

GOLF BALL DIMPLES WITH CURVATURE CONTINUITY

5 The present invention relates to a golf ball with a dimple pattern on its surface. More specifically, the present invention relates to a dimple pattern for a golf ball where each dimple has a curvature continuity at the entry radius, the inflection point and the center point at the bottom of the dimple.

Golfers realized perhaps as early as the 1800's that golf balls with indented surfaces flew better than those with smooth surfaces. Hand-hammered gutta-percha golf balls could be purchased at least by the 1860's, and golf balls with brambles (bumps rather than dents) were in style from the late 1800's to 1908. In 1908, an Englishman, William Taylor, received a patent for a golf ball with indentations (dimples) that flew better and more accurately than golf balls with brambles. A.G. Spalding & Bros., purchased the U.S. rights to the patent and introduced the GLORY ball featuring the TAYLOR dimples. Until the 1970s, the GLORY ball, and most other golf balls with dimples had 336 dimples of the same size using the same pattern, the ATTI pattern. The ATTI pattern was an octohedron pattern, split into eight concentric straight line rows, which was named after the main producer of molds for golf balls.

The only innovation related to the surface of a golf ball during this sixty year period came from Albert Penfold who invented a mesh-pattern golf ball for Dunlop. This pattern was invented in 1912 and was accepted until the 1930's.

25 In the 1970's, dimple pattern innovations appeared from the major golf ball manufacturers. In 1973, Titleist introduced an icosahedron pattern which divides the golf ball into twenty triangular regions. An icosahedron pattern was disclosed in British Patent Number 377,354 to John Vernon Pugh, however, this pattern had



dimples lying on the equator of the golf ball which is typically the parting line of the mold for the golf ball. Nevertheless, the icosahedron pattern has become the dominant pattern on golf balls today.

In the late 1970s and the 1980's the mathematicians of the major golf ball
5 manufacturers focused their intention on increasing the dimpled surface area (the area covered by dimples) of a golf ball. The dimpled surface for the ATTI pattern golf balls was approximately 50%. In the 1970's, the dimpled surface area increased to greater than 60% of the surface of a golf ball. Further breakthroughs increased the dimpled surface area to over 70%. U.S. Patent Number 4,949,976 to William Gobush discloses
10 a golf ball with 78% dimple coverage with up to 422 dimples. The 1990's have seen the dimple surface area break into the 80% coverage.

The number of different dimples on a golf ball surface has also increased with the surface area coverage. The ATTI pattern disclosed a dimple pattern with only one size of dimple. The number of different types of dimples increased, with three different
15 types of dimples becoming the preferred number of different types of dimples. U.S. Patent Number 4,463 to Oka et al., discloses a dimple pattern with four different types of dimples on surface where the non-dimpled surface cannot contain an additional dimple. United Kingdom patent application number 2157959, to Steven Aoyama, discloses dimples with five different diameters. Further, William Gobush invented a
20 cuboctahedron pattern that has dimples with eleven different diameters. See *500 Year of Golf Balls*, Antique Trade Books, page 189. However, inventing dimple patterns with multiple dimples for a golf ball only has value if such a golf ball is commercialized and available for the typical golfer to play.

Additionally, dimple patterns have been based on the sectional shapes, such as
25 octahedron, dodecahedron and icosahedron patterns. U.S. Patent 5,201,522 discloses a golf ball dimple pattern having pentagonal formations with equally number of dimples therein. U.S. Patent Number 4,880,241 discloses a golf ball dimple pattern having a modified icosahedron pattern wherein small triangular sections lie along the equator to

provide a dimple-free equator.

To further enhance aerodynamics for the flight of a golf ball, the designs of the dimples have been studied and improved upon by the golf industry. For example, Shimosaka et al., U.S. Patent Number 5,720,676 for a Golf Ball, discloses a cross-sectional area of each dimple that is equal 0.01 mm below the dimple edge. The dimples of the Shimoska patent have an equivalent cross-section below this level since the edges of the dimples above 0.01 mm are rounded after painting thereby departing from a master's reverse dimple pattern.

Another example is Ihara et al, U.S. Patent Number 4,840,381, for a Golf Ball, and Yamagishi et al., U. S. Patent Number 5,752,889, for a Two-Piece Solid Golf Ball, both of which disclose a gentle transition over the edge portion of each dimple. The Ihara and Yamagishi patents are particularly directed at a golf ball with a cover composed of an ionomer material.

Yet another example is Kasashima et al., U.S. Patent Number 5,906,551 for a Golf Ball, which discloses having dimples on the parting line. The dimples on the parting line have an entry angle that is greater than dimples that do not lie on the parting line. The use of a larger entry angle for parting line dimples in the Kasashima patent is to improve the symmetry.

Another example of entry angles of dimples is disclosed in Miyagawa et al, U.S. Patent Number 5,857,924, for a Golf Ball. The Miyagawa patent has the entry angle between 5 and 20 degrees in order to prevent lowering of the spin susceptibility due to repetitive hits.

Another example of manipulation of the edge of a dimple is disclosed in Oka, et al., U.S. Patent Number 4,813,677, for a Golf Ball. The Oka patent has a sharp inclination for the dimple wall surface to increase the volume of the dimple.

A departure from gradual dimples edges is disclosed in Boehm, U.S. Patent Number 5,566,943 for a Golf Ball. The Boehm patent discloses dimples that have a constant depth for the entire dimple area. Essentially, the side wall of the dimple of the

Boehm patent is at a 90 degree angle to the surface which should improve resistance to hits with an iron.

Although there are hundreds of published patents related to golf ball dimples, there still remains a need to improve upon current dimples, particularly for golf balls with thermoset polyurethane covers. Golf balls with thermoset polyurethane covers such as the Maxfli REVOLUTION, the Maxfli HT, the Titleist PROFESSIONAL, the Titleist TOUR PRESTIGE, and the Slazenger RAM 420 all need to compensate for the inherent properties of the polyurethane material which prevents the use of certain manufacturing techniques available to covers composed of ionomer materials such as roto-finishing. One example to overcome this problem is a dual radius design such as disclosed in Moriyama, U.S. Patent Number 5,735,757. However, there is still a need for a dimple designed to maximize the aerodynamics of a golf ball with a thermoset polyurethane cover.

Disclosure of the Invention

The present invention provides a novel dimple cross-section that reduces the drag on a golf ball while increasing its lift for greater distances. The present invention is able to accomplish this by providing a continuous curvature for each of the dimples based on a quintic Bézier.

One aspect of the present invention is a golf ball having a surface thereon with a plurality of dimples on the surface. The contour of each of the dimples is continuous from a first edge of each of the dimples to a second opposing edge of each of the dimples. The contour at the first edge may be equal to the curvature of a sphere of the golf ball. The curvature of each of the dimples may be convex from the first edge to a first inflection point and from the second edge to a second inflection point, and the curvature may be concave between the first inflection point and the second inflection point. The dimple contour may be defined by the following equation:

$$P(t) = 3 B_i J_{n,i}(t) \quad 0 < t < 1$$

wherein $J_{n,i}(t) = \binom{n}{i} t^i (1-t)^{n-i}$, n is equal to at least five, and $i = n + 1$.

The radius of each point from a bottom center to the first edge may be different from any other point from the bottom center to the first edge. The radius may be greatest at the bottom center.

- 5 Another aspect of the present invention is a golf ball having a thermoset polyurethane cover with a surface thereon. The surface of the thermoset polyurethane cover is coated with at least a base coat. The golf ball has a plurality of dimples on the surface, and the contour of each of the dimples is continuous from a first edge of each of the dimples to a second opposing edge of each of the dimples.

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Brief Description of the Drawings

FIG. 1 is an equatorial view of a preferred embodiment of a golf ball of the present invention.

