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(71) Applicant(s)
**Easton Sports, Inc.**

(72) Inventor(s)
**Chuang, Hsing-Yen;Giannetti, William B.;Hernandez, Enemecio;Chauvin, Dewey**

(74) Agent / Attorney
**Spruson & Ferguson, Level 35 St Martins Tower 31 Market Street, Sydney, NSW, 2000**

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(71) **Applicant** *(for all designated States except US)*: **JAS. D. EASTON, INC.** [US/US]; Suite 202, 7855 Haskell Avenue, Van Nuys, CA 91406 (US).

(72) **Inventors; and**

(75) **Inventors/Applicants** *(for US only)*: **GIANNETTI, William, B.** [US/US]; 20840 Community Street, #5, Winnetka, CA 91306 (US). **CHAUVIN, Dewey** [US/US]; 3460 Coastal Oak Drive, Simi Valley, CA 93065 (US). **CHUANG, Hsing-Yen** [CA/US]; 12801 Moorpark Street, Studio City, CA 91604 (US). **HERNANDEZ, Enemecio** [—/US]; 6956 Kester Avenue #17, Van Nuys, CA 91406 (US).

(74) **Agent: CARREYN, Rodger, K.**; Perkins Coie LLP, P.O. Box 1208, Seattle, WA 98111-1208 (US).

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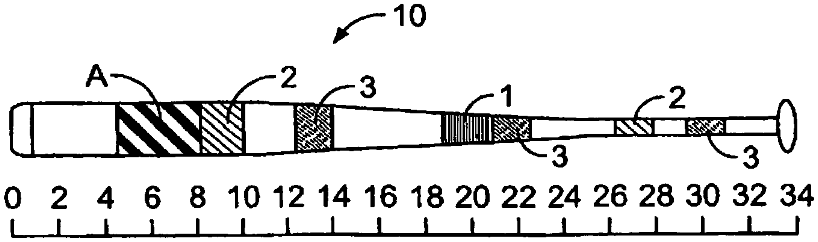

(57) **Abstract:** A ball bat (10) exhibits improved performance, flexure, and/or feel characteristics as a result of material selection and laminate tailoring.

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# OPTIMIZED BALL BAT

## BACKGROUND

**[0001]** This application claims priority to United States Application Serial Numbers 10/903,493 filed July 29, 2004, 11/034,993 filed January 12, 2005, 11/078,782 filed March 11, 2005, 11/152,036 filed June 14, 2005, and not yet assigned filed July 22, 2005.

**[0002]** Baseball and softball bat manufacturers are continually attempting to develop ball bats that exhibit increased durability and improved performance characteristics, flexure, and feel. Hollow bats having a single-wall construction, and more recently, a multi-wall construction, have been developed.

**[0003]** Single-wall bats generally include a single tubular spring in the barrel section. Multi-wall barrels typically include two or more tubular springs, or similar structures, that may be of the same or different material composition, in the barrel section. The tubular springs in these multi-wall bats are typically either in contact with one another, such that they form friction joints, are bonded to one another with weld or bonding adhesive, or are separated from one another forming frictionless joints. If the tubular springs are bonded using a structural adhesive, or other structural bonding material, the barrel is essentially a single-wall construction.

**[0004]** Hollow bats typically exhibit a phenomenon known as “trampoline effect,” which essentially refers to the rebound velocity of a ball leaving the bat barrel as a result of dynamic coupling between the bat and the ball. It is generally desirable to construct a ball bat having a high “trampoline effect,” so that the bat may provide a high rebound velocity to a pitched ball upon contact.

**[0005]** Multi-walled bats were developed in an effort to increase the amount of acceptable barrel deflection beyond that which is possible in typical single-wall and solid wood designs. These multi-walled constructions generally provide added barrel deflection, without increasing stresses beyond the material limits of the barrel materials. Accordingly, multi-wall barrels are typically more efficient at transferring energy back to the ball. In general, multi-walled bats accomplish higher performance by lowering the barrel stiffness through decoupling of the shear interfaces between the barrel layers. The lower barrel stiffness decreases the highly inefficient ball deformation and increases barrel deformation. Barrel deformation is more efficient in returning the impact energy to the ball, thus resulting in improved performance.

**[0006]** An example of a multi-wall ball bat 100 is illustrated in Fig. 1. The barrel 102 of the ball bat 100 includes an inner wall 104 separated from an outer wall 106 by an interface shear control zone ("ISCZ") 108 or layer, such as an elastomeric layer, a friction joint, a bond-inhibiting layer, or another suitable shear-controlling zone or layer. Each of the inner and outer walls 104, 106 typically includes one or more plies 110 of one or more fiber-reinforced composite materials. Additionally, or alternatively, one or both of the inner and outer walls 104, 106 may include a metallic material, such as aluminum.

**[0007]** One way that a multi-wall bat differs from a single-wall bat is that there is no shear energy transfer through the ISCZ(s) in the multi-wall barrel, i.e., through the region(s) between the barrel walls that de-couple the shear interface between those walls. As a result of strain energy equilibrium, this shear energy, which creates shear deformation in a single-wall barrel, is converted into bending energy in a multi-wall barrel. And since bending deformation is more efficient in transferring energy than is shear deformation, the walls of a multi-wall bat typically exhibit a lower strain energy loss than does a single wall design. Thus, multi-wall barrels are generally preferred over single-wall barrels for producing efficient bat-ball collision dynamics, or more efficient dynamic coupling "trampoline effect."

**[0008]** To illustrate, Fig. 2 shows a graphical comparison of the relative performance characteristics of a typical wood bat barrel, a typical single-wall bat barrel, and a typical double-wall bat barrel. As Fig. 2 indicates, double-wall bats generally perform better along the length of the barrel than do single-wall bats and wood bats. While double-wall bats have generally produced improved results along the barrel length, these results still decrease as impact occurs away from the barrel's "sweet spot."

**[0009]** The sweet spot is the impact location in the barrel where the transfer of energy from the bat to the ball is maximal, while the transfer of energy to a player's hands is minimal. The sweet spot is generally located at the intersection of the bat's center of percussion (COP), and the superposition of the bat's first three axial fundamental modes of vibration. This location, which is typically about 4 to 8 inches from the free end of the barrel (it is shown at 6 inches from the free end of the barrel in Fig. 2, by way of example only), does not move when the bat is vibrating in its fundamental bending modes. As a result, when a ball impacts the sweet spot, the bat vibration energy loss is minimal, and a player swinging the bat feels little or no vibration.

**[0010]** When a ball strikes a location of the bat that is not in the vicinity of a primary vibration node or the COP, the bat deforms into its fundamental and harmonic mode shapes. The magnitude of this deformation is a direct function of the mode that is excited and the distance from the vibration node and the COP to the impact location. If the acceleration of the bat into its mode shapes is significantly high, and is at a specific frequency, the bat will vibrate and produce shock waves.

**[0011]** Shock waves travel at a high velocity and, depending upon their energy, can actually sting a player's hands. Sting typically results from displacements in the bat handle caused by rigid body rotations resulting from impact away from the COP, and/or from modal vibrations caused by impact away from the primary vibration nodes of the ball bat. Impacts of this nature are commonly referred to as "off-center hits," because the "sweet spot" of a bat barrel is typically located at approximately the center of its length where the COP and the first primary vibration node are in close proximity to one another. The sting resulting from off-center hits may be distracting and painful to the player, and is therefore undesirable. To minimize sting, and improve the "feel" of the bat, shock waves resulting from off-center hits must be absorbed or otherwise attenuated prior to reaching the bat's handle.

**[0012]** Furthermore, the barrel regions between the sweet spot and the free end of the barrel, and between the sweet spot and the tapered or transition section (and beyond) of the bat, in particular, do not exhibit the optimal performance characteristics that occur at the sweet spot, due to energy loss resulting from vibration and rotational inertia effects. Indeed, as shown in Fig. 2, in a typical ball bat, the barrel performance decreases considerably as the impact location moves away from the sweet spot. As a result, a player is required to make very precise contact with a pitched ball, which is generally very challenging to do, to achieve optimal results and to avoid stinging bat vibration.

[0013] Another important factor in bat design is the location of the "kick point" of the bat. The kick point is the point of maximum curvature in the ball bat resulting from inertia that occurs during rotation of the bat. Low kick point bats (i.e., bats where bending occurs just above the hands) can deliver high energy but are often prone to lagging, and as a result, poor general bat performance. High kick point bats (i.e., bats where bending occurs closer to the barrel), conversely, often lack sufficient recoil energy to be effective, since typical bat diameters at this location are relatively large, and such bats are therefore very stiff in this region.

## OBJECT OF THE INVENTION

[0014] It is an object of the present invention to substantially overcome or at least ameliorate at least one of the above disadvantages.

## SUMMARY

[0015] In a first aspect, the present invention provides a ball bat including a barrel, a handle, and a tapered section joining the barrel to the handle, comprising:

a first region in the barrel, adjacent to the tapered section, including at least one solid interface shear control zone;

a second region in the barrel, adjacent to a free end of the barrel, including at least one solid interface shear control zone;

a third region in the barrel, between the first and second regions, including at least one fewer solid interface shear control zone than at least one of the first and second regions;

wherein at least one of the solid interface shear control zones in the barrel comprises a bond-inhibiting layer.

[0016] In a second aspect, the present invention provides a ball bat including a barrel, a handle, and a tapered section joining the barrel to the handle, comprising:

a first region in the barrel, adjacent to the tapered section;

a second region in the barrel, adjacent to a free end of the barrel;

a third region in the barrel, between the first and second regions, including the sweet spot of the barrel;

wherein the second and third regions each include at least one non-gaseous interface shear control zone, and the first region includes at least one more non-gaseous interface shear control zone than does the third region.

[0017] In a third aspect, the present invention provides a ball bat including a barrel, a handle, and a tapered section joining the barrel to the handle, comprising:

a first region in the barrel, adjacent to the tapered section;

a second region in the barrel, adjacent to a free end of the barrel;

a third region in the barrel, between the first and second regions;

wherein at least one of the first and second regions includes at least two non-gaseous interface shear control zones, and the third region includes at least one non-gaseous interface shear control zone.

[0018] In a fourth aspect, the present invention provides a ball bat, comprising:

a barrel;

a handle comprising a plurality of layers of at least one composite material;

at least one non-gaseous interface shear control zone separating at least two layers of the composite material in the handle; and

a tapered section joining the barrel to the handle.

[0019] In a fifth aspect, the present invention provides a ball bat including a barrel, a handle, and a tapered section joining the barrel to the handle, comprising:

a first region in the barrel, adjacent to the tapered section, comprising a plurality of layers;

a second region in the barrel, adjacent to a free end of the barrel, comprising a plurality of layers;

a third region in the barrel, between the first and second regions, comprising a plurality of layers; and

a continuous interface shear control zone traversing the first region, the third region, and the second region, wherein the continuous interface shear control zone intersects a plurality of the layers in at least one of the first region, the third region, and the second region.

[0020] In a sixth aspect, the present invention provides a ball bat, comprising:

a barrel comprising a first material;

a handle comprising a second material; and

a transition section joining the barrel to the handle, with at least a portion of the transition section comprising a third material different than the first and second materials, wherein the third material has a lower axial stiffness than the first and second materials.

[0021] In a seventh aspect, the present invention provides a ball bat, comprising:

a first region comprising a first material;

a second region comprising a second material; and a third region joining the first region to the second region, with the third region comprising a third material different than the first and second materials, wherein the third material has a lower axial Young's modulus than the first and second materials.

[0022] In an eighth aspect, the present invention provides a ball bat including a barrel, a handle, and a tapered section joining the barrel to the handle, comprising:

a first region in the barrel, adjacent to the tapered section, having a first radial stiffness;

a second region in the barrel, adjacent to a free end of the barrel, having a second radial stiffness that is greater than the first radial stiffness; and

a third region in the barrel, between the first and second regions, having a third radial stiffness that is greater than the second radial stiffness.

[0023] In a ninth aspect, the present invention provides a ball bat including a barrel, a handle, and a tapered section joining the barrel to the handle, comprising:

a first region in the barrel, adjacent to the tapered section, having a first radial stiffness;

a second region in the barrel, adjacent to a free end of the barrel, having a second radial stiffness;

a third region in the barrel, between the first and second regions, including the sweet spot of the barrel, having a third radial stiffness;

wherein the third radial stiffness is at least 1.5 times greater than the second radial stiffness, and at least three times greater than the first radial stiffness.

[0024] In a tenth aspect, the present invention provides a ball bat, comprising:

a handle comprising a first structural material;

a barrel comprising a second structural material; and

a transition section connecting the barrel to the handle, with at least a portion of the transition section including a radially inner region comprising a third structural material, and a radially outermost region comprising a dampening material having a lower axial elastic modulus than that of at least one of the first, second, and third structural materials.

[0025] In an eleventh aspect, the present invention provides a ball bat including a barrel, a handle, and a transition section joining the barrel to the handle, each comprising at least one structural material, the ball bat comprising:

a focused flexure region in at least one of the barrel, the handle, and the transition section including:

a radially outermost region comprising a dampening material having a lower axial elastic modulus than that of the at least one structural material; and

a radially inner structural region having a smaller outer diameter than that of longitudinally neighboring structural regions in the ball bat.

**[0026]** A ball bat according to one or more embodiments exhibits improved performance, flexure, and/or feel characteristics as a result of material selection and tailoring. The ball bat may be a single wall or a multi-wall composite ball bat, and may optionally include metal or other suitable materials.

**[0027]** Bat performance and/or feel may be improved in regions located away from the sweet spot of the barrel as a result of strategic placement of interface shear control zones ("ISCZs") in the bat barrel. ISCZs may additionally, or alternatively, be strategically placed in the bat handle and/or the tapered section of the bat to improve the compliance and overall performance of those sections.

