ply being characterized as having a rupture force greater than 210 N per 15 mm of the cap ply width, or any other cap ply forming a variation thereof as described herein;
- b. where, at each widthwise extent of a radially outermost belt ply, as defined by the center of the laterally outermost reinforcement at its most laterally outward location, each widthwise extent being defined by the center of the laterally

- outermost reinforcement at its most laterally outward location, the tread thickness extends in a direction perpendicular to the outer, ground-engaging side a distance greater than 61% of the skid depth at the equatorial plane or in accordance with other variations thereof as described herein;
- c. where, at each widthwise extent of the rolling width, the tread thickness extends in a direction perpendicular to the outer, ground-engaging side a distance greater than 52% of the skid depth at the equatorial plane or in accordance with other variations thereof as described herein;
 - d. where, at each widthwise extent of the radially outermost belt layer, as defined by the center of the laterally outermost reinforcement at its most laterally outward location, the tread thickness extends a radial distance from a horizontal line, the horizontal line extending from the skid depth at the equatorial plane, the radial distance extending to a bottom of the skid depth and equaling 50% to 80% of the skid depth at the corresponding widthwise extent of the radially outermost belt layer or in accordance with other variations thereof as described herein; and,
 - e. where for a taper equation of $d_x = d_D(L_x/L_D)^P$, P is less than 3 or in accordance with other variations thereof as described herein.

[0067] When comparing such tires with the prior art tires described previously, in achieving a Y speed rating, an improvement in the high speed limit was observed when performing high speed testing, where tires are loaded on a test wheel and run continuously, where the speeds are increased incrementally every 10 minutes by 10 km/hr until the tire fails. When comparing the prior art tire to the tire described above using the high speed test, a high speed limit improvement between 15 km/hr (kilometer per hour) and 25 km/hr was achieved, which is an approximately 7% improvement. Additionally, these tires achieved a 20% improvement in wear over the prior art tires without sacrificing snow handling performance, which was observed a slight gain (a 0.75 SAE subjective point gain in accordance with SAE subjective testing standards). In sum, improved high speed performance is achievable using the unique combinations of features described herein, all while resulting in a thicker and less tapered tread in the shoulder areas, which typically reduces high speed performance. By virtue of providing a thicker tread in the shoulder areas, deeper grooves are achieved (represented by skid depth). Together, wear, hydroplaning, and snow performance is able to be improved. These results are surprising, and unexpected to one of ordinary skill.

[0068] To the extent used, the terms “comprising,” “including,” and “having,” or any variation thereof, as used in the claims and/or specification herein, shall be considered as indicating an open group that may include other elements not specified. The terms “a,” “an,” and the singular forms of words shall be taken to include the plural form of the same words, such that the terms mean that one or more of something is provided. The terms “at least one” and “one or more” are used interchangeably. The term “single” shall be used to indicate that one and only one of something is intended. Similarly, other specific integer values, such as “two,” are used when a specific number of things is intended. The terms “preferably,” “preferred,” “prefer,” “optionally,” “may,” and similar terms are used to indicate that an item, condition or step being referred to is an optional (i.e., not required) feature of the embodiments. Ranges that are described as being “between a and b” are inclusive of the values for “a” and “b” unless otherwise specified.

[0069] While various improvements have been described herein with reference to particular embodiments thereof, it shall be understood that such description is by way of illustration only and should not be construed as limiting the scope of any claimed invention. Accordingly, the scope and content of any claimed invention is to be defined only by the terms of the following claims, in the present form or as amended during prosecution or pursued in any continuation application. Furthermore, it is understood that the features of any specific embodiment discussed herein may be combined with one or more features of any one or more embodiments otherwise discussed or contemplated herein unless otherwise stated.

