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(54) Title: SHEET OF MATERIAL WITH FLUID-RESISTANT BEND CONTROLLING DISPLACEMENTS AND METHOD OF FORMING THE SAME

(57) Abstract: A method of preparing a two-dimensional sheet of material for bending along a bend line to form a three-dimensional article having a fluid-resistant bend includes the steps of forming at least one bend-controlling displacement in the thickness direction of the sheet of material, a portion of a periphery of the bend-controlling displacement proximate the bend line defining a sheared face directed toward an opposed sheet surface in the sheet of material on an opposite side of the bend line, and bending the sheet of material. A balancing of the forces during bending produces face-to-surface engagement between the sheared face and the opposed sheet surface such that the sheet material is substantially fluid-resistant along the bend line.



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SHEET OF MATERIAL WITH FLUID-RESISTANT BEND CONTROLLING DISPLACEMENTS AND METHOD OF FORMING THE SAME

FIELD OF THE INVENTION

[0001] This invention relates, in general, to preparing a sheet of material for bending along a bend line into a three-dimensional structure, and more particularly to preparing a sheet of material with bend controlling displacements for folding into a three-dimensional structure with fluid-resistant bends.

BACKGROUND OF THE INVENTION

[0002] The present invention is related to techniques for preparing a sheet of material to bend or fold along a desired bend line. Such techniques are disclosed in depth in Patent Nos. 7,152,449, 7,032,426, 6,877,349, 6,481,259 and in U.S. Patent Application Publication Nos. US 2005/0097937, all to Durney et al., which are each incorporated herein by reference in their entireties. In these applications several techniques and manufacturing processes for forming slits and/or grooves that will precisely control bending of sheet material are disclosed. The emphasis in these related applications is in connection with the use of slits which penetrate completely through the sheet of material. Both slits and grooves can be provided which control bending.

[0003] These innovative slitting and displacement techniques allow preparation of a sheet of material in two dimensions for folding along a precisely-located bend line. However, these techniques and other conventional techniques may create a gap in the sheet of material and along the resulting bend line, the edge of the bend-controlling structures may not provide a sealed bend. For example, slits and displacements with large kerfs, punch heights, and/or planar displacements are more prone to create “light” or gaps in the bend line after bending.

[0004] For example, U.S. Patent No. 6,640,605 to Gitlin et al. discloses slits or grooves along the bend line or offset on opposite sides of the bend line. In the Gitlin et al. patent, the bending webs between discontinuous grooves have centerlines which are parallel to the desired bend line. This approach requires that the bending straps between slits undergo substantial twisting and little bending while the continuous webs at the bottom of the slits are being bent. The approach results in little, if any, fluid resistance, which may be entirely insufficient for many applications such as HVAC, ducts, and weather-resistant enclosures.

[0005] In light of the foregoing, it would be beneficial to have methods and apparatuses which overcome the above and other disadvantages of known methods. What is needed is a method which is capable of preparing sheet materials that are capable of being folded into three-dimensional products having bends that are fluid-resistant.

BRIEF SUMMARY OF THE INVENTION

[0006] In summary, one aspect of the present invention is directed to a method of preparing a two-dimensional sheet of material for bending along a bend line to form a three-dimensional article having a fluid-resistant bend. The method may include one or more of the following steps: forming at least one bend-controlling displacement in the thickness direction of the sheet of material, a portion of a periphery of the bend-controlling displacement proximate the bend line defining a sheared face directed toward an opposed sheet surface in the sheet of material on an opposite side of the bend line; and bending the sheet of material whereby a balancing of the forces during bending produces face-to-surface engagement between the sheared face and the opposed sheet surface such that the sheet material is substantially fluid-resistant along the bend line.