**[0028]** The ball bat may include multiple layers of one or more composite materials. One or more integral shock attenuation ("ISA") regions, which have a significantly lower axial stiffness than one or more neighboring regions in the bat, may be provided to attenuate shock waves resulting from an "off-center" hit. The shock waves are absorbed or attenuated when they enter the ISA region(s). ISA regions may be incorporated into the transition region, the handle, and/or the barrel of the ball bat to provide vibration dampening, shock attenuation, stiffness control, increased flexure, and/or improved feel.

**[0029]** The ball bat may exhibit improved performance in regions located away from the sweet spot of the bat barrel, as a result of discrete lamina tailoring in those regions. In general, one or more layers, or laminae, in regions of the bat barrel away from the sweet spot, may be tailored to increase the radial compliance, i.e., to reduce the radial stiffness, of the bat barrel in those regions, so that they perform more like the sweet spot of the barrel through improved barrel mechanics. Additionally, or alternatively, one or more laminae in the bat handle and/or the tapered section of the bat may be tailored to increase (or decrease) the radial compliance in those regions.

**[0030]** In an embodiment of a composite ball bat, one or more dampening elements are located primarily at or near one or more vibration anti- nodes of the ball bat to provide vibration dampening and improved bat "feel." The dampening elements may be made of viscoelastic and/or elastomeric materials, and/or other vibration-attenuating materials, and may be located in the barrel, the handle, and/or the tapered or transition region of the ball bat.

**[0030a]** A focused flexure region may be included in the transition section (and/or in the barrel and/or the handle) of the ball bat. The focused flexure region may be made up of a radially outer region including a dampening material having a lower axial elastic modulus than that of the surrounding structural material in the ball bat, and a radially inner structural region having a smaller outer diameter than that of longitudinally neighboring structural regions in the ball bat.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0030b]** Preferred embodiments of the present invention will now be described, by way of example only, with reference to the accompanying drawings wherein:

**[0030c]** Fig. 1 is a partially cutaway view of a multi-wall ball bat.

**[0030d]** Fig. 2 is a graph comparing relative performance characteristics of a typical wood bat barrel, a typical single-wall bat barrel, and a typical double-wall bat barrel.

**[0030e]** Fig. 3 is side view of a ball bat.

**[0030f]** Figs. 4-7 are cross-sections of Zones 1-3 of the bat barrel shown in Fig. 3, according to four separate "multi-wall" embodiments.

**[0030g]** Fig. 8 is a graph comparing relative performance characteristics of a typical double-wall bat barrel and a bat barrel utilizing multiple interface shear control zones to create a "multi-wall" bat.

**[0030h]** Figs. 9-10 are cross-sections of Zones 1-3 of the bat barrel shown in Fig. 3, according to two alternative embodiments.

**[0030i]** Fig. 11 is a partial side-sectional view of a ball bat including an ISA region located in the tapered section of the ball bat.

**[0030j]** Fig. 12 is a partial side-sectional view of a ball bat including an ISA region located in the handle, and extending into the tapered section, of the ball bat.

**[0031]** Fig. 13 is a partial side-sectional view of a ball bat including a sandwich construction ISA region located in the handle, and extending into the tapered section, of the ball bat.

**[0032]** Fig. 14 is a partial side-sectional view of a ball bat including multiple ISA regions located in the barrel of the ball bat.

**[0033]** Fig. 15 is a table displaying the axial and radial Young's moduli of a ply of graphite and a ply of s-glass when oriented at various angles relative to the longitudinal axis of a ball bat.

**[0034]** Fig. 16 is a graph conceptually illustrating the amount of radial compliance required in each region of a typical bat barrel to optimize performance of the bat barrel.

**[0035]** Fig. 17 is at least a partial cross-section of Zones 1-3 of the bat barrel shown in Fig. 3.

**[0036]** Fig. 18 is a graph comparing relative performance characteristics of a typical double-wall bat barrel and an optimized bat barrel using discrete lamina tailoring.

**[0037]** Fig. 19 is a side view of a ball bat.

**[0038]** Fig. 20 is a partial sectional view of Section X of Fig. 19.

**[0039]** Fig. 21A is a magnified view of Section Y of Fig. 20, according to one embodiment.

**[0040]** Fig. 21B is a magnified view of Section Y of Fig. 20, according to another embodiment.

**[0041]** Fig. 21C is a magnified view of Section Y of Fig. 20, according to another embodiment.

**[0042]** Fig. 22 is a side view of a ball bat showing the conceptual locations of the predominant vibration anti-nodes of the ball bat, according to one embodiment.

**[0043]** Fig. 23 is a partial side-sectional view of a ball bat including a focused flexure region.

**[0044]** Fig. 24 is a partial side-sectional view of one possible configuration of the focused flexure region.

## DETAILED DESCRIPTION OF THE DRAWINGS

**[0045]** Various embodiments of the invention will now be described. The following description provides specific details for a thorough understanding and enabling description of these embodiments. One skilled in the art will understand, however, that the invention may be practiced without many of these details. Additionally, some well-known structures or functions may not be shown or described in detail so as to avoid unnecessarily obscuring the relevant description of the various embodiments.

**[0046]** The terminology used in the description presented below is intended to be interpreted in its broadest reasonable manner, even though it is being used in conjunction with a detailed description of certain specific embodiments of the invention. Certain terms may even be emphasized below; however, any terminology intended to be interpreted in any restricted manner will be overtly and specifically defined as such in this detailed description section.

**[0047]** As shown in Fig. 3, a baseball or softball bat 10, hereinafter collectively referred to as a "ball bat" or "bat," includes a handle 12, a barrel 14, and a transition region or tapered section 16 joining the handle 12 to the barrel 14. The free end of the handle 12 includes a knob 18 or similar structure. The barrel 14 is preferably closed off by a suitable cap, plug, or other end closure 20. The interior of the bat

10 is preferably hollow, which facilitates the bat 10 being relatively lightweight so that ball players may generate substantial bat speed when swinging the bat 10.

**[0048]** The ball bat 10 preferably has an overall length of 20 to 40 inches, more preferably 26 to 34. The overall barrel diameter is preferably 2.0 to 3.0 inches, more preferably 2.25 to 2.75 inches. Typical bats have diameters of 2.25, 2.625, or 2.75 inches. Bats having various combinations of these overall lengths and barrel diameters, as well as any other suitable dimensions, are contemplated herein. The specific preferred combination of bat dimensions is generally dictated by the user of the bat 10, and may vary greatly between users.

**[0049]** The bat barrel 14 may be a single-wall or a multi-wall structure. If it is a multi-wall structure, the barrel walls may be separated by one or more interface shear control zones ("ISCZs"), as described in detail in U.S. Patent Application Serial No. 10/903,493. Any ISCZ used preferably has a radial thickness of approximately 0.001 to 0.010 inches, more preferably 0.004 to 0.006 inches. Any other suitable size ISCZ may alternatively be used.

**[0050]** An ISCZ may include a bond-inhibiting layer, a friction joint, a sliding joint, an elastomeric joint, an interface between two dissimilar materials (e.g., aluminum and a composite material), or any other suitable element or means for separating the barrel into "multiple walls." If a bond-inhibiting layer is used, it is preferably made of a fluoropolymer material, such as Teflon® (polyfluoroethylene), FEP (fluorinated ethylene propylene), ETFE (ethylene tetrafluoroethylene), PCTFE (polychlorotrifluoroethylene), or PVF (polyvinyl fluoride), and/or another suitable material, such as PMP (polymethylpentene), nylon (polyamide), or cellophane.

**[0051]** In one embodiment, one or more ISCZs may be integral with, or embedded within, layers of barrel material, such that the barrel 14 acts as a one-piece/multi-wall construction. In such a case, the barrel layers at at least one end of the barrel are preferably blended together to form the one-piece/multi-wall construction. The entire ball bat 10 may also be formed as "one piece." A one-piece bat design generally refers to the barrel 14, the tapered section 16, and the handle 12 of the bat 10 having no gaps, inserts, jackets, or bonded structures that act to appreciably thicken the barrel wall(s). In such a design, the distinct laminate layers are preferably integral to the barrel structure so that they all act in unison under loading conditions. To accomplish this one-piece design, the layers of the bat 10 are preferably co-cured, and are therefore not made up of a series of connected tubes (inserts or jackets) that each have a separate wall thickness at the ends of the tubes.

**[0052]** The blending of the barrel walls into a one-piece construction, around one or more ISCZs, like tying the ends of a leaf spring together, offers a stable, durable assembly, especially for when impact occurs at the extreme ends of the barrel 14. Bringing multiple laminate layers together assures that the system acts as a unitized structure, with no one layer working independent of the others. By redistributing stresses to the extreme ends of the barrel, local stresses are reduced, resulting in increased bat durability. In an alternative multi-wall embodiment, the bat and/or barrel layers are not blended together at either end.

**[0053]** The one or more barrel walls are preferably each made up of one or more composite plies 25. The composite materials that make up the plies are preferably fiber-reinforced, and may include fibers of glass, graphite, boron, carbon, aramid (e.g., Kevlar®), ceramic, metallic, and/or any other suitable structural fibrous materials, preferably in epoxy form or another suitable form. Each composite ply preferably has a thickness of approximately 0.002 to 0.060 inches, more preferably 0.003 to 0.008 inches. Any other suitable ply thickness may alternatively be used.

**[0054]** In one embodiment, the bat barrel 14 may comprise a hybrid metallic-composite structure. For example, the barrel may include one or more walls made of composite material(s), and one or more walls made of metallic material(s). Alternatively, composite and metallic materials may be interspersed within a given barrel wall. When the barrel includes a metal portion, such as an aluminum portion, and a composite portion, regions of the composite portion may be tailored for barrel optimization, as described in detail below. In another embodiment, nano-tubes, such as high-strength carbon nano-tube composite structures, may alternatively or additionally be used in the barrel construction.

**[0055]** Increasing the number of walls in a bat barrel increases the acceptable deflection in the bat barrel, and also converts shear energy into bending energy, via the strategic placement of one or more ISCZs. As a result, the bat's trampoline effect is improved. In existing multi-wall bats, however, optimum results are not achieved throughout the entire length of the barrel, since barrel performance naturally deteriorates the further that impact occurs from the sweet spot.

**[0056]** For purposes of this description, as illustrated in Figs. 3-7, 16, and 17, the bat barrel 14 is divided into three conceptual regions or zones. The first region 21, or "Zone 1," extends approximately from the tapered section 16 of the ball bat 10 to a location near the "sweet spot" (as described above) of the bat barrel 14. The second region 22, or "Zone 2," extends approximately from the free end of the bat barrel 14 to a location near the sweet spot. The third region 24, or "Zone 3," extends between the first and second zones 21, 22, and includes the sweet spot of the barrel 14.

**[0057]** The actual dimensions and locations of these zones may vary, as may the total number of zones. Furthermore, the individual Zones may have different lengths and may occupy different regions. For example, Zone 1 may extend into the tapered section 16 of the ball bat 10, an infinite number of Zones may be delineated along the length of the barrel (and beyond), Zone 3 may be narrower than Zone 2, and so forth. Thus, the specific Zones 1-3 shown in the figures are used for ease of description only.

**[0058]** To improve barrel performance in Zones 1 and/or 2, a separate "multi-wall" approach, created by strategic placement of ISCZs in one or both of those zones, may be utilized. In one barrel embodiment, shown in Fig. 4, a first ISCZ 30 is located in Zone 3 of the bat barrel 14. The first ISCZ 30 is preferably located at or near the neutral axis of the bat barrel 14, where the shear stresses in the barrel 14 are the highest. In this manner, an optimal amount of shear stress can be converted into bending stress. The first ISCZ 30 may alternatively be located at any other radial location in Zone 3 of the bat barrel 14. The neutral axis is located approximately at the radial midpoint of the barrel wall if the barrel 14 is made up of homogeneous isotropic layers. If more than one composite material is used in the barrel 14, and/or if the material is not uniformly distributed, the neutral axis may reside at a different radial location, which can be readily determined.

**[0059]** For ease of description, the composite barrel material(s) used in the embodiments shown in Figs. 4-7 will be considered to be homogeneous, isotropic layers, such that the neutral axis of the barrel 14 is located approximately at the radial midpoint of the barrel wall. In practice, however, any suitable combination of composite and/or metallic materials may be used to construct the barrel 14, such that the neutral axis may be located at other locations in the barrel 14. Moreover, once an ISCZ is added to the barrel 14, it divides the barrel 14 into two barrel "walls," each of which has its own neutral axis, as described in detail in U.S. Patent Application Serial No. 10/712,251.

**[0060]** Returning to the embodiment shown in Fig. 4, Zone 1 includes two ISCZs 32, 34, and Zone 2 includes two ISCZs 36, 38. Each of the ISCZs 32, 34, 36, 38 may be located approximately at thirds of the radial barrel thickness, or may be positioned in another manner. By locating two ISCZs in each of Zones 1 and 2 of the bat barrel 14, those regions essentially perform as tri-wall structures, and thus exhibit increased deflection as compared to Zone 3, which is essentially a double-wall structure. As a result, the barrel deflection and trampoline effect of Zones 1 and 2 are improved relative to Zone 3, thus causing them to better approximate the performance of Zone 3 of the bat barrel 14. Accordingly, when a ball impacts the barrel 14 at either Zone 1 or Zone 2, the barrel 14 produces a trampoline effect that more closely approximates that which is produced at the sweet spot of the ball bat.

**[0061]** In the embodiment shown in Fig. 4, the ISCZs 32, 34, 36, 38 are oriented such that they are continuous with the first ISCZ 30 in Zone 3. Additionally, the ISCZs 32, 34 in Zone 1 are substantially symmetrical with the ISCZs 36, 38 in Zone 3. One or more of the ISCZs 32, 34, 36, 38 may alternatively be discontinuous with the first ISCZ 30, and the ISCZs 32, 34 in Zone 1 may be asymmetrical with the ISCZs 36, 38 in Zone 3, as further described below.