CLAIMS

What is claimed is:

1. A pneumatic tire comprising:

a pair of annular beads areas spaced apart axially along a rotational axis of the tire;

a pair of sidewalls spaced apart axially along the rotational axis of the tire, each sidewall of the pair of sidewalls extending outwardly in a radial direction from one bead area of the pair of bead areas relative to the rotational axis;

a crown portion arranged widthwise between the pair of sidewalls and extending annularly around the tire;

the crown portion including a tread arranged annularly around the crown portion and forming an outer, ground-engaging side upon which the tire is intended to roll upon, the tread having a thickness extending radially and a width extending axially, the tread forming a wearing portion the tire;

the crown portion further including one or more belt plies each forming a layer of elastomeric material reinforced with a plurality of elongate reinforcements spaced apart in an array;

the crown portion further including a pair of shoulders, each shoulder forming a portion of the crown arranged adjacent to each sidewall,

the crown portion further including a cap ply arranged radially outward from the one or more belt plies and between the tread and the one or more belt plies, the cap ply extending substantially across a full width of at least one of the belt plies and being arranged at least partially within each shoulder, the cap ply forming a layer of elastomeric material reinforced with a plurality of elongate reinforcements spaced apart in an array, the cap ply being characterized as having a rupture force greater than 210 N per 15 mm of the cap ply width; and,

the tread including a plurality of tread features including grooves extending a depth within the tread thickness;

the tread features extending into the tread thickness substantially to a depth defining a skid depth of the tread, the skid depth being the thickness of the tread intended to be worn during the intended life of the tire tread;

at each widthwise extent of the radially outermost belt ply, each widthwise extent defined by the center of the laterally outermost reinforcement at its most laterally

outward location, the tread thickness extending in a direction perpendicular to the outer, ground-engaging side is greater than 61% of the skid depth at the equatorial plane;

at each widthwise extent of the rolling width, the tread thickness extending in a direction perpendicular to the outer, ground-engaging side is greater than 52% of the skid depth at the equatorial plane;

at each widthwise extent of the radially outermost belt layer, as defined by the center of the laterally outermost reinforcement at its most laterally outward location, the tread thickness extends a radial distance from a horizontal line, the horizontal line extending from the skid depth at the equatorial plane, the radial distance extending to a bottom of the skid depth and equaling 50% to 80% of the skid depth at the corresponding widthwise extent of the radially outermost belt layer;

where for a taper equation of $d_x = d_D(L_x/L_D)^P$, P is less than 3.

2. The tire of claim 1, where at each widthwise extent of the rolling width, the total thickness of the tire extending from an interior side to the outer, ground-engaging side is less than 480% of the tread thickness as measured in a direction perpendicular to the outer, ground-engaging side.
3. The tire of any one of claims 1 to 2, where at each widthwise extent of the radially outermost belt ply, the tread thickness extending in a direction perpendicular to the outer, ground-engaging side ranges from 68% to 70% of the skid depth at the equatorial plane.
4. The tire of any one of claims 1 to 3, where at each widthwise extent of the rolling width, the tread thickness extending in a direction perpendicular to the outer, ground-engaging side ranges from 62% to 64% of the skid depth at the equatorial plane.
5. The tire of any one of claims 1 to 4, where for taper equation $d_x = d_D(L_x/L_D)^P$, P is 2 to 2.7.
6. The tire of any one of claims 1 to 5, where the tread is formed of an outer layer of elastomeric material characterized as having a glass transition temperature of -25 °C to -10 °C, a tan delta of 0.4 to 0.6, a dynamic shear modulus of 1.0 to 1.4 MPa, a Mooney viscosity of 80 to 120, and a modulus of elongation (MA10) of 5.75 to 9.5.
7. The tire of any one of claims 1 to 6, where the tread is formed of an outer layer of elastomeric material and an inner layer of elastomeric material, the inner layer arranged radially inward from the tread between the tread and the one or more belt

plies and cap ply, the inner layer being characterized as having a dynamic shear modulus equal to 58% to 68% of a dynamic shear modulus characterizing the tread, a modulus of elongation equal to 40% to 50% of the tread modulus of elongation, and a tan delta equal to 60% to 75% of the tread tan delta.