[0007] The forming step may include forming a plurality of bend-controlling displacements having a pair of bending straps in the sheet of material intersecting the bend line and a respective sheared face extending therebetween, and wherein the bending step subjects the straps to tension such that the sheared face closely abuts

against the opposed sheet surface when the sheet of material is bent. The plurality of bend-controlling displacements may be formed in the sheet of material with a sheared edge extending along a respective sheared face along one side of the bend line, and wherein the forming step defines an opposed face opposite each sheared face such that bending produces edge-to-face engagement of the sheet of material during the bending step. The bending step may seal the opposed surface to the sheared face when the sheet of material is bent. The seal may be substantially formed by close abutment of the sheared face to the opposed surface. Abutment may be substantially uniform along the sheared face. The seal may be formed with substantially no use of sealing materials. The method may further include after the forming step, adhering a layer of coating material to the sheet of material across the bend-controlling displacements. The adhering step provides a continuous layer of flexible coating material to the sheet of material across the plurality of bend-controlling displacements, which continuous layer remains substantially intact after the bending step. The coating material may be paint. The method may further include after the bending step, adhering a layer of coating material to the sheet of material across the bend-controlling displacements.

[0008] The forming step forms the bend-controlling displacement with a substantially oval-shape and may include a periphery with end portions and a crown portion extending between the end portions. The forming step provides the crown portion of the bend-controlling displacement with an arcuate profile. The crown portion may be a large radii arc. The end portions may be a small radii arc. The bend-controlling displacement may further include transition zones between the crown portion and the end portions. The transition zones have a radius of curvature intermediate the radii of curvature of the end portions and the crown portion.

[0009] The forming step forms a joggle zone connecting an unsheared portion of the bend-controlling displacement to the sheet material, wherein each end portion may include a portion of the sheared face and a portion of the joggle zone. The sheared edge extends below the opposed sheet surface a distance that may be at least 75% the thickness of the material. The sheared edge has a z-depth of between 0.095-0.110

mm. The sheet of material may be steel. The sheared face may extend to within approximately 40° of a longitudinal axis of the displacement with respect to a radial center of the end portion. The forming may be accomplished using one of a stamping process, punching process, a roll forming process, or an embossing process. The three-dimensional article may be a NEMA-3 pull box.

[0010] Another aspect of the present invention is directed to a method of preparing a two-dimensional sheet of material for bending along a bend line to form a three-dimensional article having a fluid-resistant bend. The method may include: forming at least one bend-controlling displacement in the thickness direction of the sheet of material with a substantially oval shape, the bend-controlling displacement including a periphery with end portions and a curved crown extending between the end portions proximate the bend line, the bend-controlling displacement including a sheared face extending along the crown portion and into the end portions and facing an opposed sheet surface in the sheet of material on an opposite side of the bend line; bending the sheet of material about the bend line. The curved crown portion may be dimensioned to produce face-to-surface engagement between the sheared face and the opposed sheet surface.

[0011] The end portions may have a smaller radius of curvature than the crown portions. The crown portion may be a large radii arc. The end portions may be a small radii arc. The bend-controlling displacement may further include transition zones between the crown portion and the end portions. The transition zones have a radius of curvature intermediate the radii of curvature of the end portions and the crown portion. The bend line may be substantially fluid-resistant when the sheet of material is bent. A portion of the periphery proximate the bend line may define a sheared face directed toward an opposed sheet surface in the sheet of material on an opposite side of the bend line, whereby during the bending step a balancing of forces during bending produces face-to-surface engagement between the sheared face and the opposed sheet surface such that the sheet material is substantially fluid-resistant along the bend line. The forming step may form a joggle zone connecting an unsheared portion of the bend-controlling displacement to the sheet material, wherein

each end portion may include a portion of the sheared face and a portion of the joggle zone. The sheared face may extend to within approximately 40° of a longitudinal axis of the displacement with respect to a radial center of the end portion.

[0012] A further aspect of the present invention is directed to a two-dimensional sheet of material formed for bending along a bend line to form a three-dimensional article having a fluid-resistant bend. The sheet of material may include a sheet of material including a bend-controlling displacement in the thickness direction of the sheet of material, a portion of a periphery of the bend-controlling displacement proximate the bend line defining a sheared face directed toward an opposed sheet surface in the sheet of material on an opposite side of the bend line, the sheared face and opposed sheet surface configured and positioned to produce face-to-surface engagement of the sheet of material after bending such the bend is substantially fluid-resistant when bent.