**[0062]** In the barrel embodiments shown in Figs. 5 and 6, a greater number of ISCZs are located in Zone 1 than in Zone 2 of the bat barrel 14. Such an arrangement may be preferable due to the effects of rotational inertia. During a typical bat swing, the rotational inertia produced in Zone 1 is less than that produced in Zone 2, due to the relative proximity of Zone 1, as compared to Zone

2, to the bat handle 12. Accordingly, bat performance is typically inferior in Zone 1 than in Zone 2. To counteract this difference in performance, in the embodiments shown in Figs. 5 and 6, a greater number of ISCZs are included in Zone 1 than in Zone 2, to increase the barrel deflection in Zone 1 to a greater extent than in Zone 2.

**[0063]** In the barrel embodiment shown in Fig. 5, a continuous ISCZ 40 runs through Zones 1, 2, and 3, approximately at the radial midpoint of the barrel wall. Two separate discontinuous ISCZs 42, 44 are located in Zone 1 between the ISCZ 40 and the central axis of the bat barrel 14, while an additional discontinuous ISCZ 46 is located in Zone 1 between the ISCZ 40 and the outer surface of the bat barrel 14. Thus, Zone 1 includes a total of four ISCZs, such that the barrel 14 essentially performs like a 5-wall structure in Zone 1. Zone 2 includes one discontinuous ISCZ 48 located between the ISCZ 40 and the central axis of the bat barrel 14, add an additional discontinuous ISCZ 50 located between the ISCZ 40 and the outer surface of the bat barrel 14. Thus, Zone 2 includes a total of three ISCZs, such that the barrel 14 essentially performs like a 4-wall structure in Zone 2.

**[0064]** In the barrel embodiment shown in Fig. 6, Zone 3 includes one ISCZ 60 located approximately at the radial midpoint of the barrel wall. Zone 1 includes two ISCZs 62, 64 located between the radial midpoint and the outer surface of the barrel wall, and one ISCZ 66 located between the radial midpoint of the barrel wall and the central axis of the barrel 14. Thus, Zone 1 includes a total of three ISCZs, such that the barrel 14 essentially performs like a 4-wall structure in Zone 1. Zone 2 includes one ISCZ 68 located between the radial midpoint and the outer surface of the barrel wall, and one ISCZ 70 located between the radial midpoint of the barrel wall and the central axis of the barrel 14. Thus, Zone 2 includes a total of two ISCZs, such that the barrel 14 essentially performs like a 3-wall structure in Zone 2. The three ISCZs 62, 64, 66 in Zone 1, and the two ISCZs 68, 70 in Zone 2, are all continuous with the ISCZ 60 in Zone 3.

**[0065]** The barrel embodiments shown in Figs. 5 and 6 illustrate the design flexibility contemplated herein. For example, one or more ISCZs in Zones 1 and 2 may be continuous or discontinuous with one or more ISCZs in Zone 3, one or more ISCZs in any of Zones 1-3 may be located between the radial midpoint and the outer surface of the barrel wall, at or near the radial midpoint of the barrel wall, and/or between the radial midpoint of the barrel wall and the central axis of the bat barrel 14, and so forth. Additionally, Zones 1 and 2 may include the same or a different number of ISCZs than one another.

**[0066]** Importantly, the termination of an ISCZ need not occur specifically where two zones meet. Indeed, an ICSZ may overlap, or reside in, more than one zone, and the zones may be shorter or longer than those which are depicted in the drawings. Moreover, a greater or lesser number of zones may be specified. Indeed, the “zones” are used for illustrative purposes only, and do not provide a physical or theoretical barrier of any kind. Thus, ISCZs may be positioned in the bat barrel 14 (as well as in the tapered section 16 and the handle 12) at a wide variety of locations, according to an infinite number of designs, to achieve desired barrel and overall ball bat performance characteristics.

**[0067]** To this end, in some embodiments it may be desirable to have a greater number of ISCZs in at least one barrel region located away from the sweet spot than the number of ISCZs that are located in a barrel region including the sweet spot, in order to provide improved barrel deflection and trampoline effect in those regions. Additionally, in some embodiments, it may be desirable to include a greater number of ISCZs in a barrel region between the tapered section of the bat and the sweet spot, than in a region between the sweet spot and the free end of the barrel, to compensate for the differences in the effects of rotational inertia in those regions. It is recognized, however, that any suitable number of ISCZs may be located in any regions of the barrel (and other portions of the ball bat), in any suitable configuration, depending on the design goals for a particular ball bat.

**[0068]** Fig. 7 illustrates an alternative barrel embodiment in which the bat barrel 14 includes a metal outer region 80 and a composite inner region 82. The metal outer region 80 is preferably separated from the composite inner region 82 by a suitable ISCZ 86, such as a bond-inhibiting layer. Alternatively, the non-bonded interface between the metal outer region 80 and the composite inner region may itself form an ISCZ.

**[0069]** The metal outer region 80 preferably includes aluminum and/or another suitable metallic material. The composite inner region 82 preferably includes one or more ISCZs 84, in at least Zones 1 and 2 of the barrel 14, to provide increased barrel deflection in those regions. This hybrid metal/composite construction provides increased durability, due to the presence of the metal outer region 80, while still providing the advantages of increased regional barrel deflection, due to the placement of one or more ISCZs in specific zones of the composite inner region 82. In an alternative embodiment, the barrel 14 may include a composite outer region and a metal inner region.

**[0070]** Fig. 8 shows a graphical comparison of the relative performance characteristics of a typical double-wall bat barrel (the double-wall barrel curve in the graph of Fig. 8 is the same as the double-wall barrel curve shown in the graph of Fig. 2), and a "multi-wall" bat barrel incorporating additional ISCZs in Zones 1 and 2 of the bat barrel 14. As Fig. 8 illustrates, by locating additional ISCZs in Zones 1 and 2 of the bat barrel 14, performance is generally improved along the length of the barrel 14 as compared to a typical double-wall bat.

**[0071]** Figs. 9 and 10 illustrate alternative embodiments in which a single continuous ISCZ passes through Zone 1, Zone 3, and Zone 2 of the bat barrel, essentially forming a double-wall bat barrel. The single continuous ISCZs in these embodiments, however, intersect more than one ply in each of Zones 1, 2, and 3, i.e., the thickness of each of the barrel walls varies throughout the length of the barrel. Accordingly, the bat barrel does not perform like a typical double-wall barrel having a single continuous ISCZ running along the length of the barrel at substantially the same radial location.

**[0072]** Fig. 9 illustrates a bat barrel including a single continuous ISCZ 90 that runs closer to the outer surface of the barrel 14 in Zone 3 than in Zones 1 and 2. Fig. 10 illustrates a bat barrel including a single continuous "stepped" ISCZ 92 that runs closer to the outer surface of the barrel 14 in Zone 2 than in Zone 3, and closer to the outer surface of the barrel 14 in Zone 3 than in Zone 1. The continuous ISCZ need not be symmetric, and it may be positioned inversely to the embodiments shown in Figs. 9 and 10, or it may be oriented in any other suitable fashion. By varying the location of the single continuous ISCZ throughout the bat barrel, the sweet spot of the barrel may be increased and/or modified. In an alternative embodiment, the continuous ISCZ may intersect greater than one ply in a lesser number of zones or barrel regions, such that the thickness of the barrel walls varies only in those regions.

**[0073]** It is further contemplated that ISCZs may be located in the bat handle 12 and/or the tapered section 16 (to provide increased deformation for off-barrel hits) of the ball bat 10, to provide increased deflection in those regions. Use of ICSZs in the bat handle 12 provides increased handle compliance, due to the efficient energy transfer resulting from bending deformation, as opposed to shear deformation. In addition, by using one or more ICSZs to de-couple the handle 12, the “feel” of the bat 10 is improved, as a greater number of interfaces are provided for dissipating vibration energy.

**[0074]** When one or more ISCZs are placed in the handle 12 near the tapered section 16, the ball bat 10 exhibits a quicker “snap back” to axial alignment during a swing than if the ISCZ(s) are placed closer to the user grip location of the handle 12. This quicker snap back is generally preferred by skilled players who generate high swing speeds. Placing ISCZs closer to the grip location on the handle 12 tends to rob skilled players of control, as the bat 10 is too slow to return to the axial position at or just prior to the time of ball impact.

**[0075]** For novice players, however, it may be preferable to locate ISCZ(s) in the bat handle 12 closer to the user the grip location, since lesser-skilled players tend to “push” the bat through the strike zone, and therefore do not cause the bat 10 to “bend” significantly out of axial alignment. Those skilled in the art will recognize that the specific placement of the ISCZs in the handle 12 is generally dependent upon the flexibility of the remaining bat handle 12, the weight of the bat barrel 14, the skill level of the intended user, and the materials used in the handle 12.

**[0076]** Figs. 11-15 illustrate embodiments in which one or more Integral Shock Attenuation ("ISA") regions are included in the ball bat 10. Referring to Fig. 11, an ISA region 130 is located in the transition region or tapered section 16 of the ball bat 10. The ISA region 130 (as well as the other ISA regions in the embodiments described below) includes one or more high damping and/or low modulus materials, which are effective at dissipating or attenuating vibrational energy from shock waves entering the ISA region 130. The one or more materials that make up the ISA region 130 preferably have a substantially lower longitudinal or axial Young's modulus than do the adjacent material(s) located longitudinally above and/or below the ISA region 130 in the bat construction. As a result, assuming a relatively uniform sectional thickness, the ISA region 130 has a lower axial stiffness (structural axial stiffness = axial Young's modulus * cross-sectional modulus of the material) than do the material(s) located longitudinally above and/or below the ISA region 130 (i.e., the barrel 14 and handle 12 materials in Fig. 11).

**[0077]** The ISA region 130 is preferably made of one or more materials having an axial Young's modulus that is 15-85%, or 30-70%, or 40-60%, or 50% of the axial Young's modulus of the adjacent material(s) located longitudinally above and/or below the ISA region 130 in the bat construction. The ISA region 130 may, for example, be made of a material having an axial Young's modulus of approximately 3 to 7 msi, or 4 to 6 msi, while the adjacent regions of the bat construction may have an axial Young's modulus of approximately 8 to 12 msi, or 10 msi.

**[0078]** As shown in the table of Fig. 15, the axial Young's modulus of a given ply of material (graphite and s-glass, a type of fiberglass, are shown in the table by way of example only) varies with its orientation relative to the longitudinal axis 135 of the ball bat 10. Accordingly, the specific material(s) selected for the ISA region 130 may vary depending on the orientation of the material layers within the bat structure.

**[0079]** To meet the parameters outlined in the example above, for example, the ISA region 130 may include one or more composite layers or plies including reinforcement fibers of s-glass, with substantially each ply oriented at an angle of 10° to 20° from a longitudinal axis of the ball bat (such that the axial Young' modulus of each ply is approximately 4.21 to 5.87 msi). Similarly, the ISA region 130 may include one or more composite layers or plies including reinforcement fibers of graphite, with substantially each ply oriented at an angle of 25° to 35° from a longitudinal axis of the ball bat (such that the axial Young' modulus of each ply is approximately 4.02 to 6.47 msi).

**[0080]** Other possible ISA region materials include, but are not limited to, composite layers or plies including reinforcement fibers of aramid (e.g., Kevlar®, Spectra®, and the like), PBO (Zylon®), UHMWPE (Ultra High Molecular Weight Polyethylene), and/or any other suitable material having a relatively low axial Young's modulus at various ply orientations and/or otherwise having high damping characteristics. Viscoelastic materials, such as elastomeric rubbers, may also be used in the ISA region 130. The ISA region 130 preferably further includes reinforcement resins, such as thermoset, thermoplastic, and/or infused resins, or any other suitable resins.

**[0081]** By placing the ISA region 130 in the transition region or tapered section 16 of the ball bat 10, vibrational energy can be attenuated in the bat structure without affecting barrel performance kinetics. The low modulus, high damping ISA layer(s) act as a dissipation barrier to shock waves, resulting from an off-center hit, that travel from the barrel 14 toward the handle 12 of the ball bat 10. The ISA region 130 attenuates, or absorbs, the shock waves, thus substantially or completely preventing the shock waves from reaching the bat handle 12 and the batter's hands. As a result, sting is substantially reduced or eliminated.

**[0082]** Referring to Fig. 12, in another embodiment, an ISA region 140 is located in the region of the ball bat 10 where the handle 12 merges into the tapered section 16, such that the ISA region 140 resides in both the handle 12 and the tapered section 16 of the ball bat 10. Positioning the ISA region 140 in this section is advantageous due to its relatively low cross-sectional modulus, which contributes to a relatively low axial stiffness of the section, thereby facilitating vibrational movement of the ISA region 140 to dissipate energy of shock waves entering the ISA region 140.

**[0083]** Referring to Fig. 13, in another embodiment, an ISA region 150 is formed as a sandwich construction including an insert 155, which is made of one or more highly damping materials, surrounded by one or more plies of fiber-reinforced composite material(s). The insert 155 is preferably a viscoelastic or elastomeric rubber, urethane, and/or foam material, or any other material that effectively dampens vibrational energy. Including such an insert 155 in the ISA region 150 can increase the efficiency and durability of the ISA region 150, especially in cases where the surrounding ISA region fibers have low compressive strength and/or poor strain energy recovery. The sandwich ISA region 150 may be located in the handle 12, the tapered section 16, and/or any other suitable region of the bat construction. In Fig. 14, the sandwich ISA region 150 is shown located in the region of the ball bat 10 where the handle 12 merges into the tapered section 16 by way of example only.

**[0084]** Referring to Fig. 14, in another embodiment, two (or more) ISA regions 160, 170 may be used to isolate the hitting portion of the bat barrel 14 from the handle 12 and end closure 20 of the ball bat 10. The end closure 20 of a ball bat 10 is typically stiffer than the adjacent barrel section so that the end closure 20 can provide sufficient durability to the open end of the bat barrel 14. Forging the end of the bat barrel, rolling over the rim of the barrel to form a full or nearly full closure, and/or filling the barrel with a urethane or similar semi-rigid material are typical methods used for stiffening the end of the bat barrel 14.