8. The tire of claim 7, where the outer layer of elastomeric material is characterized as having a glass transition temperature of -25 °C to -10 °C, a tan delta of 0.4 to 0.6, a dynamic shear modulus of 1.0 to 1.4 MPa, a Mooney viscosity of 80 to 120, and a modulus of elongation (MA10) of 5.75 to 9.5.
9. The tire of any one of claims 1 to 8, where each of the elongate reinforcements of the one or more belt plies form a 0.60 mm thick steel cable formed of two twisted steel cables each having a diameter of 0.3 mm and where the plurality of elongate reinforcements in each of the one or more belt plies are spaced apart centerline-to-centerline by substantially 1 mm and being characterized as having a modulus of elongation of less than 10.5 and loss due to hysteresis (P60) at 60 degrees of less than 26.5.
10. The tire of any one of claims 1 to 9, where the one or more belt plies forms a pair of belt plies.
11. The tire of any one of claims 1 to 10, where the rupture force is 310 to 410 N per 15 mm of width.
12. The tire of any one of claims 1 to 11, where the rupture force is 360 N per 15 mm of width.
13. The tire of any one of claims 1 to 12, where the cap ply extends helically across the width of at least one of the one or more belt plies in a substantially abutted configuration.
14. The tire of claim 13, where the cap ply is formed of a strip wound continuously around the tire in a helical configuration with a circumferential wind at each widthwise extent of the cap ply width.

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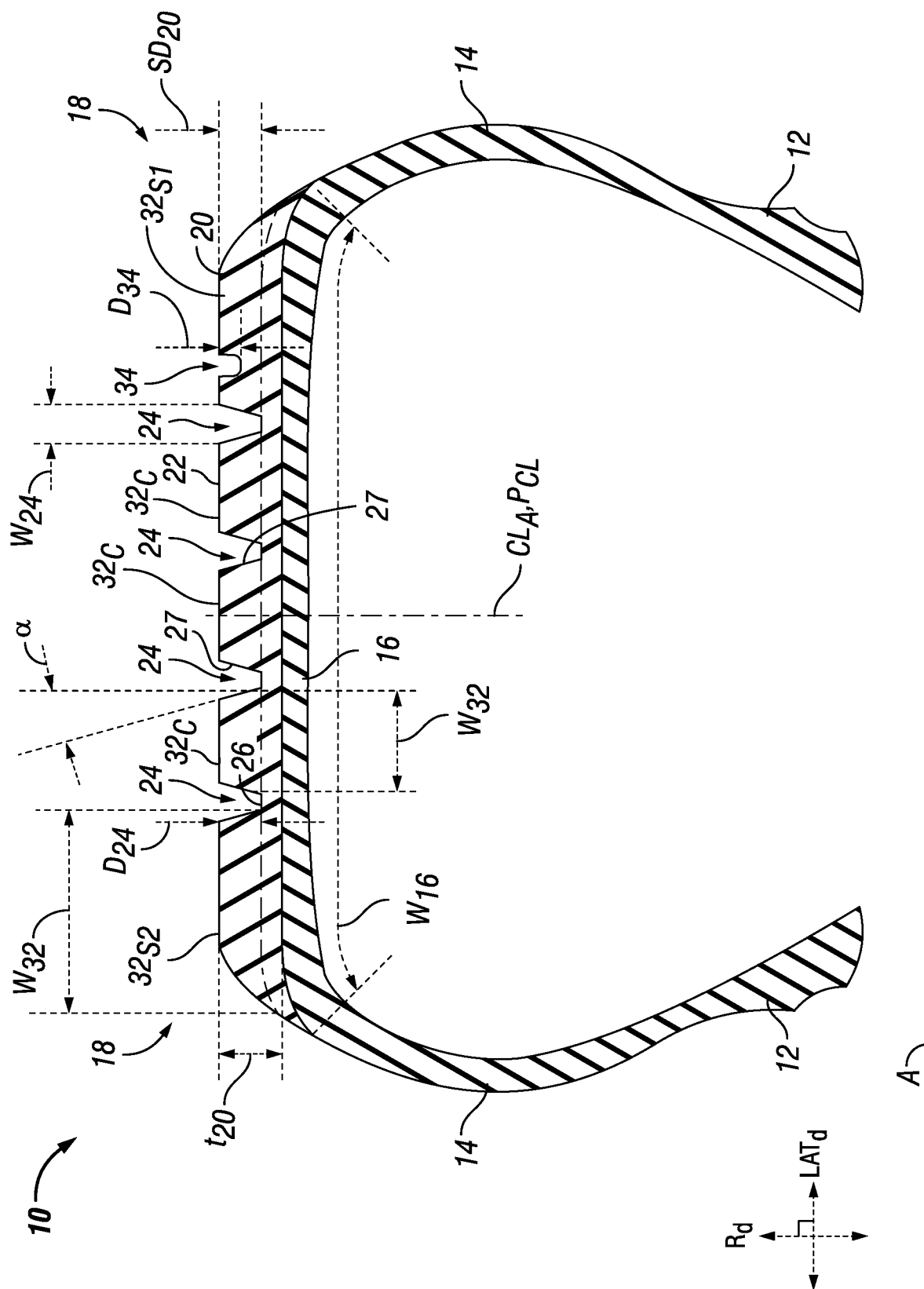