[0013] The bend-controlling displacement having an oval shape and may further include a periphery with end portions and a crown portion extending between the end portions. The crown portion may have an arcuate profile. The end portions have an arcuate profile with a radius of curvature smaller than a radius of curvature of the crown portion. The bend-controlling displacement may further include transition zones between the crown portion and the end portions. Each of the transition zones may have a radius of curvature intermediate the radii of curvature of the end portions and the crown portion. The bend-controlling displacements may further include a joggle zone connecting an unsheared portion of the bend-controlling displacement to the sheet material, wherein each end portion may include a portion of the sheared face and a portion of the joggle zone.

[0014] Yet a further aspect is directed to a two-dimensional sheet of material formed for bending along a bend line to form a three-dimensional article including a sheet of material including a bend-controlling displacement in the thickness direction of the sheet of material with a substantially oval shape, the bend-controlling displacement including a periphery with end portions and a curved crown extending between the

end portions proximate the bend line, the bend-controlling displacement including a sheared face extending along the crown portion and into the end portions and facing an opposed sheet surface in the sheet of material on an opposite side of the bend line. The curved crown portion may be dimensioned to produce face-to-surface engagement between the sheared face and the opposed sheet surface.

[0015] The end portions may have a smaller radius of curvature than the crown portions. The crown portion may be a large radii arc. The end portions may be a small radii arc. The bend-controlling displacement may further include transition zones between the crown portion and the end portions. The transition zones have a radius of curvature intermediate the radii of curvature of the end portions and the crown portion.

[0016] Still a further aspect of the present invention is directed to a rigid three-dimensional article formed by bending a two-dimensional sheet of material along at least one bend line. The article may include at least one bend-inducing displacement in the thickness direction of the sheet of material, a portion of a periphery of the bend-inducing displacement proximate the bend line defining a sheared face directed toward an opposed sheet surface in the sheet of material on an opposite side of the bend line. The sheared face and opposed sheet surface may be in engagement such that the sheet material is substantially fluid-resistant along the bend line. The sheared face and opposed sheet surface may be in close abutment along a periphery of the sheared face.

[0017] The methods, sheet materials, and structures of the present inventions have other features and advantages which will be apparent from or are set forth in more detail in the accompanying drawings, which are incorporated in and form a part of this specification, and the following Detailed Description of the Invention, which together serve to explain the principles of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] FIG. 1 is a perspective view of a three-dimensional enclosure prepared in accordance with the present invention having a fluid-resistant bend line.

[0019] FIG. 2 is a top view of the prepared two-dimensional sheet of material of FIG. 1 prior to folding into the three-dimensional article.

[0020] FIG. 3 is a schematic plan view of the two-dimensional sheet of material of FIG. 2 having bend-controlling displacements on alternate sides of the end line, and FIG. 3A is an enlarged detail thereof.

[0021] FIG. 4A is an enlarged perspective view of a plurality of bend-controlling displacements along a multiple bend line utilized in the sheet of material of FIG. 2 illustrating displacements extending downward, and FIG. 4B is an isometric rendering of a portion of the same.

[0022] FIG. 5A is an enlarged perspective view of the plurality of bend-controlling displacements after the sheet of material of FIG. 2 has been folded into the three-dimensional article of FIG. 1, and FIG. 5B is an isometric rendering of a portion of the same.

[0023] FIG. 6A is an enlarged isometric rendering view of a portion of a sheet material with bend-controlling displacements of FIG. 3, and FIG. 6B is an enlarged isometric rendering of the portion after the sheet material has been bent along the bend line.

[0024] FIG. 7 is a schematic view of a bend-controlling displacement utilized in the sheet of material of FIG. 2 illustrating a periphery of the bend-controlling displacement.

[0025] FIG. 8 is a schematic view of a bend-controlling displacement utilized in the sheet of material of FIG. 2 illustrating the transition from a sheared face to a transition zone along the periphery of the bend-controlling displacement.

[0026] FIG. 9 is a schematic view of exemplary tooling profiles and orientation thereof used to form the bend-controlling displacement of FIGS. 2.

[0027] FIGs. 10 and 11 are schematic views of other tooling profiles used to form the bend-controlling displacements of FIGS. 2 and 3.