**[0085]** The stiffening of the end closure 20, however, may increase the vibrational response of the ball bat 10, while not allowing for sufficient barrel movement to effectively dissipate vibrational energy. By locating a first ISA region 170 adjacent to the end closure 20 of the bat 10, and a second ISA region 160 at or adjacent to the tapered section 16 (or the handle 12) of the bat 10, vibration induced at the hitting portion of the bat 10 is isolated from both the handle 12 and the end closure 20, such that little or no vibrational energy travels to the bat handle 12 (and the batter's hands), or to the relatively stiff end closure 20. As a result, sting is substantially reduced or eliminated.

**[0086]** In any of the ISA embodiments described above, the ISA region(s) used may occupy the entire radial thickness (as shown in Figs. 11-14, for example), or only a portion of the radial thickness, of the bat wall in a single-wall barrel design. In a multi-wall barrel design, an ISA region may be included in only one of the bat walls, or in two or more of the bat walls. Additionally, any ISA region used in a multi-wall barrel may occupy all or a portion of the radial thickness of one or more of the bat walls. While shock waves will generally be better attenuated when the one or more ISA regions occupy the entire radial wall thickness, any suitable portion of the radial wall thickness may be occupied by the one or more ISA regions.

**[0087]** The structural layer orientations of the one or more ISA regions may be varied to achieve a desired level of vibration attenuation. The table of Fig. 15

illustrates how the axial Young's modulus of a given ply of material (graphite and s-glass are shown as examples), and thus, the ply's axial stiffness, may be modified by varying the orientation of the ply relative to the longitudinal axis of the ball bat 10. By varying one or more ISA region plies in this manner, an ISA region can be tailored to meet the needs of a variety of players. For example, the axial stiffness throughout the one or more ISA region(s) in a ball bat 10 may be manipulated to provide more elastic recoil for less skilled players, or less elastic recoil for more skilled players. ISA regions may also be located in specific regions of the ball bat 10 to provide increased flexure in those regions.

**[0088]** Figs. 16-18 are directed to optimization of bat performance by increasing radial compliance in at least one barrel region located away from the sweet spot. In typical existing single-wall metal bats, material strength and isotropic behavior have limited the degree to which the bat stiffness can be altered along the longitudinal axis of the bat. Lowering the stiffness of a bat barrel near the end of the barrel, either at the cap or at the tapered section, has generally lowered the durability of the bat, due to insufficient material strength. The anisotropic strengths of composite materials, however, allow a bat designer to independently alter the hoop and axial stiffnesses of a bat barrel along the bat's longitudinal axis. A multi-wall composite bat may offer even larger decreases in the barrel stiffness than a single-wall design, and is therefore generally preferred. A single-wall barrel, however, can also be enhanced using the following techniques.

**[0089]** It is well known that a typical ball bat's performance lessens as hits occur away from the sweet spot of the bat barrel. In general, a ball bat's performance is less optimal the farther away from the sweet spot that a ball strikes the bat. Additionally, it is well known that the rotational inertia produced by a bat swing is greater at the free end of the bat than at the tapered section of the bat. This rotational inertia contributes to the overall performance of the bat. Thus, barrel performance, absent discrete lamina tailoring or other enhancements, is generally better in Zone 2 than in Zone 1 of a ball bat.

**[0090]** To optimize the barrel's performance throughout its length, therefore, the performance of Zone 2, and especially Zone 1, of the bat barrel 14 must be improved. Increasing the radial compliance, i.e., reducing the radial stiffness, of Zones 1 and 2, is one way to improve the performance of those regions of the bat barrel 14. By increasing the radial compliance in Zones 1 and 2, relative to Zone 3, the regions of the bat barrel 14 between the tapered section and the sweet spot, and between the free end and the sweet spot, can be made to perform more like the sweet spot of the bat barrel 14.

**[0091]** Fig. 16 is a graph conceptually illustrating the amount of radial compliance required in Zones 1 and 2 of the bat barrel 14 to optimize the barrel's performance throughout its length, i.e., to make the performance of Zones 1 and 2 better approximate the performance of Zone 3 (and the sweet spot) of the barrel 14. As shown in Fig. 16, more radial compliance, i.e., a lower radial stiffness, is required in Zone 1 than in Zone 2, due to the greater rotational inertia that occurs in Zone 2 relative to Zone 1, as described above.

**[0092]** In an exemplary embodiment, to optimize the performance of the bat barrel 14, i.e., to substantially equalize the performance in all three barrel Zones, the radial stiffness in Zone 1 is generally tailored to be 5% to 75% of the radial stiffness in Zone 3, and the radial stiffness in Zone 2 is generally tailored to be 10% to 90% of the radial stiffness in Zone 3. In one preferred embodiment, the radial stiffness in Zone 3 is tailored to be approximately 3000 pounds/inch, the radial stiffness in Zone 1 is tailored to be less than 1000 pounds/inch, and the radial stiffness in Zone 2 is tailored to be less than 2000 pounds per inch, as described in detail below.

**[0093]** The radial stiffness in each region may of course be higher or lower than these ranges, and not every region needs to be tailored to meet the compliance curve illustrated in Fig. 16. While a bat barrel meeting the compliance curve is ideally optimized, a bat barrel may be designed where radial compliance is increased (or decreased) in only one region, or in two regions, or in all three regions, and the radial compliance in any given region may be modified to a greater or lesser extent than that which is outlined in the exemplary embodiment above.

**[0094]** Fig. 17 illustrates an exemplary cross-section of at least a portion of the barrel layers of Zones 1-3, according to one embodiment. The barrel 14 may include any suitable number of composite layers, and/or layers of other material(s), and may be divided into any suitable number of walls, via one or more ISCZs, for example. Alternatively, the barrel 14 may include one single wall with no ISCZs. Furthermore, one or more Zones may be divided into two or more walls, while one or more of the other Zones may include only a single wall. Of course, any ISCZ present may terminate at any point, or extend throughout the length of the barrel 14 (or longer), and does not necessarily have to terminate where two of the conceptual Zones meet. Indeed, any ISCZ may overlap two or more Zones, and may terminate between Zones or within a single Zone, as described in detail in U.S. Patent Application Serial No. 10/903,493.

**[0095]** Increased radial compliance, or reduced radial stiffness, may be achieved in one or more barrel regions via one or more methods. In one embodiment, individual composite layers, or plies, in the bat barrel 14 may be oriented at various angles relative to the longitudinal axis of the ball bat 10, to increase the radial compliance in one or more regions of the bat barrel 14. In general, radial compliance increases, and radial stiffness decreases, the closer to the longitudinal axis of the ball bat 10 that a ply is oriented. Thus, as the angular orientation of a ply, measured from the bat's longitudinal axis, increases, the radial compliance of that ply decreases, i.e., the radial stiffness is greatest when a ply is oriented at 90 degrees from the longitudinal axis of the ball bat 10 (as shown in the table of Fig. 15, for example).

**[0096]** Accordingly, a composite ply running the length of the barrel 14, for example, may be oriented at a lesser angle, relative to the longitudinal axis of the ball bat, in Zone 1 than in Zone 2, and in Zone 2 than in Zone 3, to optimize the compliance of that ply. For example, layer 1 in Fig. 17 (which is shown oriented at substantially zero degrees relative to the bat's longitudinal axis for ease of illustration only), may be oriented at +/- 10° in Zone 1, +/- 20° in Zone 2, and +/- 60° in Zone 3, relative to the bat's longitudinal axis. This, of course, is just one of the infinite layer-orientation combinations that are possible.

**[0097]** In this example, the radial stiffness of layer 1 is less in Zone 1 than in Zone 2, and less in Zone 2 than in Zone 3 (assuming that layer 1 is made of uniform material, has uniform thickness, etc.). Accordingly, the radial compliance relative to Zone 3 is increased in Zone 2, and increased even more so in Zone 1, to better approximate the performance of Zone 3 in Zones 1 and 2 (i.e., to substantially meet the compliance curve illustrated in Fig. 16).

**[0098]** In general, optimizing the bat barrel 14 as a whole is desired, although it may be desirable to optimize only specific regions. Thus, while the concept that plies may be oriented at lesser angles, relative to the longitudinal axis of the bat 10, in regions of the bat barrel 14 requiring increased compliance, may generally be followed, each individual ply need not be oriented in such a manner to improve the overall barrel compliance. Indeed, as long as the angular orientations of the plies, relative to the longitudinal axis of the ball bat 10, in the barrel regions requiring increased radial compliance are generally smaller than those in the regions requiring less or no compliance, the relative overall radial compliance of the bat barrel 14 will generally be improved (assuming that the barrel layers are made of uniform material, have uniform thickness, etc.).

**[0099]** In another embodiment, the thickness of one or more barrel walls, in one or more regions of the barrel, may be reduced relative to the other barrel regions, to reduce the radial stiffness in the reduced thickness regions. For example, the thickness of a barrel wall in Zone 1 and/or Zone 2 may be reduced relative to the corresponding barrel wall thickness in Zone 3. By reducing the thickness of a barrel wall in one or both of those regions, the radial stiffness of those regions may be reduced relative to the radial stiffness in Zone 3 of the bat barrel 14.

**[00100]** Similar to the layer orientation embodiment described above, the barrel wall thickness may be reduced to a greater extent in Zone 1 than in Zone 2, to reduce the radial stiffness to a greater extent in Zone 1 than in Zone 2 (assuming that uniform barrel materials, layer orientations, etc. are used). As a result, the radial compliance in Zones 1 and 2 may be increased in accordance with the compliance curve illustrated in Fig. 16 to optimize the barrel performance.

**[00101]** In another embodiment, different materials, having different radial stiffness properties, may be located in different barrel regions, to optimize the barrel stiffness throughout the barrel 14. For example, a material having a lower radial stiffness (at a given orientation), than material(s) located in other regions of the bat barrel 14, may be positioned in portions of Zone 1 and/or Zone 2 (or portions of Zone 3, if desired) of the barrel 14 to reduce the radial stiffness in those regions relative to the other regions in the barrel 14. As with the embodiments described above, it is generally desirable to reduce the radial stiffness to a greater extent in Zone 1 than in Zone 2. Accordingly, a greater amount of material having a lower radial stiffness, at the predetermined layer orientation(s), is preferably located in Zone 1 than in Zone 2 of the bat barrel 14 to better optimize the bat barrel, according to the radial compliance curve illustrated in Fig. 16.

**[00102]** Similarly, a material having a higher radial stiffness (at a given orientation), than material(s) located in other regions of the bat barrel 14, may be positioned in portions of Zone 3 of the barrel 14 to increase the radial stiffness in that region relative to the other regions in the barrel 14. In general, any configuration where lower radial stiffness materials are used in regions where increased radial compliance is desired, and/or where higher radial stiffness materials are used in regions where less radial compliance is desired (e.g., to meet baseball association safety standards), is contemplated herein.

**[00103]** In another embodiment, any combination of the barrel optimization methods described above may be utilized to optimize the performance of the bat barrel 14. For example, one or more layers in Zone 1 and/or Zone 2 may be oriented at lesser angles relative to the longitudinal axis of the ball bat 10 than in Zone 3, and the thickness of one or more barrel walls in Zone 1 and/or Zone 2 may be less than the thickness of the barrel wall(s) in Zone 3. Additionally, one or more materials located in portions of Zone 1 and/or Zone 2 may have a lower radial stiffness than material(s) located in Zone 3, and/or one or more materials having a higher radial stiffness may be located in Zone 3. Any conceivable combination of these features, or any other methods for increasing radial compliance away from the bat's sweet spot, may be utilized to optimize barrel performance.

**[00104]** For ease of description, barrel regions exhibiting increased radial compliance, via any of the above methods, or any other suitable methods, will hereinafter be referred to as "radial compliance regions." Radial compliance regions may also be included in the tapered section 16 and/or the bat handle 12 of the ball bat 10, to provide increase radial compliance and deflection in those areas.

**[00105]** Locating one or more radial compliance regions in the tapered section 16 of the ball bat 10 provides higher bat deformation for off-barrel hits. By adding one or more radial compliance regions in the tapered section 16 of the ball bat 10, the performance of the bat 10, when ball impact occurs at the tapered section 16, will generally be improved, similar to the improvement in Zones 1 and 2 of the bat barrel 14, as described above.

**[00106]** Locating one or more radial/axial compliance regions in the bat handle 12 generally improves the "feel" of the bat 10, since a greater number of interfaces are provided for dissipating vibrational energy through dampening. The bat handle 12 also stores and releases energy in the form of bending and shear deformation. Accordingly, higher energy transfer can be realized by allowing the handle 12 to deform to a greater extent, via selective placement of radial compliance regions, upon the application of acceleration (i.e., upon swinging of the bat). In much the same manner used to tune the "dynamically coupled" barrel 14 described above, the handle 12 may be tuned for a specific player's swing style.

**[00107]** Some players may actually prefer higher radial stiffness region(s), i.e., regions having lower radial compliance, in the bat handle 12 near the tapered section 16 of the ball bat 10. Providing increased radial stiffness near the tapered section 16 allows the bat 10 to "snap back" to axial alignment more quickly during a swing than if lower radial stiffness is provided in that region. This quicker snap back is generally preferred by skilled players who generate high swing speeds. Locating radial compliance regions in the handle 12 near the tapered section 16, therefore, tends to rob skilled players of control, as the bat 10 is too slow to return to its axial position at or just prior to the time of ball impact.

**[00108]** For novice players, or players who generate lower swing speeds, however, it may be preferable to provide radial compliance region(s) adjacent to the tapered section 16 of the ball bat 10. Lesser-skilled players tend to "push" the bat through the strike zone, and therefore do not cause the bat 10 to "bend" significantly out of axial alignment. Additionally, it is generally desirable to locate radial compliance region(s) in the bat handle 12 closer to the user grip location, to improve the feel of the bat 10 during a swing. Those skilled in the art, therefore, will recognize that the optimal positioning of radial compliance regions in the bat handle 12 is generally dependent upon the flexibility of the remaining handle 12, the weight of the bat barrel 14, the skill level of the intended user, and the materials used in the handle 12.