FIG. 1

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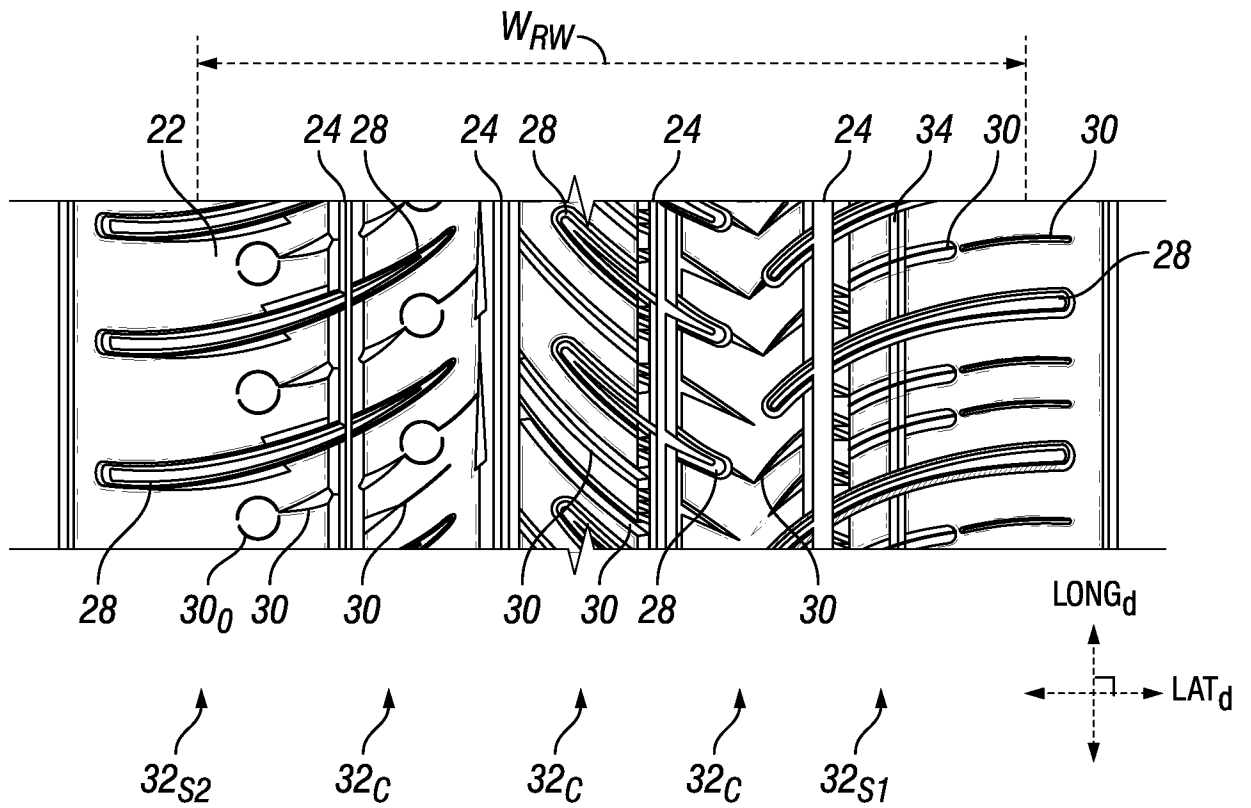