DETAILED DESCRIPTION OF THE INVENTION

[0028] Reference will now be made in detail to the preferred embodiments of the invention, examples of which are illustrated in the accompanying drawings. While the invention will be described in conjunction with the preferred embodiments, it will be understood that they are not intended to limit the invention to those embodiments. On the contrary, the invention is intended to cover alternatives, modifications and equivalents, which may be included within the spirit and scope of the invention as defined by the appended claims.

[0029] Bend-controlling structures control and precisely locate the bending of a two-dimensional sheet material into three-dimensional structures. Such bend-controlling structures lower the cost and complexity of manufacturing processes and allow for greater flexibility of manufacture and time savings. Bend-controlling structures such as displacements and the like allow a sheet of material to be prepared simply in the flat and later folded into complicated three-dimensional structures.

[0030] Such structures often include applications where it is desirable to create a fluid-resistant bend line in the region of the bend-controlling structures. However, processes for forming the bend-controlling structures such as punching, stamping, machining, photo-etching, embossing, and the like usually create gaps or separations in the sheet of material. The present application, therefore, illustrates how bend-controlling structures, particularly, bend-controlling displacements can be formed in a sheet of material that can be bent into a fluid-resistant three-dimensional structure.

[0031] Preferably, the sheet of material is a non-compressible material. Suitable materials for the sheet of material include, but are not limited to, metals such as steel, mild steel, stainless steel, galvanized steel, aluminum, alloys, and plastics.

[0032] Turning now to the drawings, wherein like components are designated by like reference numerals throughout the various figures, FIGs. 1-5 illustrate a three-dimensional article 30 having a plurality of bend lines 32. The exemplary three-dimensional article is formed from a two-dimensional sheet of material 33 shown in FIGs. 2 and 3, which sheet that has a plurality of bend-controlling displacements, generally designated 35, populated along the bend lines. The article in the illustrated embodiment is a NEMA-3R, 4, or 12 electrical enclosure which has been configured to withstand and pass the NEMA standards rain test (e.g., one hour rain test with no water intrusion on top and sides).

[0033] For the purposes of the present discussion, fluid-resistance refers to the increased resistance of fluid flow through the sheet material past the displacements in the vicinity of the bend line. For example, the bend lines of the enclosure 30 are fluid resistant and therefore resist the intrusion of fluids into the enclosure in conformance with NEMA-3R standards. Thus, rainwater and weather elements will not pass through displacements from one side of the sheet material to the other and into the enclosure when subjected to typical weather conditions. Fluid-resistance may also refer to an inappreciable amount of fluid loss along the bend line past the displacements. For example, acoustic sound tests may be utilized to measure fluid loss from HVAC and other ducting systems to determine whether the systems conform to industry standards of quality and/or efficiency.

[0034] One will appreciate, however, that the methods and sheets of the present invention are suitable for a wide variety of products including, but not limited to, electronic component chasses, automotive components, transport components, construction components, appliance parts, truck components, RF shields, HVAC components, aerospace components, toys, outdoor equipment, boats, recreational equipment, and more.

[0035] In particular, the teachings of the present application are applicable to a wide variety of 3D products and articles that are formed by folding 2D sheet materials, which products require bends where some degree of pressure tightness is required. For example, the methods and sheets disclosed herein are equally suited for use in refrigerator side-walls and automotive structural components where fluid-resistance is desired.

[0036] In many aspects, the sheet materials of the present invention are similar to those disclosed by U.S. Patent No. 6,481,259, U.S. Patent No. 6,877,349, U.S. Patent No. 7,152,449, U.S. Patent No. 7,152,450, U.S. Patent Application No. 10/821,818 (Pub. No. 2005/0005670), U.S. Patent No. 7,032,426, U.S. Patent Application No. 10/931,615 (Pub. No. 2005/0097937), U.S. Patent Application No. 10/985,373 (Pub. No. 2005/0061049), U.S. Patent Application No. 11/357,934 (Pub. No. 2006/0261139), U.S. Patent Application No. 10/952,357 (Pub. No. 2005/0064138), U.S. Patent Application No. 11/384,216 (Pub. No. 2006/0207212), U.S. Patent Application No. 11/080,288 (Pub. No. 2005/0257589), U.S. Patent Application No. 11/374,828 (Pub. No. 2006/0213245), U.S. Patent Application No. 11/180,398 (Pub. No. 2006/0021413), U.S. Patent Application No. 11/290,968 (Pub. No. 2006/0075798), U.S. Patent Application No. 11/411,440, U.S. Provisional Patent Application No. 60/665,577, U.S. Patent Application No. 11/386,463, and U.S. Provisional Patent Application No. 60/854,846, the entire contents of which patents and patent applications are incorporated herein by this reference.