**[00109]** Thus, radial compliance regions may be included in the barrel 14, the tapered section 16, and/or the handle 12 of the ball bat 10 to improve the overall performance and feel of the ball bat 10. Similarly, radial compliance may be reduced in regions not requiring increased radial compliance, such as in regions at or near the sweet spot of the bat barrel 14, and/or in the handle 12 near the tapered section 16, for players who generate high swing speeds. Reducing radial compliance in certain regions of the barrel 14 may be desirable, for example, to meet baseball association safety standards or other safety rules.

**[00110]** Fig. 18 shows a graphical comparison of the relative performance characteristics of a typical double-wall bat barrel (the double-wall barrel curve in the graph of Fig. 18 is the same as the double-wall barrel curve shown in the graph of Fig. 2), and an optimized bat barrel 14 having radial compliance regions in Zones 1 and 2 of the bat barrel 14, as described above. As Fig. 18 illustrates, by increasing radial compliance in Zones 1 and 2 of the bat barrel 14, performance is generally improved throughout the length of the barrel 14, as compared to a typical double-wall bat.

**[00111]** Importantly, the termination of any radial compliance region need not occur specifically where two Zones meet. Indeed, a radial compliance region may overlap, or reside in, more than one Zone, and the Zones may be shorter or longer than those which are depicted in the drawings. Moreover, a greater or lesser number of Zones may be specified. Indeed, the "Zones" are used for illustrative purposes only, and do not provide a physical or theoretical barrier of any kind. Thus, radial compliance regions may be positioned, oriented, and/or or created in the bat barrel 14 (as well as in the tapered section 16 and the handle 12) at a wide variety of locations, according to an infinite number of designs, to achieve desired barrel and overall ball bat performance characteristics.

**[00112]** To this end, the embodiments illustrated in figures 16-18 are generally directed to a ball bat having increased radial compliance in at least one barrel region located away from the sweet spot of the barrel, to optimize the performance of the bat. Additionally, in one embodiment, it is preferable to increase the radial compliance to a greater extent in the barrel region between the tapered section of the bat and the sweet spot, than in the barrel region between the sweet spot and the free end of the barrel, to compensate for the different effects of rotational inertia in those regions. It is recognized, however, that radial compliance may be increased (or decreased) in any regions of the barrel (and/or other portions of the ball bat), in any suitable configuration, depending on the design goals for a particular ball bat.

**[00113]** Figures 19-22 are directed to a ball bat including constrained layer dampening. Fig. 20 illustrates an interior section of one embodiment of a bat barrel 14 including one or more vibration dampening elements, or dampeners 230, incorporated into the composite layers 232 of the bat barrel 14. The one or more dampeners 230 may be made of any suitable vibration attenuating or dampening material(s), i.e., any material(s) having a lower axial elastic modulus than that of the neighboring or surrounding materials in the ball bat. In one embodiment, one or more of the dampeners 230 may have an axial elastic modulus that is 0.01 to 50%, or 0.02 to 25%, or 0.05 to 10%, or 0.10 to 5.0%, or 0.50 to 2.5%, or 0.75 to 1.25%, of the axial elastic modulus of the neighboring or surrounding materials in the ball bat 10. Any material having a lower elastic modulus than the neighboring or surrounding materials in the ball bat 10 may be used, however.

**[00114]** In one embodiment, one or more of the dampeners 230 are made of one or more viscoelastic and/or elastomeric materials, such as elastomeric rubber, silicone, gel foam, or other similar materials. The dampeners 230 may alternatively or additionally be made of any other suitable dampening materials, including but not limited to PBO (polybenzoxazole), UHMWPE (ultra high molecular weight polyethylene, e.g., Dyneema®), fiberglass, dacron® ("polyethylene terephthalate" - PET or PETE), nylon® (polyamide), certran®, Pentex®, Zylon®, Vectran®, and/or aramid, that are effective at dissipating or otherwise attenuating vibrational energy relative to the neighboring or surrounding materials in the ball bat 10.

**[00115]** Thus, depending on the one or more materials that are used to form the structural layers of the ball bat 10, a wide variety of dampening materials (relative to those neighboring or surrounding structural materials) may be used in the ball bat 10. For example, a soft rubber dampening material may have an axial elastic modulus of approximately 10,000 psi, whereas a "dampening" material such as aramid may have an axial elastic modulus of approximately 12,000,000 psi. While the dampening effect of aramid is significantly less than that of a typical soft rubber material, it may still have an appreciable dampening effect on surrounding or neighboring structural bat material(s) having an even higher axial elastic modulus, and it may provide increased durability relative to softer materials. Accordingly, materials having a relatively high axial elastic modulus, such as aramid, may be used as effective dampeners in some ball bat constructions.

**[00116]** Each dampener 230 may form part of one or more of the composite layers within the ball bat 10, or may be included as a separate layer. Each dampener 230 may also optionally be sandwiched between neighboring composite layers, as shown in Fig. 21A. Each dampener 230 is preferably bonded, fastened, or otherwise attached or fused to the surrounding composite material in the ball bat 10. The composite material at one or both ends of the ball bat 10, and/or at locations adjacent to one or both ends of the dampener 230, may also be fused or blended together to provide a continuous load path between the bat structure and the dampener 230.

**[00117]** In the embodiment illustrated in Fig. 21A, the dampener 230 is shown located substantially at the mid-plane of a barrel wall, where shear stresses are the highest, by way of example only. One or more dampeners 230 may alternatively or additionally be located anywhere within the radial thickness of the one or more barrel walls that make up the bat barrel 14, or within any of the other regions of the ball bat 10. Fig. 21B, for example, illustrates an embodiment in which a dampener 230 is located at an inner portion of a barrel wall. In this embodiment, at least one inner layer of composite material preferably confines the dampener 230 within the barrel structure, and preferably extends at least one inch or more beyond each end of the dampener 230. In another embodiment, one or more dampeners 230 may additionally or alternatively be similarly positioned at an outer portion of one or more barrel walls, or other bat regions.

**[00118]** Fig. 21C shows an embodiment in which multiple dampeners 230 are positioned in series within a single layer at the inner portion of a barrel wall. In another embodiment, multiple dampeners 230 may additionally or alternatively be located in parallel, i.e., positioned at approximately the same longitudinal location of the ball bat 10 at different radial locations within the barrel 14 or other bat region. If the ball bat 10 includes a multi-wall barrel 14, and/or one or more ISCZs, dampeners 230 may be located in one or more of the barrel walls, at any suitable locations, including at the plane between adjacent barrel walls and/or against one or both sides of an ISCZ. Thus, one or more dampeners 230 may be located anywhere within the barrel 14, the transition region 16, and/or the handle 12 of the ball bat 10 to achieve a desired response, as further described below.

**[00119]** The one or more dampeners 230 may each have any suitable length and/or thickness. For example, a dampener 230 may be 0.25 to 5.00 inches in length (or longer, if desired), and 0.004 to 0.100 inches thick (or any other suitable thickness). In one embodiment, each dampener has a thickness of 0.008 to 0.020 inches. While the dampeners 230 may be any conceivable size, and could theoretically run approximately the entire length of the ball bat 10, it is preferable to incorporate one or more discrete dampeners of smaller size, at one or more strategic locations, to selectively dampen vibration while not adding substantial weight to, or significantly lowering the durability of, the ball bat 10.

**[00120]** Fig. 22 illustrates one embodiment of a 34 inch ball bat 10, including the locations of the predominant vibration anti-nodes of the ball bat 10. An anti-node is a point in a standing wave at which the amplitude is a maximum. Thus, under impact conditions, the vibration anti-nodes of the ball bat 10 are located at the regions of maximum deflection (specific to the mode shape of the bat in vibration) in the ball bat 10. The vibration anti-nodes, as used herein, generally refer to anti-nodes of the bending and/or hoop modes of the ball bat 10. The locations of one or more of these vibration anti-nodes, which are readily determinable by those skilled in the art, may vary depending on the overall dimensions and makeup of the ball bat 10. Thus, the specific anti-node locations illustrated in Fig. 22 are shown by way of example only.

**[00121]** In one embodiment, one or more vibration dampeners 230 are located at, and are optionally substantially centered about, one or more of the vibration anti-nodes in the ball bat 10 to reduce the amplitude of vibrations excited at those locations by off-center hits. Alternatively, one or more dampeners 230 may be located adjacent to or substantially near one or more of the vibration anti-nodes, since deflection is also relatively high at bat regions near the anti-nodes. Terms and phrases used herein to describe dampener location, such as "substantially at" or "at or near," generally refer to the idea that a dampener is ideally located directly at an anti-node location, but that a dampener could alternatively or additionally be located near an anti-node to produce a dampening effect. Thus, such language is intended to mean that a dampener may be located directly at an anti-node, or very close to the anti-node.

**[00122]** The one or more dampeners 230 reduce the amplitude of impact reaction forces and modal vibrations by absorbing significant shear strain energy and dissipating it into the environment in the form of heat energy. A dampener 230 made from a viscoelastic material, for example, dissipates energy at a lower rate (due to hysteresis) than a typical elastic material, such that dissipation of the impact energy occurs relatively slowly, resulting in high dampening of the initial impact impulse.

**[00123]** One preferred location for a dampener 230 is at or near the anti-node of the first bending mode (i.e., of the fundamental harmonic) of the ball bat 10, indicated by a "1" in Fig. 22. The anti-node of the first bending mode exhibits the largest deformation, and the highest strain energy, of all the anti-nodes of the principal modes. Thus, by locating one or more dampeners 230 at or near the anti-node of the first bending mode, i.e., at approximately 19 to 21 inches from the cap end of the ball bat 10 shown in Fig. 22, a large amount of vibration energy resulting from off-center hits may be dissipated or otherwise attenuated.

**[00124]** One or more dampeners 230 may also be located at or near the anti-nodes of the second and/or third bending modes (which do not exhibit as much deformation as does the anti-node of the first bending mode, but which still contribute to vibrational effects) of the ball bat 10, indicated by the numbers "2" and "3", respectively, in Fig. 22, to suppress the second and/or third bending modes. To suppress the second bending mode of the ball bat 10 illustrated in Fig. 22, for example, one or more dampeners 230 may be positioned at approximately 8 to 10 inches, and/or 26 to 28 inches, from the cap end of the ball bat 10.

**[00125]** In another embodiment, a dampener 230 is additionally or alternatively positioned at or near the anti-node of the fundamental or first hoop mode, indicated by the letter "A" in Fig. 22, of the ball bat 10. Because this anti-node, which is located approximately 4 to 8 inches from the cap end of the ball bat 10 illustrated in Fig. 22, is substantially at the intersection of the COP and the first and second harmonic bending nodes (i.e., at the "sweet spot" of the ball bat), minimal, if any, vibration occurs at this location. Thus, only a minimal amount of vibration attenuation (if any) is required at this location to prevent sting. By adding one or more dampeners 230 at or near this “sweet spot” location, however, the perceived size of the sweet spot generally increases, providing improved feel for batters.

**[00126]** Multiple dampeners 230 may be located throughout the bat structure, at or near any combination of the anti-nodes, to minimize vibrations in the ball bat 10. Each of the dampeners 230 is preferably discrete and discontinuous with respect to other dampeners 230, and is located primarily at or near a single anti-node. It is contemplated, however, that one or more individual dampeners 230 could overlap two or more anti-nodes.

**[00127]** For example, a single dampener 230 could be positioned to overlap the anti-node "1" of the first bending mode and the anti-node "3" of the third bending mode located in the transition region of the ball bat (e.g., at approximately 19-22 inches from the cap end of the ball bat 10 illustrated in Fig. 22). To minimize the overall weight and maintain sufficient durability of the bat structure, however, it is generally preferred that substantially each of the dampeners 230 is discrete and strategically positioned at or near a single vibration anti-node. As described above, multiple dampeners may be located in parallel, i.e., at different radial locations, at or near a given anti-node.

**[00128]** Figs. 23 and 24 are directed to a ball bat including one or more focused flexure regions. Fig. 23 illustrates one embodiment of a ball bat 10 including a focused flexure region 330. The focused flexure region 330 includes a radially inner region 331 comprising one or more structural composite materials, such as those described above, and a radially outer region 333 comprising one or more "non-structural" materials having a lower axial elastic modulus than the neighboring structural composite materials in the ball bat 10. The focused flexure region 330 is preferably located predominantly or entirely in the transition region 16 of the ball bat, but it may alternatively or additionally be located partially or completely in the handle 12 and/or the barrel 14 of the ball bat 10. Furthermore, more than one focused flexure region 330 may be included in the ball bat 10.

**[00129]** The structural radially inner region 331 of the focused flexure region 330 may be continuous with the neighboring structural materials 335 in the ball bat 10 or may be a separate region with defined beginning and/or ending locations. The thickness of the radially inner region 331 may be substantially equal to the thickness of the structural materials or layers 335 in the neighboring regions, including throughout the handle, the barrel, and/or the transition section (i.e., the structural "tube" may have a relatively uniform thickness throughout the ball bat 10), or the thicknesses of the radially inner region 331 may vary relative to one or more of the other structural regions in the ball bat 10.

**[00130]** By including the "indented" focused flexure region 330, the outer and inner diameters of the structural layers or material(s), or structural "tube," in the radially inner region 331 are reduced relative to neighboring regions in the ball bat 10. The structural axial stiffness in bending (EI) of a material region, at a given longitudinal location of the ball bat 10, is a function of the outer diameter of the material region, $D_0$, the material thickness, ($D_0$-$D_i$), and the material axial elastic modulus, E, as governed by the following equation:.

$$\text{Tube Structural Stiffness in Bending} = EI = \frac{\pi E}{64}\left(D_0^4 - D_i^4\right)$$

**[00131]** In the drawings, the reference symbols $D_0$, $D_0$', $D_i$, and $D_i$' indicate locations in the ball bat 10 to which the respective diameters are measured. For example, $D_0$ refers to a location to which the outer diameter of the ball bat 10 is measured. $D_i$ refers to a location to which the inner diameter of the wall(s) or tube(s) of the ball bat 10, at any region except for the focused flexure region 330, is measured. Thus, $D_0$ and $D_i$ typically vary between and/or within the handle 12, the transition section 16, and/or the barrel 14. $D_0$' and $D_i$' refer to locations in the ball bat 10 to which outer and inner diameters, respectively, of the radially inner region 331 of the focused flexure region 30 are measured.