FIG. 1A is the view of FIG. 1 illustrating the rows of dimples.

- 15 FIG. 1B is the view of FIG. 1 illustrating the transition region of dimples.

FIG. 2 is a polar view of the golf ball of FIG. 1.

FIG. 2A is the view of FIG. 2 illustrating the cascading pentagons of dimples.

FIG. 2B is the view of FIG. 2 illustrating the single encompassing pentagon of dimples.

- 20 FIG. 3 is a polar view of the golf ball of FIG. 1 illustrating the star configuration.

FIG. 4 is an enlarged cross-sectional view of a dimple of a first set of dimples of the golf ball of the present invention.

- 25 FIG. 4A is an isolated cross-sectional view to illustrate the definition of the entry radius.

FIG. 5 is an enlarged cross-sectional view of a dimple of a second set of dimples of the golf ball of the present invention.

FIG. 6 is an enlarged cross-sectional view of a dimple of a third set of dimples

of the golf ball of the present invention.

FIG. 7 is an enlarged cross-sectional view of a dimple of a fourth set of dimples of the golf ball of the present invention.

FIG. 8 is an enlarged cross-sectional view of a dimple of a fifth set of dimples of the golf ball of the present invention.

FIG. 9 is an enlarged cross-sectional view of a dimple of a sixth set of dimples of the golf ball of the present invention.

FIG. 10 is an enlarged cross-sectional view of a dimple of a seventh set of dimples of the golf ball of the present invention.

FIG. 11 is a cross-sectional view of a dimple of the prior art.

FIG. 12 is a cross-sectional view of another dimple of the prior art.

FIG. 13 is an isolated top plan view of a dimple of the present invention.

FIG. 14 is a cross-sectional side view of the dimple of FIG. 13.

FIG. 14a is a cross-sectional side view of the dimple of FIG. 13 illustrating the entry angle and the chord depth.

FIG. 14b is a cross-sectional side view of the dimple of FIG. 13 illustrating the bridging curves used to construct the curvature of the dimple.

FIG. 15 is a combination of a graph of the distance from one end of a dimple to an opposing end versus the radius, with a cross-section of the dimple, for a dimple of the prior art to demonstrate the curvature discontinuity.

FIG. 16 is a combination of a graph of the distance from one end of a dimple to an opposing end versus the radius, with a cross-section of the dimple, for a dimple of the present invention to demonstrate the curvature continuity.

FIG. 17 is a graph of the lift coefficient versus Reynolds number.

FIG. 18 is graph of the drag coefficient versus Reynolds number.

FIG. 19 is a cross-sectional view of a golf ball of the present invention.

Best Mode(s) For Carrying Out The Invention

As shown in FIGS. 1-3, a golf ball is generally designated 20. The golf

ball may be a two-piece or a three piece golf ball. Further, the three-piece golf ball may have a wound layer, or a solid boundary layer. The cover of the golf ball 20 may be any suitable material. A preferred cover is composed of a thermoset polyurethane material. However, those skilled in the pertinent art will recognize that other cover materials may be utilized without departing from the scope and spirit of the present invention. The golf ball 20 may have a finish of a basecoat and/or top coat.

The golf ball 20 has a surface 22. The golf ball 20 also has an equator 24 dividing the golf ball 20 into a first hemisphere 26 and a second hemisphere 28. A first pole 30 is located ninety degrees along a longitudinal arc from the equator 24 in the first hemisphere 26. A second pole 32 is located ninety degrees along a longitudinal arc from the equator 24 in the second hemisphere 28.

On the surface 22, in both hemispheres 26 and 28, are 382 dimples partitioned into seven different sets of dimples. A first set of dimples 34 are the most numerous dimples consisting of two-hundred twenty dimples in the preferred embodiment. A second set of dimples 36 are the next most numerous dimples consisting of one-hundred dimples. A third set of dimples 38 and a fourth set of dimples 40 are the next most numerous with each set 38 and 40 consisting of twenty dimples in the preferred embodiment. A fifth set of dimples 42 and a sixth set of dimples 44 are the next most numerous with each set 42 and 44 consisting of ten dimples in the preferred embodiment. The seventh set of dimples 46 consist of only two dimples. In a preferred embodiment, the 382 dimples account for 86% of the surface 22 of the golf ball.

The two dimples of the seventh set of dimples 46 are each disposed on respective poles 30 and 32. Each of the fifth set of dimples 42 is adjacent one of the seventh set of dimples 46. The five dimples of the fifth set of dimples 42 that are disposed within the first hemisphere 26 are each an equal distance from the equator 24 and the first pole 30.

The five dimples of the fifth set of dimples 42 that are disposed within the second hemisphere 28 are each an equal distance from the equator 24 and the second pole 32. These polar dimples 42 and 46 account for approximately 2% of the surface 22 of the

golf ball 20.

A cross-section of a dimple of the fifth set of dimples 42 is shown in FIG. 8. The radius R_5 of the dimple 42 is approximately 0.0720 inches, the chord depth C_5 is approximately 0.0054 inches, the entry angle θ_5 is approximately 15.7 degrees, and the entry radius ER_5 is approximately 0.0336 inches. Unlike the use of the term "entry radius" or "edge radius" in the prior art, the entry radius as defined herein is a value utilized in conjunction with the entry angle to delimit the concave and convex segments of the dimple contour. The first and second derivatives of the two Bézier curves are forced to be equal at this point defined by the entry radius and the entry angle, as shown in FIG. 4A.

A cross-section of a dimple of the seventh set of dimples 46 is shown in FIG. 10. The radius R_7 of the dimple 46 is approximately 0.0510 inches, the chord depth C_7 is approximately 0.0049 inches, the entry angle θ_7 is approximately 13.4 degrees, and the entry radius ER_7 is approximately 0.0336 inches.

The ten dimples of the sixth set of dimples 44 account for approximately 3% of the surface 22 of the golf ball 20. The five dimples of the sixth set of dimples 44 that are disposed within the first hemisphere 26 are each an equal distance from the equator 24 and the first pole 30. The five dimples of the sixth set of dimples 44 that are disposed within the second hemisphere 28 are each an equal distance from the equator 24 and the second pole 32. Also, each of the sixth set of dimples 44 is adjacent to three different sets of dimples 34, 36 and 40.

A cross-section of a dimple of the sixth set of dimples 44 is shown in FIG. 9. The radius R_6 of the dimple 44 is approximately 0.0930 inches, the chord depth C_6 is approximately 0.0051 inches, the entry angle θ_6 is approximately 15.2 degrees, and the entry radius ER_6 is approximately 0.0333 inches. The extraordinarily large diameter of each of the sixth set of dimples 44 allows for the extraordinary surface coverage of the dimple pattern of the present invention. This is contrary to conventional thinking that teaches that dimples with smaller diameters would provide for greater surface coverage.

All of the fourth set of dimples 40 are adjacent to at least one of the sixth set of dimples 44. The twenty dimples of the fourth set of dimples 40 cover approximately 2.7% of the surface 22 of the golf ball 20. The ten dimples of the fourth set of dimples 40 that are disposed within the first hemisphere 26 are each an equal distance from the equator 24 and the first pole 30. The ten dimples of the fourth set of dimples 40 that are disposed within the second hemisphere 28 are each an equal distance from the equator 24 and the second pole 32. Also, each of the fourth set of dimples 40 is adjacent to three different sets of dimples 36, 38 and 44.

A cross-section of a dimple of the fourth set of dimples 40 is shown in FIG. 7. The radius R_4 of the dimple 40 is approximately 0.062 inches, the chord depth C_4 is approximately 0.0052 inches, the entry angle θ_4 is approximately 15.2 degrees, and the entry radius ER_4 is approximately 0.0358 inches.