[0037] As described in the aforementioned '450 Patent, when slits are formed with a kerf by cutting and similar processes, there is a tendency for the material on opposite sides of the bend line to open up during bending and separate or create a gap upon bending despite the edge-to-face engagement described therein. The resulting gap allows "light" to pass through and thus provide evidence of poor sealing and permeability in a particular location. For example, daylight, ambient, laser, and/or other forms of light may be used to visually fluid resistance along the bend line by shining the light against the bend line after bending. Noticeable traces of laser light may be visible through the displacements in all but the most fluid resistant seals (e.g.,

such seals passing NEMA-3R, 4, or 12 tests and/or other industry standards of fluid resistance), while significant traces of less intensity light sources may be clearly discernable in cases of poor sealing. As will be described in detail below, the approach in the illustrated embodiment is to configure a displaced tongue 37 of displacement 35 such that the tongue will minimize or shut out “light” along the bend line when the sheet of material is bent into a three-dimensional article. This approach results in the closing of the gaps or an absence thereof such as may be required by particular applications.

[0038] Referring to FIGs. 2, sheet of material 33 is prepared by forming at least one bend-controlling displacement 35 in the thickness direction of the sheet of material in a manner similar to the methods described in the above-mentioned patents and applications. One or more bend-controlling displacements are formed in the sheet of material to define bend line 32. In the illustrated embodiment, the displacements are formed on one side of the bend line. In some instances, such configuration may provide a more appealing visual appearance. One will appreciate, however, that the bend-controlling displacements may also be formed on alternate sides of the bend line.

[0039] Generally, the displacement is formed by a lance impacting the sheet of material and displacing at least a portion of the corresponding tongue into an opposing cavity in a relatively conventional manner. The bend-controlling displacement thus formed includes a tongue displaced at least partially below the plane formed by adjacent surface of the sheet of material (e.g., opposed sheet surface 44. An end of tongue 37 proximate the bend line is completely sheared such that a sheared edge 39 is at least displaced partially below a plane defined by the original sheet of material (see, e.g., FIG. 6).

[0040] In one embodiment, the sheared edge extends below the opposed sheet surface a distance that is approximately 65% to 100% the thickness of the material, preferably approximately 70% to 96%, and more preferably approximately 70% to 85%. For example, in one embodiment in which the sheet of material is 16 gauge mild steel, the

sheared edge has a maximum z-depth of approximately 0.095' to 0.110" wherein z-depth is the total measurement material thickness and displacement distance (see, e.g., FIG. 6A).

[0041] Accordingly, a portion of a periphery 40 of the bend-controlling displacement proximate the bend line defines a sheared face 42 directed toward an opposed sheet surface 44 in the sheet of material on an opposite side of the bend line. The plurality of bend-controlling displacements 35 are formed in the sheet of material with sheared edge 39 extending along respective sheared face 42. In the illustrated embodiment, the bend-controlling displacements are all located along one side of the bend line. For better understanding, FIGs. 4B and 5B are enlarged schematic views an exemplary configuration of bend-controlling displacements.

[0042] The opposed sheet surface is not to be confused with the opposed face. As shown in FIGs. 6A and 6B, sheared edge 39 extends toward and is adjacent to an end of opposed sheet surface 44. Opposed face 46 is located at an end of the opposed sheet surface. In contrast, sheared face 42 is located on a distant end of tongue 37. Although the opposed sheet surface has a face surface at an end, sheared face herein refers to the face surface at the sheared end of the bend-controlling displacement or tongue. Opposed sheet surface herein refers to the panel or portion of the sheet of material on an opposite side of the bend line from the bend-controlling displacement. Opposed face herein refers to the face surface at the end of the opposed sheet surface.