FIG. 2

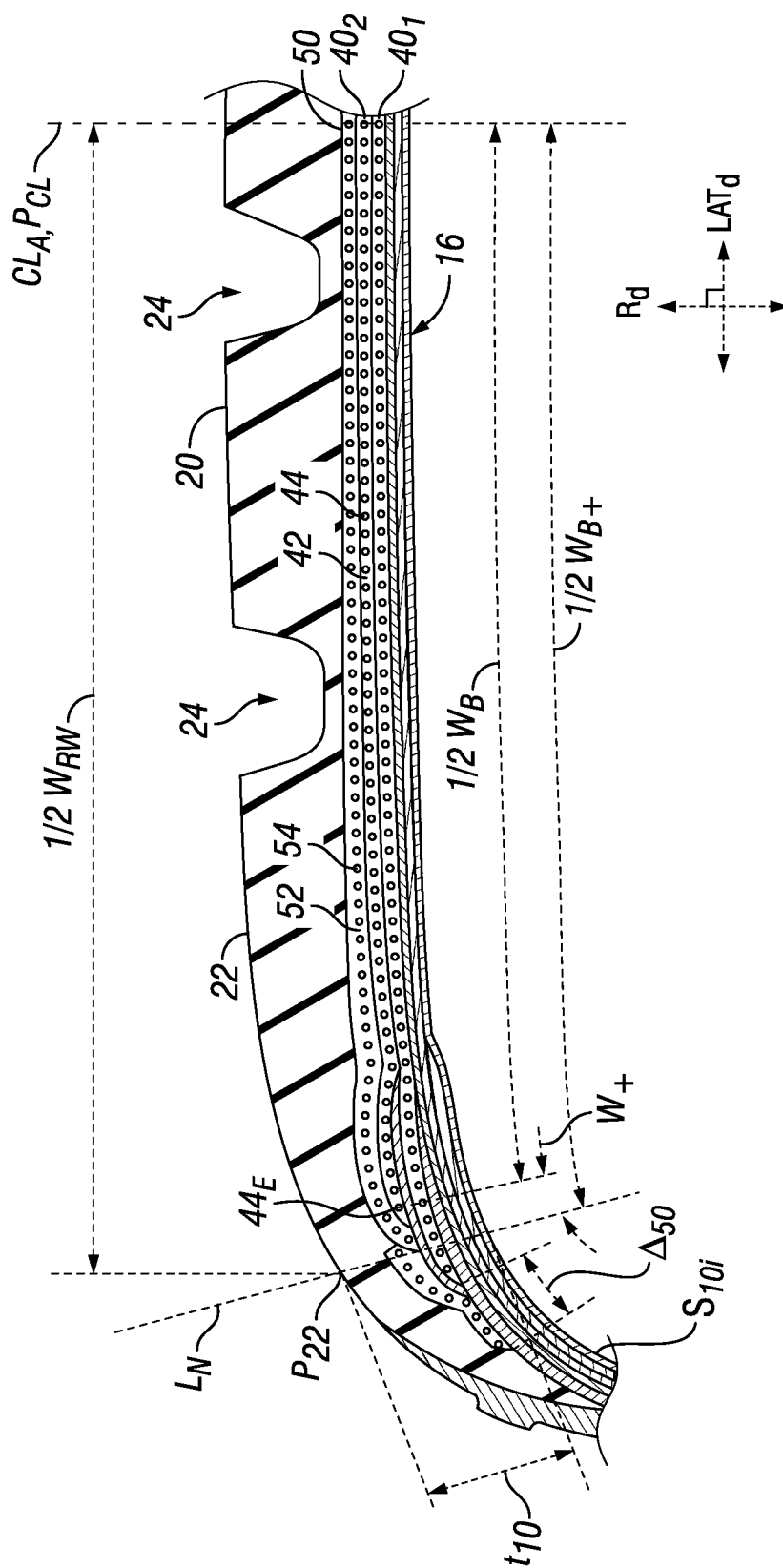


FIG. 3