All of the third set of dimples 38 are adjacent to at least one of the sixth set of dimples 44. The twenty dimples of the third set of dimples 38 cover approximately 3.8% of the surface 22 of the golf ball 20. The ten dimples of the third set of dimples 38 that are disposed within the first hemisphere 26 are each an equal distance from the equator 24 and the first pole 30. The ten dimples of the third set of dimples 38 that are disposed within the second hemisphere 28 are each an equal distance from the equator 24 and the second pole 32. Also, each of the fourth set of dimples 38 is adjacent to three different sets of dimples 34, 36 and 40.

A cross-section of a dimple of the third set of dimples 38 is shown in FIG. 6. The radius R_3 of the dimple 38 is approximately 0.074 inches, the chord depth C_3 is approximately 0.0053 inches, the entry angle θ_3 is approximately 15.3 degrees, and the entry radius ER_3 is approximately 0.0344 inches.

The two-hundred twenty dimples of the first set of dimples 34 are the most influential of the different sets of dimples 34-46 due to their number, size and placement on the surface 22 of the golf ball 20. The two-hundred twenty dimples of the first set of dimples 34 cover approximately 53% of the surface 22 of the golf ball 20.

The one-hundred ten dimples of the first set of dimples 34 that are disposed within the first hemisphere 26 are disposed in either a first row 80 and a second row 82 above the equator 24, or a pseudo-star configuration 84 about the first pole 30 that is best illustrated in FIG. 3. Similarly, the one-hundred ten dimples of the first set of dimples 34 that are disposed within the second hemisphere 28 are disposed in either a first row 90 and a second row 92 below the equator 24, or a pseudo-star configuration 94, not shown, about the second pole 32, not shown.

A cross-section of a dimple of the first set of dimples 34 is shown in FIG. 4. The radius R_1 of the dimple 34 is approximately 0.0834 inches, the chord depth C_1 is approximately 0.0053 inches, the entry angle θ_1 is approximately 15.3 degrees, and the entry radius ER_1 is approximately 0.0344 inches.

The one-hundred dimples of the second set of dimples 36 are the next most influential of the different sets of dimples 34-46 due to their number, size and placement on the surface 22 of the golf ball 20. The one-hundred dimples of the second set of dimples 36 cover approximately 22% of the surface 22 of the golf ball 20. Thus, together the first set of dimples 34 and the second set of dimples 36 cover over approximately 75% of the surface 22 of the golf ball 20. The fifty dimples of the second set of dimples 36 that are disposed within the first hemisphere 26 are disposed in either a third row 86 above the equator, a second pentagon 102 about the first pole 30, or along a transition latitudinal region 70. Similarly, the fifty dimples of the second set of dimples 36 that are disposed within the second hemisphere 28 are disposed in either a third row 96 below the equator 24, a second pentagon 102a, not shown, about the second pole 32, or along a transition latitudinal region 72.

A cross-section of a dimple of the second set of dimples 36 is shown in FIG. 5. The radius R_2 of the dimple 36 is approximately 0.079 inches, the chord depth C_2 is approximately 0.0053 inches, the entry angle θ_2 is approximately 15.1 degrees, and the entry radius ER_2 is approximately 0.0315 inches.

As best illustrated in FIG. 1A, each hemisphere 26 and 28 begins with three rows

from the equator 24. The first and second rows 80 and 82 of the first hemisphere 26 and the first and second rows 90 and 92 of the second hemisphere 28 are composed of the first set of dimples 34. The third row 86 of the first hemisphere 26 and the third row 96 of the second hemisphere 28 are composed of the second set of dimples 36. This

5 pattern of rows is utilized to achieve greater surface area coverage of the dimples on the golf ball 20. However, as mentioned previously, conventional teaching would dictate that additional rows of smaller diameter dimples should be utilized to achieve greater surface area coverage. However, the dimple pattern of the present invention transitions from rows of equal dimples into a pentagonal region 98. The pentagonal region 98 is

10 best seen in FIG. 2A. A similar pentagonal region 98a, not shown, is disposed about the second pole 32. The pentagonal region 98 has five pentagons 100, 102, 104, 106 and 108 expanding from the first pole 30. Similar pentagons 100a, 102a, 104a, 106a and 108a expand from the second pole 32. The first pentagon 100 consists of the fifth set of dimples 42. The second pentagon 102 consists of the second set of dimples 36.

15 The third pentagon 104 consists of the first set of dimples 34. The fourth pentagon 106 also consists of the first set of dimples 34. The fifth pentagon 108 consists of the first set of dimples 34 and the sixth set of dimples 44. However, the greater fifth pentagon 108' would include the fifth pentagon 108 and all dimples disposed between the third row 86 and the fifth pentagon 108. The pentagonal region 98 allows for the greater

20 surface area of the dimple pattern of the present invention.

FIG. 2B illustrates five triangles 130-138 that compose the pentagonal region 98. Dashed line 140 illustrates the extent of the greater pentagonal region 98' which overlaps with the transition latitudinal region 70.

As best illustrated in FIG. 1B, all of the dimples of the third set of dimples 38, the

25 fourth set of dimples 40 and the sixth set of dimples 44 are disposed within the transition latitudinal regions 70 and 72. The transition latitudinal regions 70 and 72 transition the dimple pattern of the present invention from the rows 80, 82, 86, 90, 92 and 96 to the pentagonal regions 98 and 98a. Each of the transition latitudinal regions

70 and 72 cover a circumferential area between 40 to 60 longitudinal degrees from the equator 24 in their respective hemispheres 26 and 28. The first transition latitudinal region 70 has a polar boundary 120 at approximately 60 longitudinal degrees from the equator 24, and an equatorial boundary 122 at approximately 40 longitudinal degrees from the equator 24. Similarly, the second transition latitudinal region 72 has a polar boundary 120a at approximately 60 longitudinal degrees from the equator 24, and an equatorial boundary 122a at approximately 40 longitudinal degrees from the equator 24.

FIGS. 11 and 12 illustrate the cross-sections of dimples of the prior art. As shown in FIG. 11, the prior art golf ball 171 has a cross-section of a dimple 173 that has the same radius, "R", from one end 175 of the dimple 173 to the other end 177 of the dimple 173. More precisely, the radius R of the center 179 of the dimple 173 is equal to the radius R at either end 175 or 177. Such a golf ball 171 of the prior art usually has a cover composed of an ionomer material that allows for roto-finishing to create a smoother edge where the spherical surface of the golf ball 171 ends and the dimple 173 begins.

The golf ball 171a of the prior art shown in FIG. 12 usually has a cover composed of a thermoset polyurethane material which has greater durability than an ionomer material. However, the polyurethane cover cannot be roto-finished to create a smoother edge. Therefore, the prior art, such as disclosed in U.S. Patent Number 5,735,757, has created a dimple 173a that has a dual radius. As illustrated in FIG. 12, the center 179a has a radius R2 that is different from that of either end 175a or 177a. Thus, between transition points 181a-b, the dimple 173a has a radius R2, and from points 181a to 175a and 181b to 177a, the dimple 173a has a radius R1. The radius R3 illustrates the desired radius to simulate a roto-finished golf ball. This creates a discontinuous contour for the dimple 173a.

As shown in FIGS. 13, 14, 14A and 14B, the golf ball 20 of the present invention has a contour 199 that is unlike the contour of the prior art golf balls. The dimples of

the golf ball 20 of the present invention have a continuous contour 199 with a changing radius along the entire contour 199. The contour 199 begins at an edge 200a and ends at another edge 200b. The contour 199 inflects at inflection points 202a and 202b. A dashed line 203 illustrates annular inflection of the dimple 40. The contour 199 has a bottom center 204 where the depth of the dimple 40 is at its greatest depth. The golf ball 20 has a curvature 206 that matches the spherical surface 211 of the non-dimpled area of the golf ball 20. The dashed lines indicate the phantom curvature 206 of the golf ball over the dimple 40. The curvature 206 of the golf ball 20 is equal to the contour 199 of the dimple at each of the edges 200a and 200b. This equality in the contour 199 and the curvature 206 at the edges 200a and 200b allows for a smooth transition of air into the dimple 40 during the flight of the golf ball 20. The air pressure acting on the golf ball 20 during its flight is driven by the contour 199 of each dimple 40. Reducing the discontinuity of the contour 199 reduces the discontinuity in the air pressure distribution during the flight of the golf ball 20 which reduces the separation of the turbulent boundary layer that is created during the flight of the golf ball 20.