**[00132]** By reducing the outer diameter $D_0$' of the structural material in the radially inner region 331 of the focused flexure region 330, the axial stiffness of the structural "tube" is significantly reduced at that location relative to neighboring regions in the ball bat 10. Accordingly, the focused flexure region 330 generally coincides with the "kick point" of the ball bat 10. The kick point refers to the point of maximum curvature in the ball bat 10 resulting from inertia that occurs during rotation of the bat 10.

**[00133]** One possible location for the focused flexure region 330 is in the transition section 16, near the primary fundamental vibration anti-node of the ball bat 10. Generally, this location is at or near the end of the handle 12 just as the outer bat diameter ($D_0$) starts to increase. This region is subjected to the highest axial deflection during a swing and, as a result, can be tuned to a player's specific swing style by utilizing the natural tendency of the bat 10 to bend in this specific area. Some advantages to this location are that the outer diameter ($D_0$) of a typical ball bat 10 is not so large at this location that it significantly increases the sectional stiffness, and that there is enough barrel mass beyond this section for the inertial load during the bat swing acceleration to cause the bat to bend. Additionally, ball impacts are typically rare in this location, so bat durability should not be significantly adversely affected by making the bat axially flexible in this location.

**[00134]** For a specific homogeneous material, such as aluminum ($E = 10^6$ psi), for example, the bending stiffness of a wall or structural tube having an outer diameter $D_0$ of 1.50 inches and a thickness ($D_0$-$D_i$) of 0.10 inches is approximately 235% greater (i.e., 2.35 times stiffer) than an identical thickness wall or tube having an outer diameter $D_0$' of 1.15 inches. Accordingly, it requires approximately 2.35 times the load to bend the 1.50 inch diameter tube to the same deflection as the 1.15 inch diameter tube. Put another way, for a fixed energy swing, a 1.15 inch diameter structural region of a ball bat 10 will deflect and rebound with approximately 235% more potential energy than will a 1.50 inch diameter structural region (the actual difference will vary depending upon the material properties of the radially outer region 333 of the focused flexure region 330).

**[00135]** Thus, by making minor changes to the local diameter ($D_0$') of the structural material in the radially inner region 331 of the focused flexure region 330, the local axial stiffness and flexibility of the ball bat 10 may be significantly reduced or otherwise altered. To achieve the desired effect of these diameter changes in the structural material(s), the radially outer region 333 of the focused flexure region 330 is preferably made up of one or more materials having a lower axial elastic modulus than the axial elastic modulus/moduli of the one or more neighboring structural materials 335 in the ball bat 10.

**[00136]** These lower axial elastic modulus materials, referred to herein as "dampening materials," may include one or more viscoelastic and/or elastomeric materials, such as elastomeric rubber, silicone, gel foam, or other similar materials that have relatively low axial elastic moduli. Any other material(s) having a lower elastic modulus than the neighboring structural materials 335 in the ball bat may alternatively or additionally be used in the radially outer region 333, including, but not limited to, PBO (polybenzoxazole), UHMWPE (ultra high molecular weight polyethylene, e.g., Dyneema®), fiberglass, dacron® ("polyethylene terephthalate" - PET or PETE), nylon® (polyamide), certran®, Pentex®, Zylon®, Vectran®, and/or aramid.

**[00137]** Thus, depending on the one or more materials that are used to form the structural layers 335 of the ball bat 10, a wide variety of dampening materials (relative to the neighboring or surrounding structural materials 335) may be used in the radially outer region 333 of the focused flexure region 330. For example, a soft rubber dampening material may have an axial elastic modulus of approximately 10,000 psi, whereas a "dampening" material such as aramid may have an axial elastic modulus of approximately 12,000,000 psi. While the axial elastic modulus of aramid is significantly greater than that of a typical soft rubber material, aramid may still have an appreciable dampening effect on surrounding or neighboring structural bat material(s) having an even higher axial elastic modulus, and it may provide increased durability relative to softer materials. Accordingly, materials having a relatively high axial elastic modulus, such as aramid, may be used as effective dampeners in some ball bat constructions.

**[00138]** Fig. 24 illustrates one possible configuration of the focused flexure region 330, although any other shape or configuration suitable for providing reduced axial stiffness in the focused flexure region 330 may alternatively be used. The radially outer region 333 of the focused flexure region 330 preferably has a depth (approximately equal to $D_O$-$D_O$') of approximately 0.060 to 0.250 inches, or 0.080 to 0.120 inches. Any other depth may alternatively be used. If an ISCZ or similar region is included in the ball bat 10 (in a multi-wall bat, for example), the radially outer region 333 may have a depth extending up to (or passing through an opening in) the ISCZ.

**[00139]** The base of the radially outer region 333 preferably has a length of 0.20 to 1.50 inches, or 0.40 to 0.80 inches, and the outer surface (corresponding to the outer surface of the ball bat 10) of the radially outer region 333 preferably has a length of approximately 0.25 to 2.50 inches, or 0.50 to 1.50 inches. The radially outer region 333 may have any other suitable dimensions, and may or may not have tapered end regions 334 (as shown in Fig. 24, for example).

**[00140]** In one embodiment, the depth of the radially outer region 333 is 60% to 150%, or 80% to 120%, of the thickness of the radially inner region 331. Additionally or alternatively, the outer diameter $D_O$' of the radially inner region 331 is 60% to 95%, or 70% to 85%, of the outer diameter $D_O$ of the neighboring longitudinal regions in the ball bat 10. Additionally or alternatively, the focused flexure region 330 is tuned to have an axial stiffness that is 10% to 90%, or 30% to 70%, or 40% to 60%, of the axial stiffness of the neighboring longitudinal regions of the ball bat. This reduced axial stiffness may be the result of the material in the radially outer region 333 having a lower axial elastic modulus than neighboring regions in the ball bat 10 and/or from the radially inner region 331 having a smaller outer diameter $D_0$' and/or thickness ($D_0$'-Di') than neighboring longitudinal regions in the ball bat 10. One or more of these relative percentages may vary beyond the limits described herein, depending on the dictates of a given bat design.

**[00141]** The location, shape, and configuration of the one or more focused flexure regions 330 may vary based upon the structural requirements of a given ball bat 10. By locating the focused flexure region 330 in the transition section 16, for example, bat flexure can be increased and vibrational energy can be attenuated from the bat structure, thus increasing barrel performance kinetics. The axial stiffness and location of the focused flexure region 330 can be tuned to provide specific recoil for varying styles of batting (e.g., push or snap styles). The focused flexure region 330 may, for example, be located closer to the barrel 14 in a typical baseball bat, or closer to the handle 12 in a typical fast pitch softball bat.

**[00142]** In general, a focused flexure region 330 may be positioned in the tapered section 16 toward the barrel 14 to provide increased "snap-back" during a swing, whereas it may be positioned in the tapered section 16 toward the handle 12 to provide less snap-back for players who tend to "push" the bat during a swing. Thus, depending on the requirements of a given bat design, one or more focused flexure regions 330 may be located anywhere within the bat structure.

**[00143]** The various ball bat embodiments described herein may be constructed in any suitable manner. In one embodiment, the ball bat 10 is constructed by rolling the various layers of the bat 10 onto a mandrel or similar structure having the desired bat shape. Any ISCZs, ISA regions, radial compliance regions, dampening elements, and/or focused flexure regions are preferably strategically created, placed, located, and/or oriented, as described in the above embodiments.

**[00144]** The ends of the material layers are preferably “clocked,” or offset, from one another so that they do not all terminate at the same location before curing. Additionally, if varying layer orientations and/or wall thicknesses are used, the layers may be staggered, feathered, or otherwise angled or manipulated to form the desired bat shape. Accordingly, when heat and pressure are applied to cure the bat 10, the various layers blend together into a distinctive "one-piece," or integral, construction. Furthermore, during heating and curing of the composite layers, any dampeners 230 and/or dampening material used in the radially outer region 333 of a focused flexure region 330 preferably fuse with the surrounding composite material and become an integral part of the overall bat structure.

**[00145]** Put another way, all of the layers of the bat are “co-cured” in a single step, and blend or terminate together at at least one end, resulting in a single-piece structure with no gaps (at the at least one end), such that the barrel 14 is not made up of a series of tubes each with a separate wall thickness that terminates at the ends of the tubes. As a result, all of the layers act in unison under loading conditions, such as during striking of a ball. One or both ends of the barrel 14 may terminate together in this manner to form a one-piece barrel 14, including one or more barrel walls (depending on whether any ISCZs are used). In an alternative design, neither end of the barrel is blended together, such that a multi-piece construction is formed.

**[00146]** Thus, while several embodiments have been shown and described, various changes and substitutions may of course be made, without departing from the spirit and scope of the invention. The invention, therefore, should not be limited, except by the following claims and their equivalents.

The claims defining the invention are as follows:

1. A ball bat including a barrel, a handle, and a tapered section joining the barrel to the handle, comprising:

a first region in the barrel, adjacent to the tapered section, including at least one solid interface shear control zone;

a second region in the barrel, adjacent to a free end of the barrel, including at least one solid interface shear control zone;

a third region in the barrel, between the first and second regions, including at least one fewer solid interface shear control zone than at least one of the first and second regions;

wherein at least one of the solid interface shear control zones in the barrel comprises a bond-inhibiting layer.

2. The ball bat of claim 1 wherein at least one of the first and second regions includes at least one interface control zone that is continuous with at least one interface shear control zone in the third region.

3. The ball bat of claim 1 wherein at least one of the first and second regions includes at least one interface shear control zone that is discontinuous with at least one interface shear control zone in the third region.

4. The ball bat of claim 1 wherein at least one of the interface shear control zones in the barrel comprises an elastomeric layer.

5. The ball bat of claim 1 wherein the barrel has a substantially uniform thickness, and wherein the third region includes a single interface shear control zone located substantially at a radial midpoint of the barrel.

6. The ball bat of claim 1 wherein the barrel has a substantially uniform thickness, and wherein the first region includes two interface shear control zones located substantially at one third and two thirds of the barrel thickness.

7. The ball bat of claim 1 wherein the barrel comprises at least one composite material selected from the group consisting of glass, graphite, boron, carbon, aramid, and ceramic.

8. The ball bat of claim 1 wherein the barrel comprises an outer or inner layer of metal, and a corresponding inner or outer layer of composite material, wherein at least one of the interface shear control zones is located within the layer of composite material.

9. The ball bat of claim 1 wherein the first region includes at least one more interface control zone than does the second region.

10. The ball bat of claim 1 further comprising at least one interface shear control zone in at least one of the handle and the tapered section.

11. A ball bat including a barrel, a handle, and a tapered section joining the barrel to the handle, comprising:

a first region in the barrel, adjacent to the tapered section;

a second region in the barrel, adjacent to a free end of the barrel;

a third region in the barrel, between the first and second regions, including the sweet spot of the barrel;

wherein the second and third regions each include at least one non-gaseous interface shear control zone, and the first region includes at least one more non-gaseous interface shear control zone than does the third region.

12. The ball bat of claim 11 wherein the second region includes at least one more interface shear control zone than does the third region.

13. The ball bat of claim 12 wherein the first region includes at least one more interface shear control zone than does the second region.

14. The ball bat of claim 11 further comprising at least one interface shear control zone in at least one of the handle and the tapered section.

15. A ball bat including a barrel, a handle, and a tapered section joining the barrel to the handle, comprising:

a first region in the barrel, adjacent to the tapered section;

a second region in the barrel, adjacent to a free end of the barrel;

a third region in the barrel, between the first and second regions;

wherein at least one of the first and second regions includes at least two non-gaseous interface shear control zones, and the third region includes at least one non-gaseous interface shear control zone.

16. The ball bat of claim 17 wherein the at least one of the first and second regions is divided into at least three substantially equally thick barrel walls via the at least two interface shear control zones, and the third region is divided into at least two substantially equally thick walls via the at least one interface shear control zone.

17. A ball bat, comprising:

a barrel;

a handle comprising a plurality of layers of at least one composite material;

at least one non-gaseous interface shear control zone separating at least two layers of the composite material in the handle; and

a tapered section joining the barrel to the handle.

18. A ball bat including a barrel, a handle, and a tapered section joining the barrel to the handle, comprising:

a first region in the barrel, adjacent to the tapered section, comprising a plurality of layers;

a second region in the barrel, adjacent to a free end of the barrel, comprising a plurality of layers;

a third region in the barrel, between the first and second regions, comprising a plurality of layers; and

a continuous interface shear control zone traversing the first region, the third region, and the second region, wherein the continuous interface shear control zone intersects a plurality of the layers in at least one of the first region, the third region, and the second region.

19. The ball bat of claim 18 wherein the continuous ISCZ is stepped between at least two of the first region, the third region, and the second region.

20. The ball bat of any one of claims 1, 11, 15 or 18 wherein the first region in the barrel extends into the tapered section of the ball bat.