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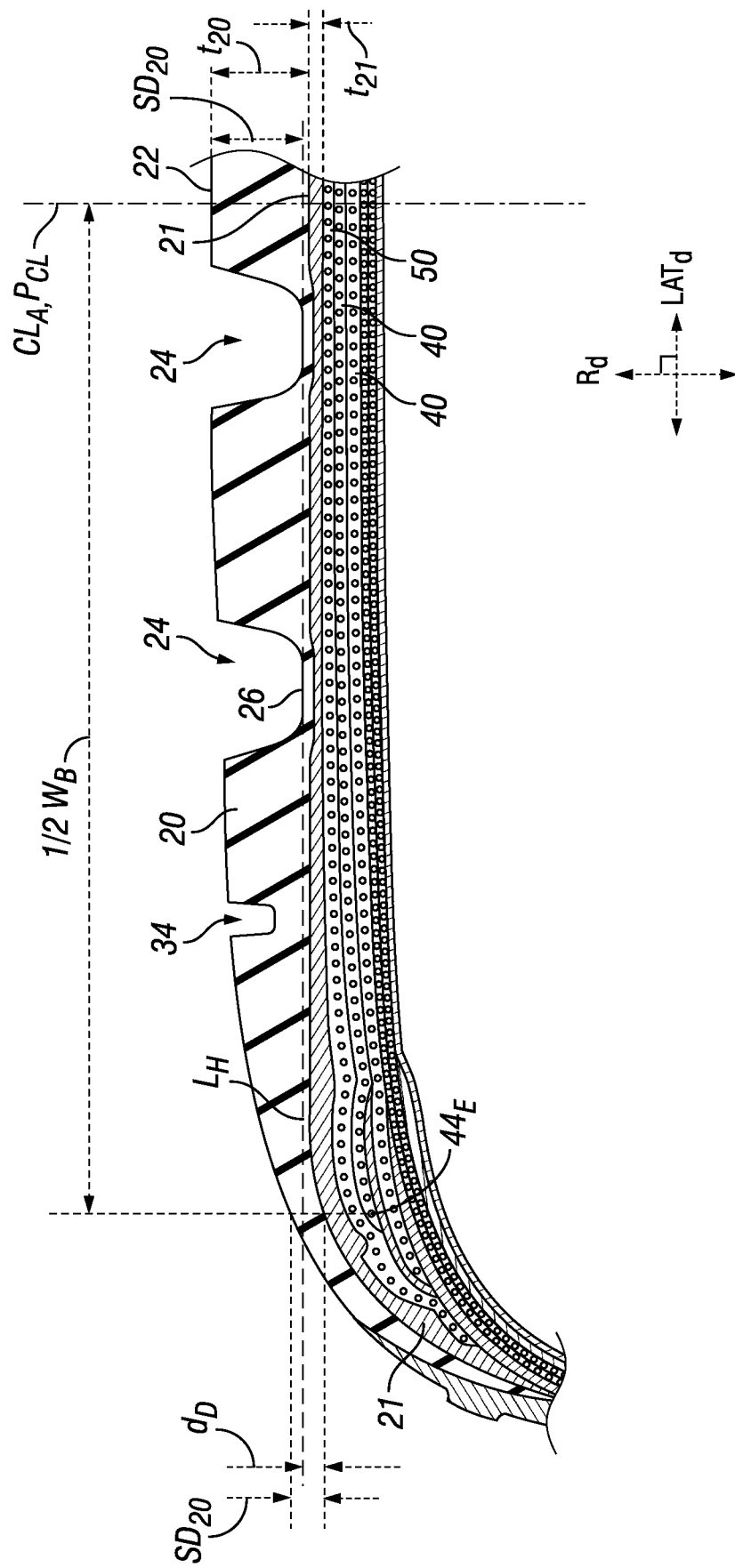