The differences in contours of dimples of the golf ball 20 of the present invention and dimples of golf balls of the prior art is best illustrated in FIGS. 15 and 16. As shown in FIG. 15 for a dual radius dimple (similar to that of FIG. 12), the contour has a discontinuity at the transition points. In contrast, as shown in FIG. 16, the contour 199 of the present invention is continuous for the entire contour with a peak at the bottom center of the dimple 40. Although the dimple 40 is shown as an example, most or all of the other dimples on a golf ball 20 of the present invention have a similar contour 199.

The contour 199 may be characterized as a concave between inflection points 202a and 202b, and as convex from edge 200a to inflection point 202a and from inflection point 202b to edge 200b.

The contour 199 of the dimples 40 of the present invention are based on a fifth degree Bézier polynomial having the formula:

$$P(t) = 3 B_i J_{n,i}(t) \quad 0 < t < 1$$

wherein $P(t)$ are the parametric defining points for both the convex and concave portions of the dimple cross section, the Bézier blending function is

$$J_{n,i}(t) = \binom{n}{i} t^i (1-t)^{n-i}$$

and n is equal to the degree of the defining Bézier blending function, which for the present invention is preferably five. t is a parametric coordinate normal to the axis of revolution of the dimple. B_i is the value of the i th vertex of defining the polygon, and $i = n + 1$. A more detailed description of the Bézier polynomial utilized in the present invention is set forth in *Mathematical Elements For Computer Graphics*, Second Edition, McGraw-Hill, Inc., David F. Rogers and J. Alan Adams, pages 289-305, which are hereby incorporated by reference.

For the present invention, the equations defining the dimple cross sectional shape requires the location of the edges 200a and 200b, the inflection points 202a and 202b, the bottom center 204, the entry angle EA, the radius of the golf ball R_{ball} , the radius of the dimple R_D , the entry radius R_E , the curvature at the bottom center 204, and the chord depth C . This information allows for the contour 199 of the dimple 40 to be designed to be continuous throughout the dimple 40. In constructing the contour 199, two associative bridge curves are prepared as the basis of the contour 199. The first bridge curve 220 is overlaid from the edge 200a to the inflection point 202a which eliminates the step discontinuity in the curvature that results from having true arcs point continuous and tangent. The second bridge curve 222 is overlaid from the inflection point 202a to the bottom center 204. The attachment of the bridge curves 220 and 222 at the inflection point 202a allows for equivalence of the curvature and controls the contour 199. The dimensions of the curvature at the bottom center 204 also controls the contour 199. The shape of the contour 199 may be refined using the parametric stiffness controls available at each of the bridge curve 220 and 222. The controls allow for the fine tuning of the shape of the dimple 40 by scaling tangent and curvature poles on each end of the bridge curves 220 and 222.

FIG. 17 illustrates the lift coefficient of a golf ball 20 with the dimple pattern of

the present invention thereon as compared to the Titleist PROFESSIONAL, the Titleist TOUR PRESTIGE, the Maxfli REVOLUTION and the Maxfli HT URETHANE. FIG. 18 illustrates the drag coefficient of a golf ball 20 with the dimple pattern of the present invention thereon as compared to the Titleist PROFESSIONAL, the Titleist TOUR PRESTIGE, the Maxfli REVOLUTION and the Maxfli HT URETHANE. All of the golf balls for the comparison test, including the golf ball 20 with the dimple pattern of the present invention, have a thermoset polyurethane cover. The golf ball 20 with the dimple pattern of the present invention was constructed as set forth in U.S. Patent Number 6,117,024, filed on July 27, 1999, for a Golf Ball With A Polyurethane Cover which is described below. The aerodynamics of the dimple pattern of the present invention provides a greater lift with a reduced drag thereby translating into a golf ball 20 that travels a greater distance than golf balls of similar constructions.

In this regard, the Rules of Golf, approved by the United States Golf Association ("USGA") and The Royal and Ancient Golf Club of Saint Andrews, limits the initial velocity of a golf ball to 76.2 meters per second. A complete description of the Rules of Golf are available on the USGA web page at www.usga.org. Thus, the initial velocity and overall distance of a golf ball must not exceed these limits in order to conform to the Rules of Golf. Therefore, the golf ball 20 should have a dimple pattern that enables the golf ball 20 to meet, yet not exceed, these limits.

As is shown in FIG 19, the golf ball 20 comprises a cover 14 over an inner core 12 and a boundary layer 13. The boundary layer 13 may be a single layer, as shown, or multiple layers. In this embodiment, the core 12 is preferably compression molded to yield a single layer solid core, the boundary layer 13 is preferably injection molded over the core 12, and the cover 14 is preferably cast over the boundary layer 13 and core 12 (which, preferably, has been pre-heated). The casting process is described below.

The solid core 12 is generally composed of a blend of a base rubber, a cross-linking agent, a free radical initiator, and one or more fillers or processing aids. A

preferred base rubber is a polybutadiene having a cis-1,4 content of above about 90%, and more preferably 98% or above. Such materials are well known to those skilled in the art.

5 The use of cross-linking agents in a golf ball core is well known, and metal acrylate salts are examples of such cross-linking agents. For example, metal salt diacrylates, dimethacrylates, or mono(meth)acrylates are preferred for use in the golf ball cores of the present invention, and zinc diacrylate is a particularly preferred cross-linking agent. In the manufacturing process it may be beneficial to pre-mix some cross-linking agent(s), such as, e.g., zinc diacrylate, with the polybutadiene in a master batch
10 prior to blending with other core components.

Free radical initiators are used to promote cross-linking of the base rubber and the cross-linking agent. Suitable free radical initiators for use in the golf ball core
12 include peroxides such as dicumyl peroxide, bis-(t-butyl peroxy) diisopropyl benzene, t-butyl perbenzoate, di-t-butyl peroxide, 2,5-dimethyl-2,5-di-5-butylperoxy-hexane,
15 1,1-di (t-butylperoxy) 3,3,5-trimethyl cyclohexane, and the like, all of which are readily commercially available.

Zinc oxide is also preferably included in the core formulation. Zinc oxide may primarily be used as a weight adjusting filler, and is also believed to participate in the cross-linking of the other components of the core (e.g. as a coagent). Additional
20 processing aids such as dispersants and activators may optionally be included. In particular, zinc stearate may be added as a processing aid (e.g. as an activator). Any of a number of specific gravity adjusting fillers may be included to obtain a preferred total weight of the core 12. Examples of such fillers include tungsten and barium sulfate.

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Table 1 below provides the ranges of materials included in the core formulations of the present invention.

Table 1: Core Formulations		
Component	Preferred Range	Most Preferred Range
Polybutadiene	100 parts	100 parts
Zinc diacrylate	20-35 phr	25-30 phr
Zinc oxide	0-50 phr	5-15 phr
Zinc stearate	0-15 phr	1-10 phr
Peroxide	0.2 – 2.5 phr	0.5 – 1.5 phr
Filler (e.g. tungsten)	As desired (e.g. 2-10 phr)	As desired (e.g. 2-10 phr)

In a preferred form, the finished core 12 has a diameter of about 1.35 to about 1.64 inches for a golf ball 10 having an outer diameter of 1.68 inches. The core weight is preferably maintained in the range of about 32 to about 40 g. The core PGA compression is preferably maintained in the range of about 50 to 90, and most preferably about 55 to 80.