**Dated 28 February, 2011**

**Easton Sports, Inc.**

**Patent Attorneys for the Applicant/Nominated Person**

**SPRUSON & FERGUSON**

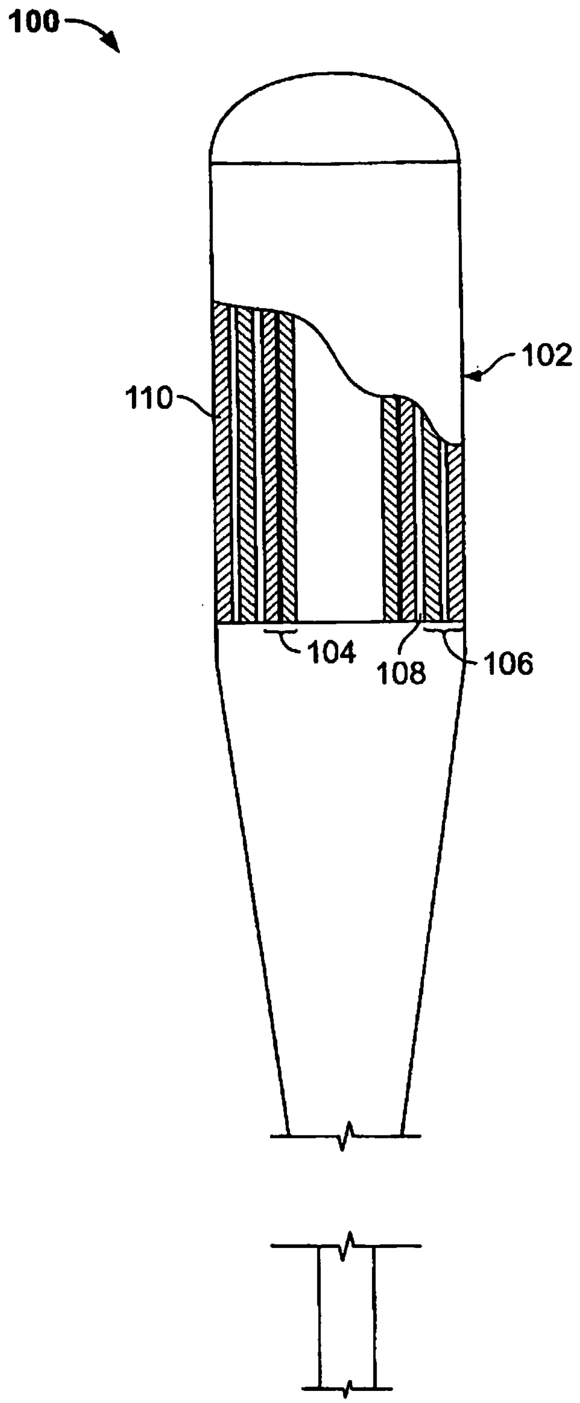

FIG. 1

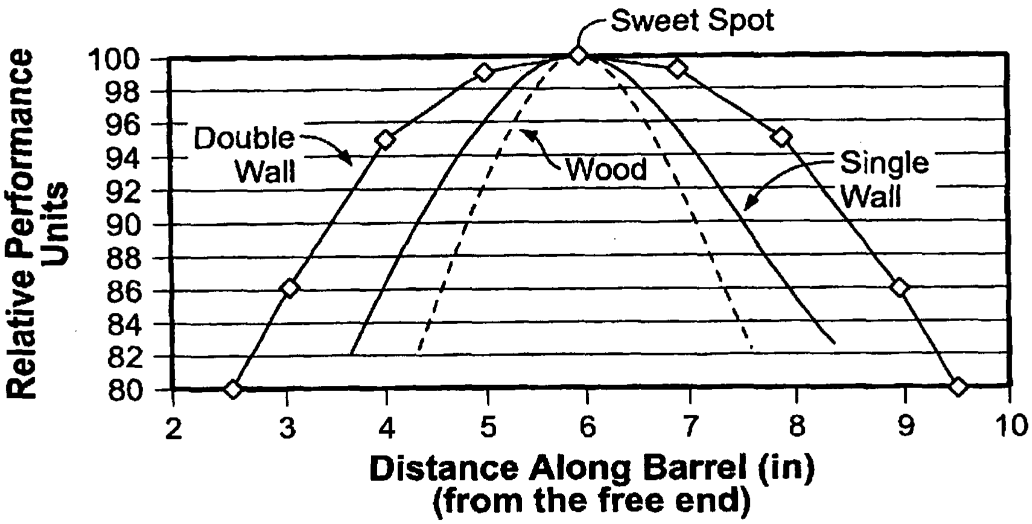
Sweet Spot
Relative Performance Units
100
98
96
94
92
90
88
86
84
82
80
Double Wall
Wood
Single Wall
2
3
4
5
6
7
8
9
10
Distance Along Barrel (in) (from the free end)

FIG. 2

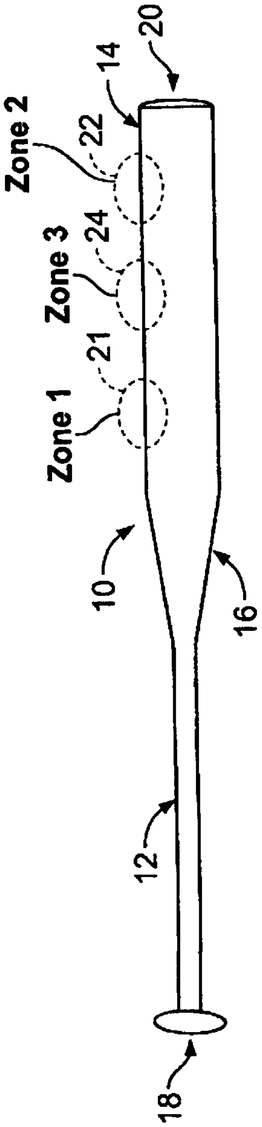
Zone 2
Zone 3
Zone 1
22
24
21
14
20
10
16
12
18