FIG. 4

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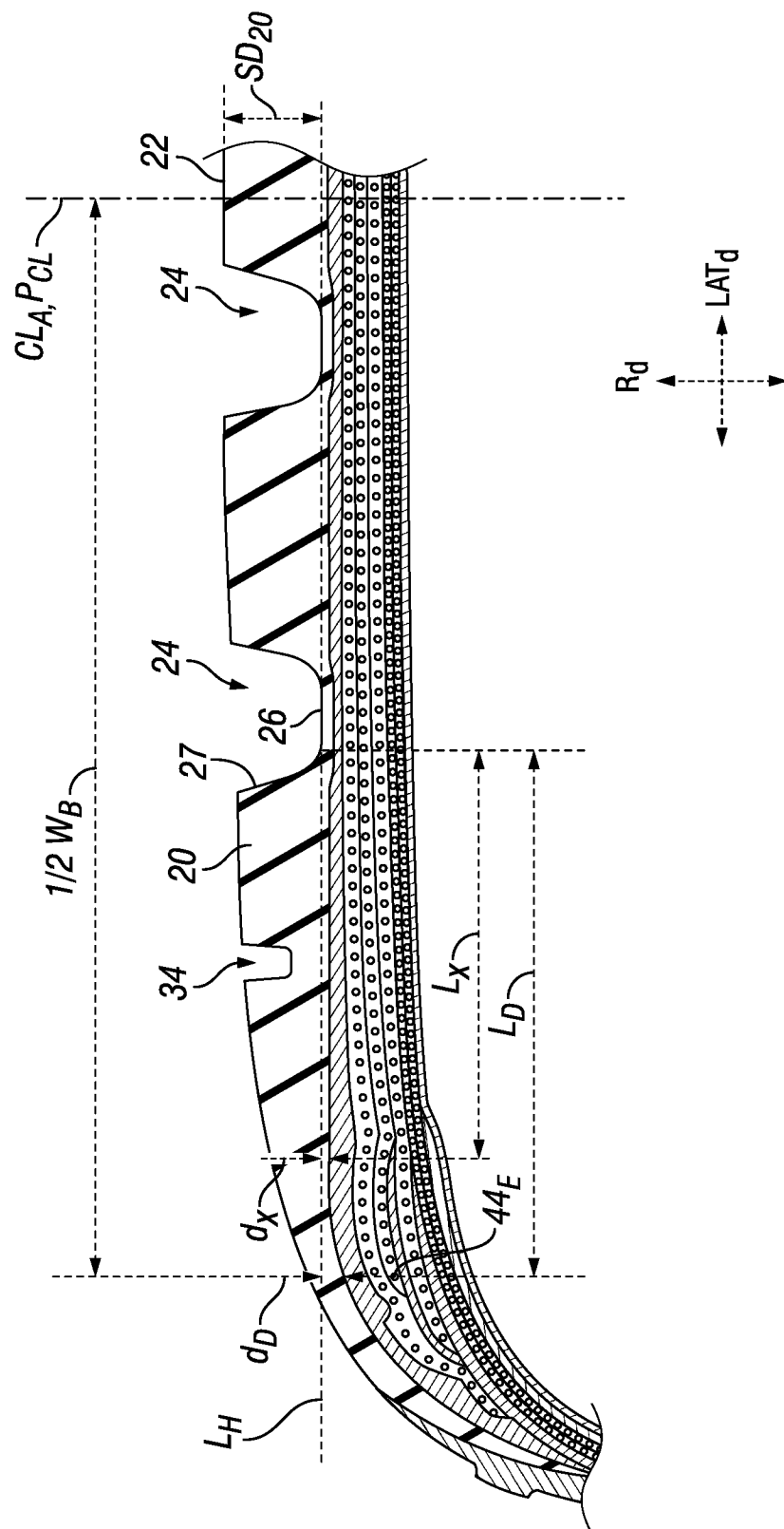


FIG. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2017/069141

A. CLASSIFICATION OF SUBJECT MATTER

INV. B60C9/20 B60C9/18 B60C9/22 B60C11/00 B60C11/01
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B60C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 2 505 386 A1 (BRIDGESTONE CORP [JP]) 3 October 2012 (2012-10-03) paragraphs [0013], [0015] - [0017]; claims; figures 1-2 -----	1-14
A	DE 11 2012 007267 T5 (YOKOHAMA RUBBER CO LTD [JP]) 24 September 2015 (2015-09-24) paragraphs [0031], [0032], [0104], [0120], [0121]; claims; figures 1,2,5 -----	1-14



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"&" document member of the same patent family

Date of the actual completion of the international search

28 September 2018

Date of mailing of the international search report

31/10/2018

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INTERNATIONAL SEARCH REPORT

Information on patent family members

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