As used herein, the term "PGA compression" is defined as follows:

PGA compression value = 180 – Riehle compression value

The Riehle compression value is the amount of deformation of a golf ball in inches under a static load of 200 pounds, multiplied by 1000. Accordingly, for a deformation of 0.095 inches under a load of 200 pounds, the Riehle compression value is 95 and the PGA compression value is 85. While the inventors are aware of formulae contained in U.S. Pat. No. 5,368,304 and U.S. Pat. No. 5,813,923 that state that "PGA compression values = 160 – Riehle compression value", the inventors have adopted the alternative formula and definition set forth above:

Table 2 sets forth physical data for cores 12 that were manufactured according to the above-description and incorporated into specific embodiments of golf balls 20. Each specific embodiment golf ball 10 is referred to and identified by the same ball example number throughout this specification.

Table 2: Core Properties			
Ball Ex. No.	Size (inches)	Specific Gravity	Compression (PGA)
1	1.500	1.139	68
2	1.505	1.142	70
3	1.520	1.142	70
4	1.530	1.142	70
5	1.494	1.157	70
6	1.510	1.157	68
7	1.489	1.157	60
8	1.510	1.155	70
9	1.510	1.155	60

The boundary layer 13 is composed of at least one thermoplastic that contains organic chain molecules and metal ions. The metal ion may be, for example, sodium, zinc, magnesium, lithium, potassium, cesium, or any polar metal ion that serves as a reversible cross-linking site and results in high levels of resilience and impact resistance. Suitable commercially available thermoplastics are ionomers based on ethylene copolymers and containing carboxylic acid groups with metal ions such as described above. The acid levels in such suitable ionomers may be neutralized to control resiliency, impact resistance and other like properties. In addition, other fillers with ionomer carriers may be used to modify (e.g. preferably increase) the specific gravity of the thermoplastic blend to control the moment of inertia and other like properties. Exemplary commercially available thermoplastic materials suitable for use in a boundary layer 13 include, for example, the following materials and/or blends of the following materials: HYTREL® and/or HYLENE® products from DuPont, Wilmington, Delaware, PEBEX® products from Elf Atochem, Philadelphia, Pennsylvania, SURLYN® products from DuPont, and/or ESCOR® or IOTEK® products from Exxon Chemical, Houston, Texas.

The Shore D hardness of the boundary layer 13 should be about 65 or less. It is preferred that the boundary layer 13 have a hardness of between about 50-65 Shore D. In a preferred embodiment, the boundary layer 13 has a Shore D hardness in the range

of about 52-65. One reason for preferring a boundary layer 13 with a Shore D hardness of 65 or lower is to improve the feel of the resultant golf ball. It is also preferred that the boundary layer 13 is composed of a blend of SURLYN® ionomer resins. Table 3 below sets forth physical data for suitable boundary layers 13 that were manufactured and incorporated into specific embodiments of golf balls 20 of the present invention. As is shown in Table 3 below, a boundary layer 13 with a lower Shore D hardness tends to have a lower flexural modulus as well.

Table 3: Boundary Layer Properties							
Ball Ex. No.	SURLYN®			Barytes (phr)	Thickness (inches)	FlexMod (psi)	Shore D Hardness
	%8150	%9150	%6320				
1	40	40	20	8	0.065	55100	58
2	50	50	0	9	0.050	78600	61
3	50	50	0	9	0.050	78600	61
4	50	50	0	9	0.050	78600	61
5	32	32	36	9	0.058	41400	55
6	37.5	37.5	25	9	0.058	51200	57
7	40	40	20	9	0.058	55100	58
8	50	50	0	9	0.055	78600	61
9	47.5	47.5	5	9	0.050	71300	61

SURLYN® 8150, 9150, and 6320 are, respectively, an ionomer resin composed of a sodium neutralized ethylene/methacrylic acid, an ionomer resin composed of a zinc neutralized ethylene/methacrylic acid, and an ionomer resin composed of a terpolymer of ethylene, methacrylic acid and n-butyl acrylate partially neutralized with magnesium, all of which are all available from DuPont, Polymer Products, Wilmington, DE.

As is indicated in Table 3, all of the boundary layers 13 in the examples include a predetermined amount of a baryte mixture. The baryte mixture is included as 8 or 9 parts per hundred parts of the ionomer resins. One preferred baryte mixture is composed of 80% barytes and 20% of an ionomer. The specific gravity for each of the boundary layers 13 in Table 3 was 1.007. The flexural modulus provided in Table 3 was determined according to ASTM D790. The Shore D hardness provided in Table 3 was determined according to ASTM D2240.

In the preferred embodiment, the cover 14 of the golf ball 20 of the present invention is composed of a PPDI-based polyurethane system. Although the monomer has a tendency to sublime, thereby making it difficult to handle, the monomer has two isocyanate groups that exhibit widely different reactivities and make it particularly effective at providing polyurethane prepolymers with low content of free PPDI (in the range of 0.1 percent).

As mentioned previously, the polyurethane utilized in the present invention is composed of a PPDI-based prepolymer reacted with a curing agent. The PPDI-based prepolymer is formed from PPDI and a polyol such as an ester polyol, a polyether polyol, or a blend thereof. A preferred polyol is polycaprolactone. The curing agent, or curative, is a diol (e.g., 1,4 butane diol, trimethylpropanol), a mixture of diols (e.g., 1,4 butane diol and ethylene glycol, or other suitable glycols), a hydroquinone, a mixture of hydroquinones, a triol, a mixture of triols, a diamine, a mixture of diamines, an oligomeric diamine, a triamine, or a blend of some or all of these materials.

Specifically, the cover 14 is most preferably composed of a polyurethane formed from a PPDI-based prepolymer and cured with a mixture of diols, such as, for example, a blend of 1,4 butane diol and glycols. Such a suitable blend of diol and glycols is available from Uniroyal Chemical Company, Inc. Middlebury, Connecticut, under the name as VIBRACURE® A250 has an equivalent weight of about 45. Other agents which may be utilized during the curing process include trimethyl glycol di-p-aminobenzoate (such as VERSALINK® 740M available from Air Products and Chemicals, Inc., Allentown, PA); toluene ethylene diamine (such as ETHACURE® 100 available from Albemarle Corp., Baton Rouge, LA); cyclohexane dimethanol (readily available); hydroquinone-bis-hydroxyethyl ether (readily available); phenyldiethanol amine mixture (such as VIBRACURE® A931 available from Uniroyal Chemical Co., Middlebury, CT); methylene dianiline sodium chloride complex (such as CAYTOR® 31 available from Uniroyal Chemical Co.); and/or prionene amine (readily available). This list of preferred agents (including chain

extenders, cross-linkers and curing agents) is not meant to be exhaustive, as any suitable (preferably polyfunctional) chain extender, cross-linker, or curing agent may be used.

5 The cover 14 is preferably a castable thermoset polyurethane elastomer. For such a thermoset polyurethane elastomer, a PPDI-based prepolymer is preferably cured with at least one diol curative. Such a diol curative includes 1,4-butane diol, trimethylpropanol, or a mixture of diols (such as 1,4-butane diol and glycol, or other suitable glycols), a hydroquinone or mixture of hydroquinones, a triol or mixture of triols, or at least one of a diamine type curative(s), such as, methylenebis(ortho-
10 chloroaniline), or ETHACURE ® 300 or ETHACURE ® 100 available from Albemarle Corp., or an oligomeric diamine, or a mixture of some or all of these materials, and most preferably using a mixture of 1,4-butane diol and glycols such as is available from Uniroyal Chemical Company, Inc., under the name VIBRACURE ® A250.