[0043] The shearing of the displacement creates a vertical displacement in the thickness direction of the sheet of material. The bend-controlling displacement defines an opposed face 46 opposite each sheared face 42. Viewed from the side, the sheared face and opposed face may in actuality be displaced not vertically but horizontally and such that they are offset from each other. This is due to the fact that the sheared face is displaced and extends below the plane defined by the opposed face and may pull away from the opposed face during displacement. In one embodiment, the sheared face and opposed face are configured and positioned such that bending of

the sheet of material about the bend line produces edge-to-face engagement of the sheet of material.

[0044] Bend-controlling displacement 35 has a substantially oval-shape and includes periphery 40 with end portions 47 and a crown portion 49 extending between the end portions. In contrast to conventional displacements, the crown portion of the bend-controlling displacement has an arcuate or curved profile. The crown portion may have a large radii arc such that the curve of the crown portion is gradual.

[0045] The curve of the crown portion also plays a noteworthy role in forming the fluid-resistance of the bend line. It has been found that the curve of the crown portion controls the forces in the sheet of material such that the material around the sheared edge and face is pulled into substantial sealing engagement to close out the “light.” That is, the arched crown portion promotes close abutment along the length of the displacement such that, once bent, minimal or no “light” passes by or through the displacement thus evidencing fluid-resistance (shown in FIG. 5A). In part, the relatively large curvature of the crown promotes elastic deformation of the opposing face and thus appears to contribute to the opposing face to “spring” against the crown.

[0046] As shown in FIGs. 10 and 11, the radius of the curvature may vary. Depending on the application, the crown portion may have a relatively small radius of curvature or the crown portion may be relatively large radius of curvature such the sheared face is only slightly convex. If the profile of the crown portion is too high, meaning the radius of curvature is not large enough, the outermost portion of the sheared face may push away the sheet of material and prevent sealing against the sheared edge.

[0047] Preferably, the bend-controlling displacement includes a second crown portion opposite the first crown portion which mirrors the first crown portion such that it has the same or substantially equal radius of curvature and shape. Such symmetric configuration would improve tool life in that punches used to form the displacements may be rotated 180° (e.g., rotated about a vertical axis) thereby almost doubling tool

life, and may also be flipped 180° (e.g., turned upside down) thereby almost quadrupling tool life. A joggle zone 51 connects an unsheared portion 53 of a periphery of bend-controlling displacement 35 to sheet material 33.

[0048] In the illustrated embodiment, the end portions have an arcuate profile similar to the crown portion except that the radius of curvature of the end portions is substantially smaller than the radius of curvature of the crown portion. The end portions are a small radii arc, meaning, the end portions have a tight curvature. For example and with reference to FIG. 3A, the centers of the radii of curvature of the end portions are located on the displacement. Preferably the radii of curvature of the end portions are within an order of magnitude of the thickness of the sheet material. For example, the end portion radii of curvature is preferably 1.5T and the diameter is 3.0T where “T” is the thickness dimension of the sheet material. In contrast, the crown portions have much larger radii of curvatures. For example, the centers of radii of curvature of the crown portions are located outside of the displacement, and may be multiple orders of magnitude greater than the thickness of the sheet material.

[0049] As shown in FIGs. 10 and 11, the radii of curvature may vary substantially, and the radii of curvature of the end portions may be modified independently of the radius of the crown portion. As discussed, the crown may be adjusted for elastic behavior with softer springing action of the material, and in particular springing action of the opposed face against the sheared edge, during and after bending.

[0050] Preferably, the bend-controlling displacement 35 includes transition zones 54 located between the crown portion 49 and each end portions 49. The transition zones have radii of curvature intermediate the radii of curvature of the end portions and the crown portion. Thus, the transition zones serve to transition periphery 40 between the larger radius of curvature of the crown portions and smaller radius of curvature of the end portions.