FIG. 3

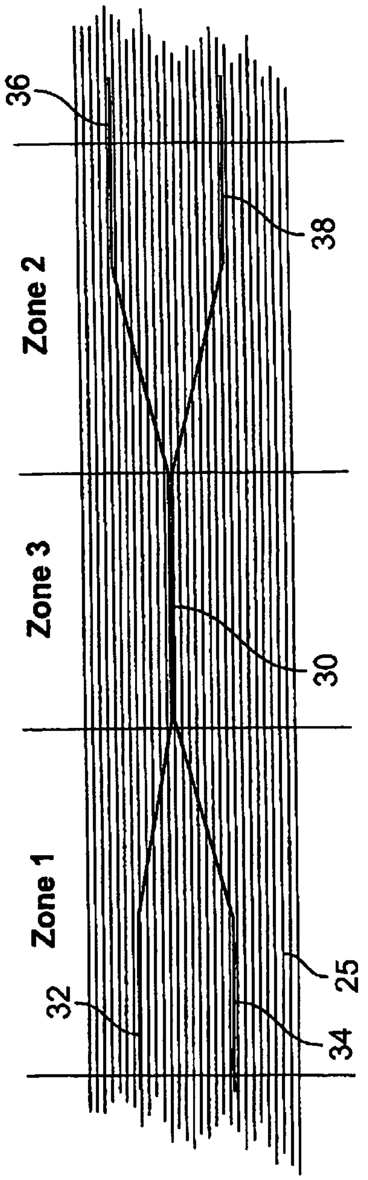
36
38
Zone 2
Zone 3
30
Zone 1
32
34
25

FIG. 4

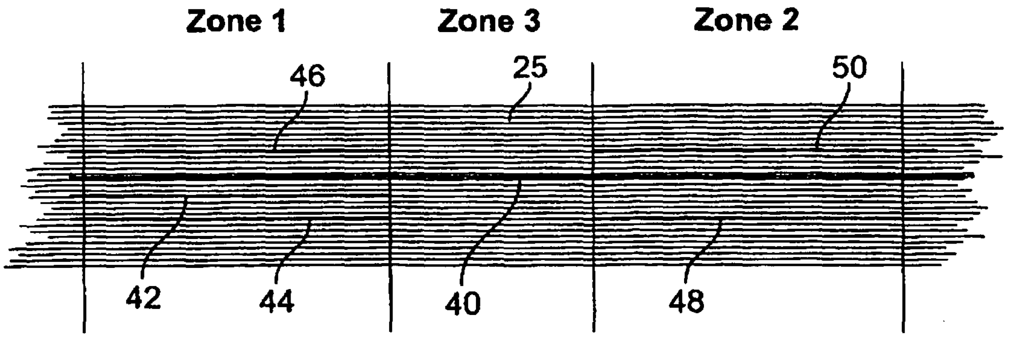

FIG. 5

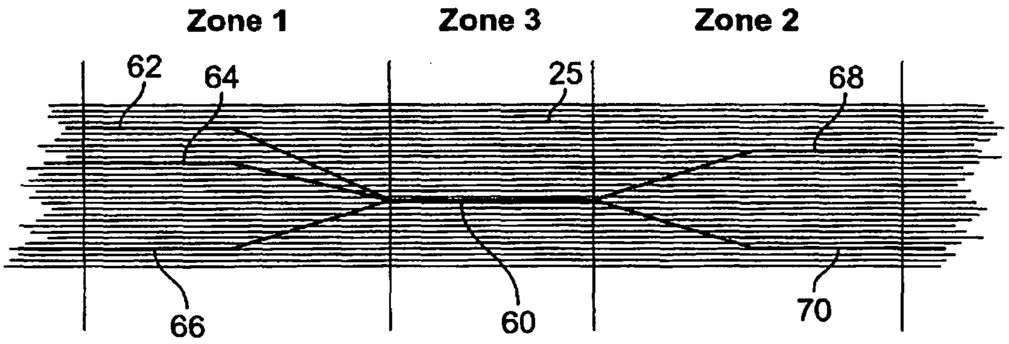

FIG. 6

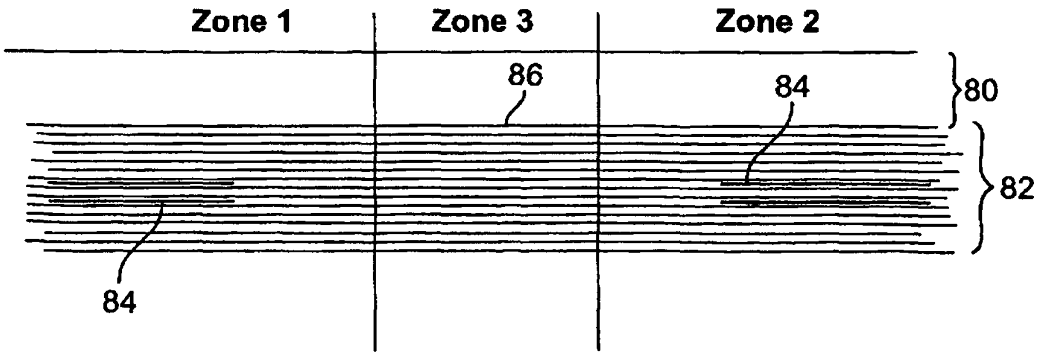

FIG. 7

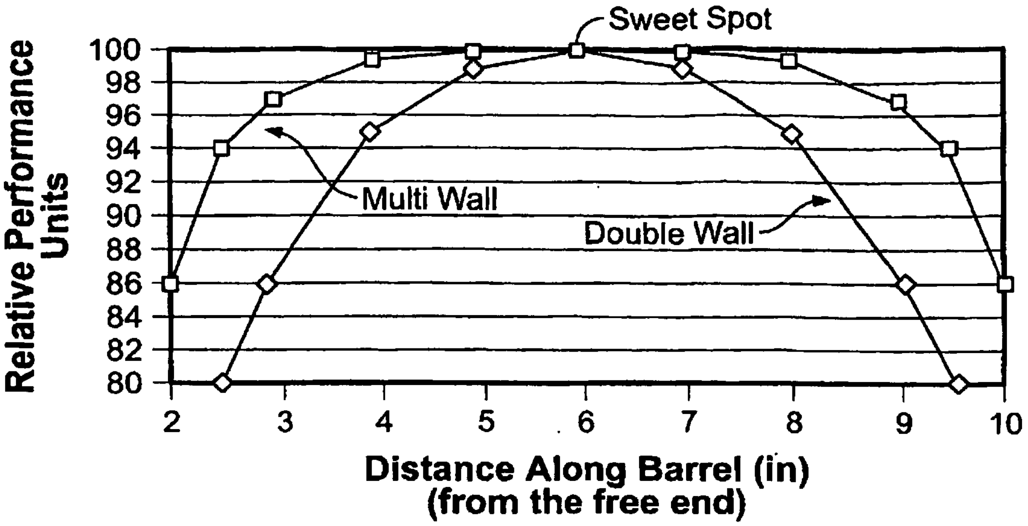

FIG. 8

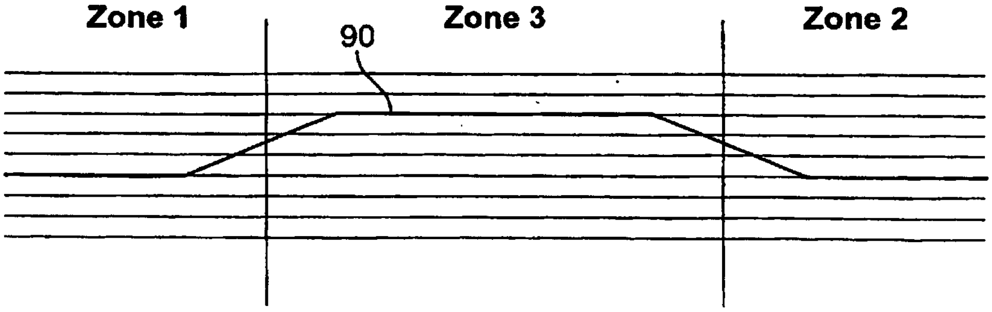

FIG. 9

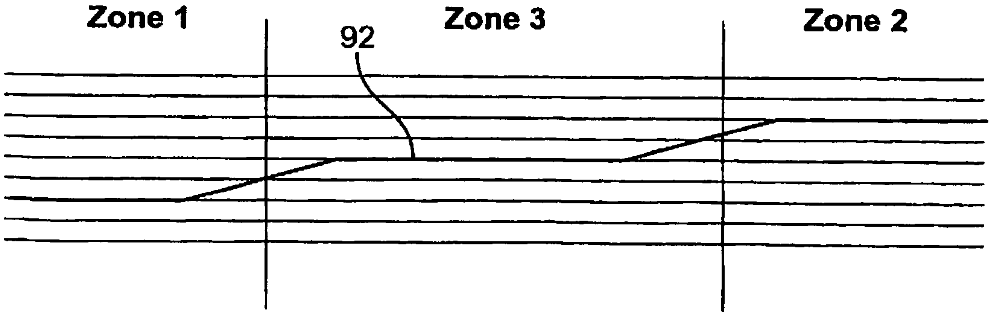

FIG. 10

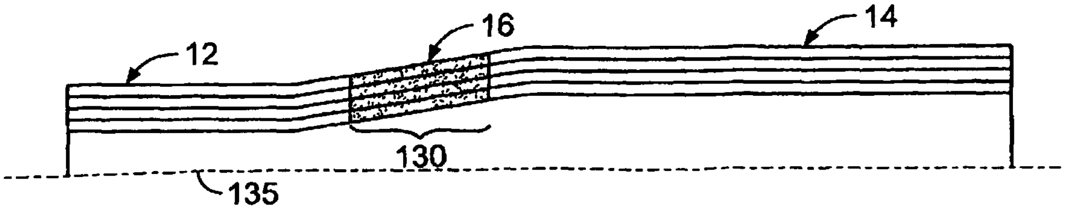

FIG. 11

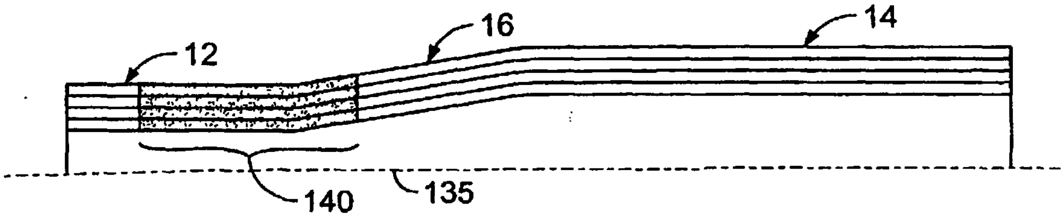

FIG. 12

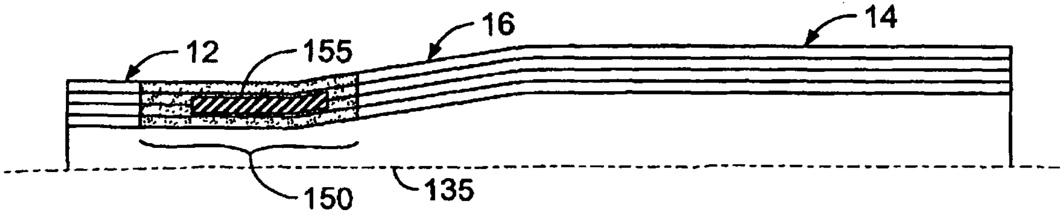

FIG. 13

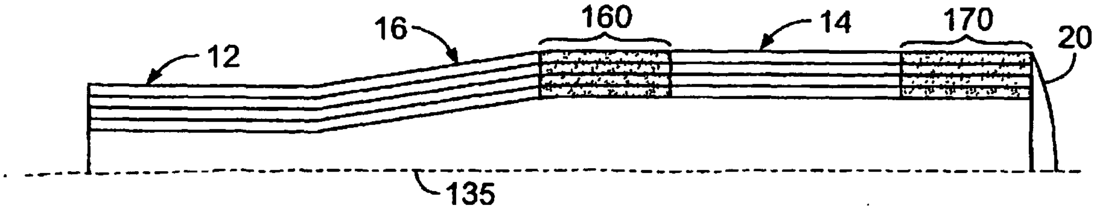

FIG. 14

| | Young's Modulus (Msi) | | | |
|---|---|---|---|---|
| Ply Orientation | Graphite | | S-glass | |
| (from longitudinal axis) | Ex (axial) | Ey (radial) | Ex (axial) | Ey (radial) |
| 0 | 19.66 | 1.34 | 6.91 | 1.93 |
| 5 | 17.67 | 1.35 | 6.61 | 1.92 |
| 10 | 13.95 | 1.37 | 5.87 | 1.90 |
| 15 | 10.70 | 1.40 | 5.01 | 1.86 |
| 20 | 8.28 | 1.47 | 4.21 | 1.83 |
| 25 | 6.47 | 1.56 | 3.53 | 1.80 |
| 30 | 5.08 | 1.70 | 3.00 | 1.79 |
| 35 | 4.02 | 1.91 | 2.56 | 1.82 |
| 40 | 3.21 | 2.20 | 2.25 | 1.89 |
| 45 | 2.63 | 2.63 | 2.03 | 2.03 |
| 50 | 2.20 | 3.21 | 1.89 | 2.25 |
| 55 | 1.91 | 4.02 | 1.82 | 2.56 |
| 60 | 1.70 | 5.08 | 1.79 | 3.00 |
| 65 | 1.56 | 6.47 | 1.80 | 3.53 |
| 70 | 1.47 | 8.28 | 1.83 | 4.21 |
| 75 | 1.40 | 10.70 | 1.86 | 5.01 |
| 80 | 1.37 | 13.95 | 1.90 | 5.87 |
| 85 | 1.35 | 17.67 | 1.92 | 6.61 |
| 90 | 1.34 | 19.66 | 1.93 | 6.91 |

FIG. 15

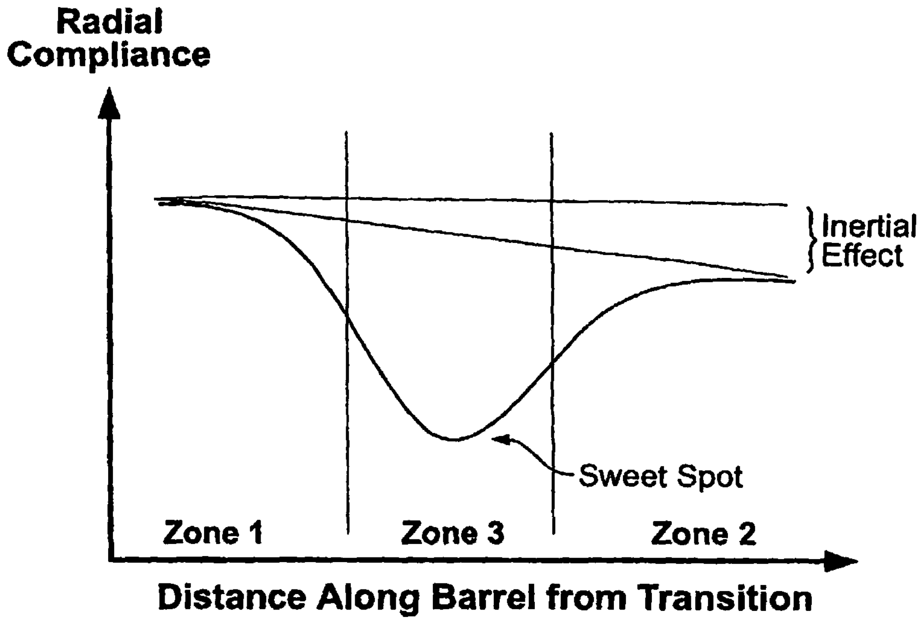
Radial Compliance
Inertial Effect
Sweet Spot
Zone 1
Zone 3
Zone 2
Distance Along Barrel from Transition

FIG. 16

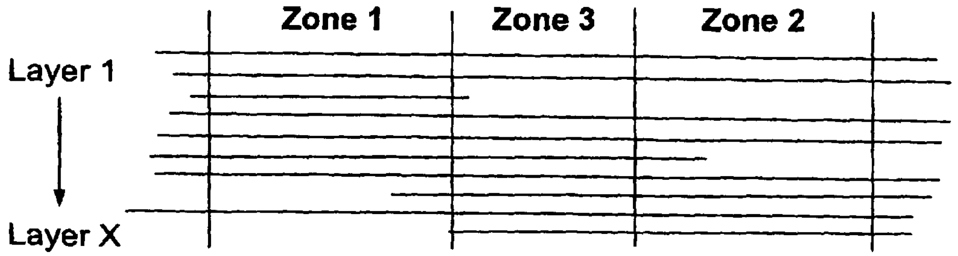
Zone 1
Zone 3
Zone 2
Layer 1
Layer X

FIG. 17

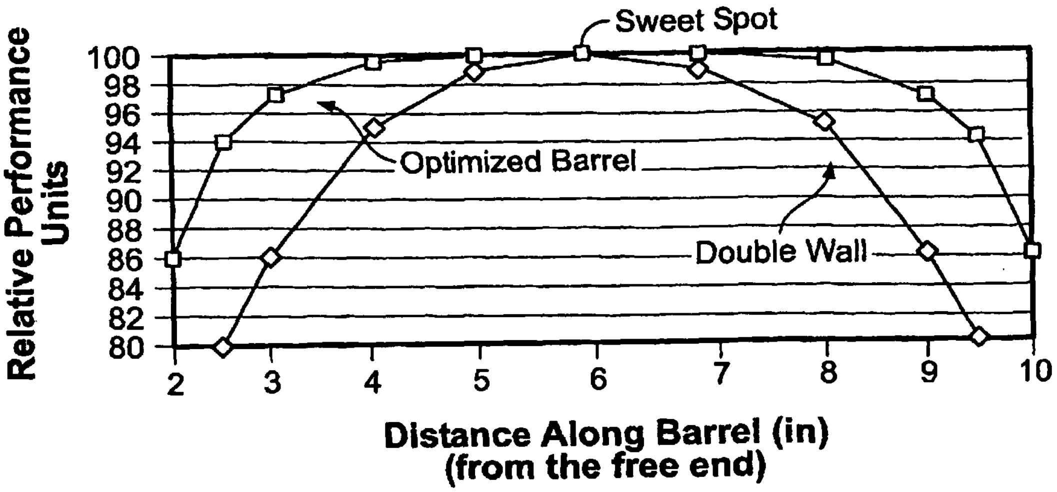

FIG. 18

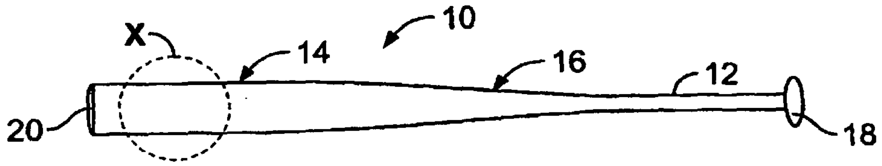

FIG. 19

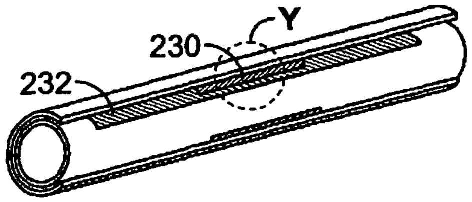

FIG. 20

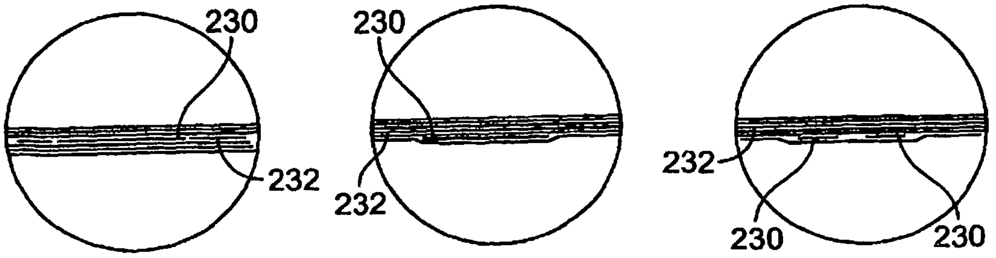

FIG. 21A FIG. 21B FIG. 21C

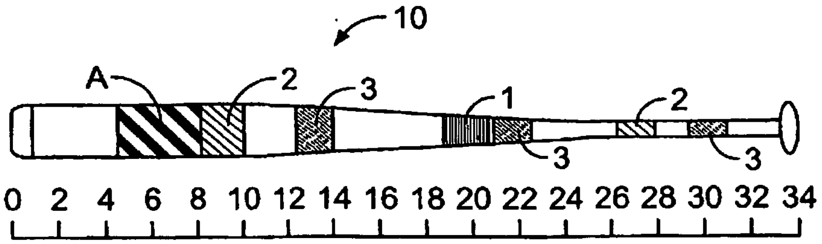

FIG. 22

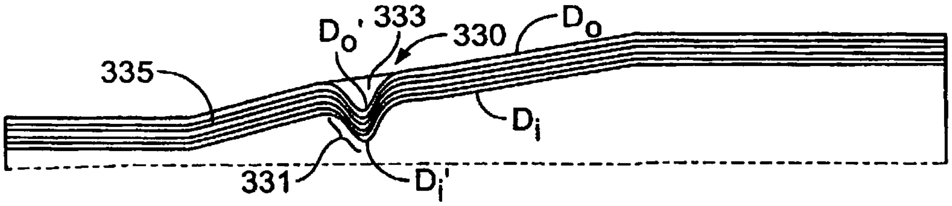

FIG. 23

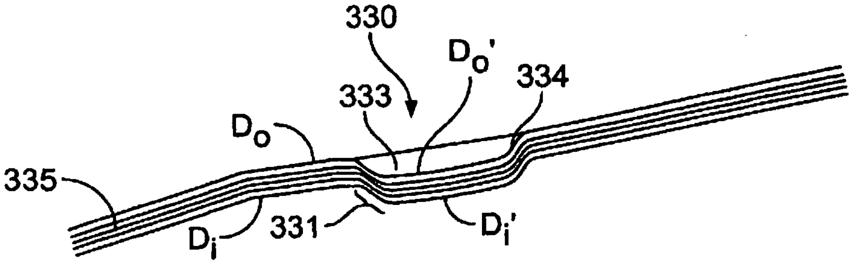

FIG. 24