15 The weight ratio of the PPDI-based prepolymer to the curative is preferably in the range of about 10:1 to about 30:1. Prior to curing, the PPDI-based prepolymer and curative are preferably stored separately. The PPDI-based polyurethane is formed by first heating and mixing the PPDI-based prepolymer with the curative in a mold, and then curing the mixture by applying heat and pressure for a predetermined time period.
20 Additionally, a catalyst (e.g. dibutyl tin dilaurate, a tertiary amine, etc.) may be added to the mixture to expedite the casting process. Specific suitable catalysts include TEDA dissolved in di propylene glycol (such as TEDA L33 available from Witco Corp. Greenwich, CT, and DABCO 33 LV available from Air Products and Chemicals Inc.,) which may be added in amounts of 2-5%, and more preferably TEDA dissolved
25 in 1,4-butane diol which may be added in amounts of 2-5%. Another suitable catalyst includes a blend of 0.5% 33LV or TEDA L33 (above) with 0.1% dibutyl tin dilaurate (available from Witco Corp. or Air Products and Chemicals, Inc.) which is added to a curative such as VIBRACURE ® A250. Furthermore, additives such as colorants may

also be added to the mixture.

Although the golf ball cover 14 of the present invention is preferably manufactured in a casting process, the cover material may alternatively be provided as a thermoplastic polyurethane for injection molding of the cover 14 over the boundary layer 13 and/or core 12. For a thermoplastic polyurethane, the PPDI-based prepolymer is formed by reacting a polyol with PPDI. The PPDI-based prepolymer is then reacted with a chain extender, such as, for example, a diol or mixture of diols, a triol or mixture of triols, a diamine or mixture of diamines, etc. The resulting product is modified using conventional procedures to form a desired thermoplastic material for injection molding of the cover 14 over the boundary layer 13 and/or core 12.

The PPDI-based polyurethane cover 14 of the present invention exhibits good tensile strength, tear properties, and flexural modulus at lower hardnesses. In addition, because the preferred material is PPDI-based, the cover 14 has a $\tan \delta$ value lower than conventional (e.g. MDI- and TDI-based) thermoplastics and thermoset urethanes. Thus, the PPDI-based polyurethane cover 14 of the present invention loses less energy as heat upon a high distortion or impact event (i.e. hysteresis) compared to these other polyurethane materials. It is believed that the relative superior mechanical and physical properties of the PPDI-based polyurethane cover 14 of the present invention is due to both the rigid rod-like structure of PPDI and the distribution of that structure throughout the polyurethane.

In the preferred embodiment, the PPDI-based prepolymer is preferably a PPDI reacted with a polycaprolactone. The PPDI-based prepolymer material is preferably degassed and warmed in a first holding container prior to processing of the cover 14. The processing temperature for the PPDI-based prepolymer is preferably in the range of about 100-220°F, and most preferably in the range of about 120-200°F. The PPDI-based prepolymer is preferably flowable from the first holding container to a mixing chamber in a range of about 200-1100 grams of material per minute, or as needed for processing. In addition, the PPDI-based prepolymer material may be agitated in the

first holding container, in the range of 0-250 rpm, to maintain a more even distribution of material and to eliminate crystallization.

In the preferred embodiment, the curative is a blend of 1,4 butane diol and glycol such as VIBRACURE ® A250. As previously mentioned, other curatives may also be utilized in forming the cover 14. The curative is preferably degassed and warmed in a second holding container prior to processing of the cover 14. The processing temperature for the curative is preferably in the range of about 50-230°F, and most preferably in the range of about 80-200°F. The curative is preferably flowable from the second holding container to the mixing chamber in the range of about 15-75 grams of material per minute, or as needed. If a catalyst is used for processing the cover 14, then the catalyst is added to the curative in the second holding container to form a curative mixture. Suitable catalyst are described above. The curative and catalyst are agitated, in the range of about 0 to 250 rpm, to maintain an even distribution of catalyst in the curative in the second holding container. It is preferred that catalyst is added in an amount in the range of about 0.25-5% by weight of the combined PPDI-based prepolymer and curative. Additives may be added to the curative as desired. It was discovered that hydrolytic instability of the polyurethane polymer may be avoided by the addition of a stabilizer such as STABOXYL® (available from Rheinchemie, Trenton, New Jersey), in amounts of about 0.25-5% of the polyurethane.

The PPDI-based prepolymer and curative mixture are preferably added to the common mixing chamber at a temperature in the range of about 160-220°F. A colorant material, such as, for example, titanium dioxide, barium sulfate, and/or zinc oxide in a glycol or castor oil carrier, and/or other additive material(s) as are well known in the art, may be added to the common mixing chamber. The amount of colorant material added is preferably in the range of about 0-10% by weight of the combined PPDI-based prepolymer and curative materials, and more preferably in the range of about 2-8%. Other additives, such as, for example, polymer fillers, metallic fillers, and/or organic and inorganic fillers (e.g. polymers, balata, ionomers, etc.) may be added as well to

increase the specific gravity of the PPDI-based polyurethane cover 14 of the present invention. It was discovered that the addition of barytes (barium sulfate) or a blend of barytes and titanium dioxide (preferably added in a carrier glycol and/or castor oil) to the mixture, in the amounts of about 0.01-30%, may add sufficient weight to the PPDI-based polyurethane cover 14. The added weight to the cover 14 allows for a lower specific gravity for the core 12 thereby allowing for an increased resiliency of the core 12. The entire mixture is preferably agitated in the mixing chamber in the range of about 1 to 250 rpm prior to molding.

The resulting PPDI-based polyurethane cover material has the physical properties as listed in Table 4 below. Table 4 illustrates the exemplary properties of the cover 14 of the present invention as compared to prior cover materials.

Table 4: Typical Approximate Values			
Property	Present Invention	Prior Polyurethanes (MDI and TDI)	Ionomers
Shore D Hardness	45-60	50-60	45-75
Tensile Strength psi	6500-7900	3500-4000	2000-3500
Bashore Resilience	55-65%	45-55%	50-60%

As can be seen by comparing the data in Table 4, the cover 14 of the present invention exhibits hardness and resilience comparable to prior materials, however the cover material exhibits a much higher tensile strength than the prior materials.

The cover 14 of the present invention preferably has a thickness of between about 0.02-0.09 inches, or more preferably between about 0.02-0.065 inches, and most preferably between about 0.02-0.04 inches. Table 5 below sets forth physical data for exemplary covers 14.

Table 5: Cover Properties						
Ball Ex.No	Adiprene® Prepolymer	Thickness inches	Tensile Strength	Specific Gravity	Bashore Resilience	Hardness Shore D
1	LFPX2950	0.0265	6500 psi	1.142	62-65%	47D
2	LFPX1951	0.0380	7900 psi	1.220	54-57%	53D
3	LFPX1951	0.0300	7900 psi	1.220	54-57%	53D
4	LFPX1951	0.0251	7900 psi	1.220	54-57%	53D

Table 5: Cover Properties						
Ball Ex.No	Adiprene® Prepolymer	Thickness inches	Tensile Strength	Specific Gravity	Bashore Resilience	Hardness Shore D
5	LFPX2950	0.0345	6500 psi	1.142	62-65%	47D
6	LFPX2950	0.0270	6500 psi	1.142	62-65%	47D
7	LFPX2950	0.0380	6500 psi	1.142	62-65%	47D
8	LFPX2950	0.0295	6500 psi	1.142	62-65%	47D
9	LFPX2950	0.0348	6500 psi	1.142	62-65%	47D

The prepolymers indicated in Table 5 are ADIPRENE® LFPX2950 and ADIPRENE® LFPX1951, which are available from Uniroyal Chemical Company. ADIPRENE® LFPX2950 and LFPX 1951 are both described by Uniroyal Chemical Company as PPDI-terminated polycaprolactone prepolymers. In the examples listed in Table 5, the PPDI-based prepolymer was cured with a 1,4-butane diol mixture (i.e. VIBRACURE ® A250 from Uniroyal). The catalyst used was TEDA L33 from Witco Corp. Three percent TEDA L33 was added to the curative for mixing with LFPX2950, and two percent TEDA L33 was added the curative for mixing with LFPX1951. It is believed that blending 0.5% TEDA L33 with 0.1% dibutyl tin dilaurate is a beneficial catalyst for use with LFPX2950 (i.e. where the catalyst blend is added to the curative, e.g. A250).