[0051] It has been found that a smoother transition between crown portion 49 and a respective end portion 47 corresponds to improved sealing of sheared face 42 when

material 33 is bent. Put another way, providing a smaller and more gradual rate of change of the radius of curvature between the crown portion and respective end portions improves fluid-resistant sealing along the bend after the sheet of material has been bent along the bend line.

[0052] The transition zones are also configured and dimensioned to accommodate the shift between primarily elastic and plastic deformation by producing even contact pressure by developing a zone in which the opposed face successfully follows the curve of the crown's periphery. Gradually diminishing the radii of curvature along the transition zone between the crown and the end portions promotes improved conformance and transition of plastic and elastic deformation and produces a better seal.

[0053] Crown portions 49 and end portions 47 form the primary shape of periphery 40 of the bend-controlling displacement. Each end portion 47 includes a portion of sheared face 42 and a portion of joggle zone 51. Likewise, joggle zone 51, transition zones 54, and end portions 47 form the peripheral edge structure of the displacement. In the illustrated embodiment, each transition zone extends around the periphery of the bend-controlling displacement within approximately 5° and 15° of a longitudinal axis of the displacement with respect to a center of the displacement as shown in FIG. 8 (see, e.g., angles "A" and "B" respectively). One will appreciate, however, that the actual dimensions and location of the transition zone may vary tremendously depending upon the respective radii of curvature of the crown and end portions. Moreover, the transition zones have regional or localized characteristics but might not have distinct structural boundaries with respect to the crown and end portions. In particular, the opposed face material may displays overlapping behavior between the zones as each fades into an adjacent zone.

[0054] Sheared face 42 extends along the crown portion, through the transition zones and into the end portions. The sheared face preferably extends within approximately 0-80°, preferably 0°-60°, more preferably 0°-40°, of the longitudinal axis of the displacement with respect to a radial center of the end portion as also shown in FIG. 8

(see, e.g., angle “C”). One will appreciate that the amount the sheared face extends may vary.

[0055] The actual location of shear termination may be adjusted by varying the configuration of tooling used to form the displacements. FIG. 9 depicts the boundaries of the lance “L” which displaces the bend-controlling displacement into cavity “C” opposing the lance. The peripheral shape of the lance largely corresponds to the shape of tongue 37, while the peripheral shape of the cavity largely corresponds to the shape of the sheared edge 39 and joggle zone 51. The edges of the lance and cavity thus form the shape of the bend-controlling displacement. In the illustrated embodiment, the distance between the lance edge and cavity edge along the crown and closes to the bend line is approximately 10% of the thickness of the sheet material, which dimension is generally understood to produce shear. The distance between the lance edge increases along the end portions. It has been observed that shear terminates when the distance expands to approximately 25% of the thickness of the sheet material. By adjusting the curvature of the lance and cavity shapes, it is possible to adjust the location of the 25% threshold and thus is possible to adjust the location of shear termination.

[0056] With continued reference to FIG. 9, the figure also illustrates the various radii of curvature found in the transition zone. For example, the radii of curvatures of the lance’s crown and end portions are designated R_{LC} and R_{LE} , respectively, where the designation refers to “lance-crown radius” and “lance-end-portion radius, while the radii of curvature of the lance’s transition zone are designated R_{LT1} , R_{LT1} , ... R_{LT5} , respectively. FIG. 9 also illustrates that the various positions of the centers of curvature.

[0057] In the bent position when the sheet of material is folded over the bend line, bend-controlling displacements 35 fold into a closed position such that no “light” or gaps remain along the bend line. In particular, the sheared edge conforms to the shape of the tongue. During bending, a balancing of the plastic behavior along the ends and the elastic behavior in the middle promotes face-to-surface contact between

sheared face 42 and opposed sheet surface 44 such that the sheet material is substantially fluid-resistant along the bend line. As best seen in FIG. 5, the face and sheet abut each other to close off the gaps which may be apparent with conventional slitting techniques.