As is mentioned above, the PPDI-based polyurethane is well suited to be used as a golf ball cover. Particularly, the PPDI-based polyurethane exhibits such good durability that a cover made from the material can be quite thin as compared to golf ball covers made from prior materials. For example, golf balls having covers made from the material of the present invention having thicknesses of between about 0.02-0.04 inches performed well in durability tests, as described below. Conventional thermoset polyurethane or polyurea golf ball covers sufficiently durable for use in competitive play (e.g. made from a polyurethane prepolymer, such as MDI, cured with a polyamine and 5-95% by weight of a difunctional glycol, see, Wu, U.S. Pat. No. 5,334,673) have a typical minimum cover thickness of at least twice this range (i.e. at least about 0.04-

0.06-0.08 inches).

The diameter of the core 12 and the thickness of the boundary layer 13 and cover 14 of the present invention are dependent on the desired diameter of the golf ball 20. The inner core 12 preferably has a diameter in the range of about 1.35 to 1.70 inches and the boundary layer 13 preferably has a wall thickness in the range of about 0.02 to 0.09 inches. If the desired diameter of the golf ball 20 is about 1.68 inches, then more preferably the core 12 has a diameter in the range of about 1.40 to 1.65 inches and the boundary layer 13 has a wall thickness in the range of about 0.02 to 0.075 inches, and most preferably the core 12 has a diameter in the range of about 1.45 to 1.60 inches and the boundary layer 13 has a wall thickness in the range of about 0.02 to 0.067 inches. If the desired diameter of the golf ball 20 is about 1.8 inches, then more preferably the core 12 has a diameter in the range of about 1.55 to 1.72 inches and the boundary layer 13 has a wall thickness in the range of about 0.02 to 0.09 inches, and most preferably the core 12 has a diameter in the range of about 1.6 to 1.72 inches and the boundary layer 13 has a wall thickness in the range of about 0.02 to 0.06 inches.

In the preferred manufacturing process, the PPDI-based polyurethane cover material (i.e. the mixture composed of the PPDI-based prepolymer, curative with catalyst, and any additives, such as colorant, etc.) is preferably introduced into a first mold cavity of a mold cavity pair at T0. About 30-90 seconds later (i.e. T0 + 30-90 seconds or T1) the golf ball precursor product (preferably including a boundary layer 13), which preferably has been preheated as described in detail below, is then held (e.g. via suction equipment) contacting the cover material in the first mold cavity in what will be the spherical center of the mold cavity pair. The cover material is allowed to at least partially cure (typically between about 10-30 seconds, i.e., until about T1 + 10-30 seconds, i.e. T2), and then the core is released. Concurrently, the cover material is preferably introduced into a second cavity of the mold cavity pair at a time which enables it to set for about 30-90 seconds prior to T2, and then the mold is closed (thereby mating the first mold cavity to the second mold cavity), and subjected to heat

and pressure to cure the cover material for about 2-10 minutes at about 140-220°F and a pressure of about 1/3-2 ton per cavity in the mold thereby forming a cover 14 on the golf ball precursor product. The covered balls are then removed from the mold, allowed to cool, and preferably post-cured at about 140-250°F for about 4-8 hours.

5 As is mentioned above, the golf ball precursor product, core or core and boundary layer combination, is preferably preheated prior the casting process.

 The pre-heating step is preferably accomplished by applying heat to the core and any boundary layers, preferably to cause the core and any boundary layers to undergo thermal expansion. It should be appreciated that while the pre-heating step is described as being after core formation, the present methods also contemplate heating the core both during and after the formation of the golf ball core. In this manner, some of the heat that may be present or liberated in the core from the core formation process may be used in the pre-heating step. By undergoing thermal expansion, the volume of the ball increases from its initial size. Preferably, the core and any intermediate boundary layer is heated, prior to applying the cover, to a temperature of about 135 °F to about 175 °F, and more preferably between about 140 °F to about 160 °F. This pre-heating preferably occurs for about one hour, or for such time as needed to achieve an amount of thermal expansion prior to cover formation such that the cover will not crack, and/or to achieve a desired improvement in cover molding cycle time, as described below. Although the duration of the pre-heating step is not believed to be critical, this preferred amount of time permits substantially even heating of the core and any intermediate boundary layer and results in substantially steady-state thermal conditions within the core and any intermediate boundary layer.

25 While the temperature ranges and heating times disclosed above are the preferred ranges and times, it should be noted that the invention is not limited to any exact temperature or heating time. The purpose of the pre-heating step is to subject the core and any intermediate boundary layer to an increase in temperature to cause volumetric thermal expansion. This expansion can occur within any number of

absolute temperatures over any period of heating time that fall within the operability range of the materials used. For example, any temperature differential and heating time that causes a sufficient amount of thermal expansion of the core and optional boundary layer can be used. The amount of thermal expansion preferred will vary depending on,
 5 at least, the cover material(s) and cover thickness to be used for manufacturing the golf ball 10. For example, for a relatively rigid cover material or a relatively thin cover, it is preferable to cause a relatively larger amount of thermal expansion to the core 12 and optional boundary layer 13 to substantially prevent cover cracking.

The Volumetric thermal expansion of the core 12 and optional boundary layer
 10 13 may be expressed as a percentage, as follows:

$$\frac{(\text{Vol}_{final} - \text{Vol}_{initial})}{\text{Vol}_{initial}} \times 100 \text{ \%}$$

where Vol_{final} is the average volume of the core 12 or the core 12 and one or more
 15 optional boundary layers 13 at the high temperature, and $\text{Vol}_{initial}$ is the average volume of the core 12 or the core 12 and one or more optional boundary layers 13 at the lower, initial starting temperature. It has been found that a volumetric expansion of at least about 1.2% is substantially sufficient to prevent cover cracking when using a thermoset polyurethane cover material in a casting process. It will be understood,
 20 however, that this is not intended to serve as a lower limit for the volumetric thermal expansion. Instead, the lower limit for a given system will depend on the materials, the golf ball construction, and the molding processes used in the system. Determination of this limit for a given system is within the level of skill of those skilled in the art.

After pre-heating the core 12, or the core 12 and one or more optional boundary
 25 layers 13, the cover 14 is applied. The cover 14 is preferably applied while the core 12 and optional boundary layers 13 are at an increased temperature, and most preferably at the increased temperature obtained during the pre-heating step.

The present invention provides a very durable cover 14 having an excellent sound and feel, and as such enables designing golf balls having a maximized core size.

Maximizing core size typically provides maximum golf ball COR and, therefore, maximum distance for a given golf club head speed.

- Exemplary golf balls 10 (examples numbered 1-9) embodying the above-
- 5 described invention were prepared and tested according to the descriptions given above.
- The golf balls 10 were each constructed having a core 12 made from the materials and having the properties described in the text and Tables 1 and 2 above, a boundary layer 13 made from the materials and having the properties described in the text and Table 3 above, and a PPDI-based polyurethane cover 14 made from the materials and having
- 10 the properties described in the text and Table 5 above.

Table 8 below compiles the data shown above for the nine exemplary balls of the present invention as described above.

Table 8: Compilation of Data									
Property	Ball Ex. 1	Ball Ex. 2	Ball Ex. 3	Ball Ex. 4	Ball Ex. 5	Ball Ex. 6	Ball Ex. 7	Ball Ex. 8	Ball Ex. 9
Core									
Size (inches)	1.500	1.505	1.520	1.530	1.494	1.510	1.489	1.510	1.510
Specific Gravity	1.139	1.142	1.142	1.142	1.157	1.157	1.157	1.155	1.155
Compression*	68	70	70	70	70	68	60	70	60
Mantle Layer									
% Surlyn 8150	40	50	50	50	32	37.5	40	50	47.5
% Surlyn 9150	40	50	50	50	32	37.5	40	50	47.5
% Surlyn 6320	20	0	0	0	36	25	20	0	5
% Barytes	8	9	9	9	9	9	9	9	9
Thickness (inches)	0.065	0.050	0.050	0.050	0.058	0.058	0.058	0.055	0.050
Flexural Modulus**	55100	78600	78600	78600	41400	51200	55100	78600	71300
Specific Gravity	1.007	1.007	1.007	1.007	1.007	1.007	1.007	1.007	1.007
Hardness***	58	61	61	61	55	57	58	61	61
Cover									
Adiprene Prepolymer	LFPX 2950	LFPX 1951	LFPX 1951	LFPX 1951	LFPX 2950	LFPX 2950	LFPX 2950	LFPX 2950	LFPX 2950

Table 8: Compilation of Data									
Property	Ball Ex. 1	Ball Ex. 2	Ball Ex. 3	Ball Ex. 4	Ball Ex. 5	Ball Ex. 6	Ball Ex. 7	Ball Ex. 8	Ball Ex. 9
Thickness (inches)	.0265	.0380	.0300	.0251	.0345	.0270	.0380	.0295	.0348
Tensile Strength (psi)	6500	7900	7900	7900	6500	6500	6500	6500	6500
Specific Gravity	1.142	1.220	1.220	1.220	1.142	1.142	1.142	1.142	1.142
Bayshore Rebound %	62-65	54-57	54-57	54-57	62-65	62-65	62-65	62-65	62-65
Flexural Modulus**	>10K	>10K	>10K	>10K	>10K	>10K	>10K	>10K	>10K
Hardness***	47	53	53	53	47	47	47	47	47
Overall Ball									
Cut	3.0	3.0	3.0	3.0	2.5	3.0	4.0	3.5	3.0
Shear	3.0	2.5	3.0	3.0	3.0	3.0	3.0	3.0	3.5
Durability:									
Maximum	61	99	98	99	26	57	69	65	n/a
Minimum	29	63	47	69	12	19	51	14	n/a
Median	59	80	98	98	20	43	60	41	n/a
COR 143.8 fps	78.4	78.2	78.3	78.5	77.9	78.8	77.8	79.4	n/a
Ave. Diameter (inches)	1.683	1.681	1.680	1.680	1.679	1.679	1.681	1.679	1.680
Ave. Weight (grams)	45.29	45.66	45.57	45.70	45.68	45.54	45.66	45.80	45.63
Ave. Compression*	98	98	98	95	89	95	87	102	89

*PGA compression; **ASTM D790; ***Shore D, ASTM D2240;

Claims

1. A golf ball having a surface thereon, the golf ball comprising:
 a plurality of dimples disposed on the surface, wherein each of the plurality of dimples has a first edge and a second edge diametrically opposing the first edge, and the radius of curvature of a contour of each of the plurality of dimples is continuous along the entire contour from the first edge to the second edge, wherein a chord depth of a bottom center of each dimple of the plurality of dimples is between 0.0049 inch and 0.0054 inch.
2. The golf ball according to claim 1 wherein the radius of curvature of the contour at the first edge is equal to the curvature of a sphere of the golf ball.
3. The golf ball according to claim 1 wherein the contour of each of the dimples is convex from the first edge to a first inflection point and from the second edge to a second inflection point, and the contour is concave between the first inflection point and the second inflection point.
4. The golf ball according to claim 3 wherein the convex and concave sections of the dimple are each defined by the following equation:

$$P(t) = 3 B_i J_{n,i}(t) \quad 0 < t < 1$$
 wherein

$$J_{n,i}(t) = \binom{n}{i} t^i (1-t)^{n-i}$$

$$n \text{ is equal to at least five, and } i = n + 1.$$
5. The golf ball according to claim 1 wherein the radius of curvature of each point of the contour from a bottom center to the first edge is different from any other point from the bottom center to the first edge.

6. The golf ball according to claim 1 wherein the plurality of dimples comprises:

a first plurality of dimples disposed on the surface, each of the first plurality of dimples having a first diameter;

5 a second plurality of dimples disposed on the surface, each of the second plurality of dimples having a second diameter, the second diameter greater than the first diameter;

a third plurality of dimples disposed on the surface, each of the third plurality of dimples having a third diameter, the third diameter greater than the second diameter;

10 a fourth plurality of dimples disposed on the surface, each of the fourth plurality of dimples having a fourth diameter, the fourth diameter greater than the third diameter; and

a fifth plurality of dimples disposed on the surface, each of the fifth plurality of dimples having a fifth diameter, the fifth diameter greater than the fourth diameter;

15 wherein the first, second, third, fourth and fifth pluralities of dimples cover at least eighty percent of the surface of the golf ball.

20 7. The golf ball according to claim 6 wherein the plurality of dimples further comprises a sixth plurality of dimples disposed on the surface, each of the sixth plurality of dimples having a sixth diameter, the sixth diameter greater than the fifth diameter, wherein the first, second, third, fourth, fifth and sixth pluralities of dimples cover at least eighty-three percent of the surface of the golf ball.

8. The golf ball according to claim 7 wherein the plurality of dimples further comprises at least one seventh dimple disposed on the surface, the at least one seventh dimple having a seventh diameter, the seventh diameter less than the first diameter, wherein the first, second, third, fourth, fifth and sixth pluralities of dimples and the at
5 least one seventh dimple cover at least eighty-six percent of the surface of the golf ball.
9. A golf ball having a thermoset polyurethane cover with a surface thereon, the surface of the thermoset polyurethane cover coated with at least a base coat, the golf ball comprising:
- 10 a plurality of dimples disposed on the surface, wherein each of the plurality of dimples has a first edge and a second edge diametrically opposing the first edge, and the radius of curvature of a contour of each of the plurality of dimples is continuous along the entire contour from the first edge to the second edge.
- 15 10. An unfinished golf ball having an uncoated thermoset polyurethane cover, the cover having an uncoated surface, the golf ball comprising:
- a plurality of different sets of dimples disposed on the uncoated surface wherein each of the dimples has a first edge and a second edge diametrically opposing the first edge, and the radius of curvature of a contour of each of the plurality of
20 dimples is continuous along the entire contour from the first edge to the second edge.
11. A golf ball comprising:
- a cover having a plurality of different sets of dimples thereon, each of the plurality of different sets of dimples having a different diameter, the cover
25 composed of a thermoset polyurethane formed from a reactants comprising a para-phenylene diisocyanate prepolymer and a mixture of diols.

12. The golf ball according to claim 11 wherein the golf ball further comprises a boundary layer and a core.

13. A golf ball having a cover with a plurality of different sets of dimples thereon,
5 each of the plurality of different sets of dimples having a different diameter, the golf ball produced in accordance with the method comprising:

forming a core, with or without a boundary layer, the core, with or without the boundary layer, having a first volume;

heating the core, with or without the boundary layer, such that the core,
10 and optionally boundary layer, undergoes volumetric thermal expansion of the first volume to create a thermally expanded core, and optionally boundary layer; and

applying the cover over the thermally expanded core, with or without the boundary layer, the cover composed of a exothermic material.

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