[0058] In one embodiment, each of the bend-controlling displacements is formed with a pair of bending straps 56 in the sheet of material which intersect bend line 32. The bend-controlling displacements are formed with bending straps on each end such that a respective sheared face 42 extends between the bending straps. The bend straps are configured and positioned such that bending of the sheet of material subjects straps 56 to tension such that sheared face 42 closely abuts against opposed sheet surface 44 when the sheet of material is bent. In particular, as the two panels of the sheet on each side of the bend line are folded, the opposed sheet surface is pulled towards and conforms against the sheared face and sheared edge. As best seen in FIG. 5, it is desirable to configure the bend-controlling displacements such that the bending straps pull over and against the outer ends of the displacements during bending, as illustrated with arrows "T". In the outer ends of each displacement the periphery transitions from a sheared edge to a continuous web of material. In this manner, these outer ends are substantially sealed when the sheet of material is bent.

[0059] In one embodiment, when sheet of material 33 is bent along the bend line, the sheared gap is closed by sealing of material along sheared edge 39. In the bent position, the sides of the sheared edge are in contact with bending straps 56. The central portion of the sheared edge is also in contact with opposed surface 44. Thus, the bending of the sheet seals the opposed surface to the sheared face when the sheet of material is bent. In one embodiment, the seal is substantially formed by close abutment of the sheared face to the opposed surface. When the abutment is substantially uniform along the sheared face the seal becomes tighter.

[0060] Further, and with reference to FIG. 5, the fluid resistant seal is formed with no use of sealing materials. Instead the seal is formed primarily by virtue of the close and substantially uniform abutment of materials formed during bending and without

the use of extra materials. Sealing materials refers to conventional sealing materials as understood in the art. Sealing materials also refers to other devices or materials formed merely to aid in the sealing function.

[0061] In one embodiment, the lance is formed with a rooftop and crown whereby a central portion of the lance is flat and ends extending longitudinally from the central portion are sloped upward. When forming the displacements with such a lance the onset of shearing in the joggle zone can be further controlled. Such a lance structure further reduces stamping forces and the possibility of “light” forming at an end of the lance.

[0062] In some applications it may be desirable to further insure that the bend in the sheet of material is fluid-resistant or even fluid-tight. Accordingly, in one embodiment a continuous, preferably flexible, layer of coating material 58 is adhered to the sheet of material across the bend-controlling displacements (see, e.g., FIG. 6). The coating layer may be applied prior to lancing or bending such that it remains substantially intact (e.g., not significantly chipped and/or cracked) after the bending. In the alternative, the sheet of material may be folded into a three-dimensional structure and thereafter treated with a coating layer along the bend lines. Suitable materials for the layer of coating include, but are not limited to, paint, plastics, grease, and relative viscous gel compounds. In an alternative embodiment the bend-controlling displacement or sheet of material includes other forms, structures, or shapes, formed separately or monolithically formed, to aid in the sealing function.

[0063] The method of forming a three-dimensional structure in accordance with the present invention can now be described. A two-dimensional sheet of material is first prepared as described above. In particular, at least one bend-controlling displacement is formed in the thickness direction of the sheet of material with a substantially oval shape at a sheet preparation station. The bend-controlling displacement may be formed using CNC machining, stamping, punching, or the like, as is discussed in the above-mentioned patents and patent applications.

[0064] The bend-controlling displacement includes a periphery with end portions 47 and curved crown 49 extending between the end portions proximate the bend line. The bend-controlling displacement is sheared along a portion of the periphery such that a sheared face extends along the crown portion and into the end portions. The sheared face faces an opposed sheet surface in the sheet of material on an opposite side of the bend line.

[0065] As described above, the curved crown portion is dimensioned to produce face-to-surface engagement between the sheared face and the opposed sheet surface. Accordingly, when the structure is formed and the sheet is bent along the bend lines, the face-to-surface engagement creates a fluid-resistant seal along the bend line. Likewise, the displacement may be configured with bending straps to seal to portions of the sheared edge.

[0066] Next, the sheet of material is bent along successive bend lines. This may be done in the same station or at a different station. Moreover, additional components and subassemblies may be fastened to the structure before or after bending. Such components may also be placed on the sheet of material and wrapped inside the sheet of material during the bending process.

[0067] As will be understood from the above description, the dimensions of the bend-controlling displacement, particularly the crown portion, end portions, transition zones, and z-distance may be modified to suit application needs. The exact configuration will depend on several characteristics including, but not limited to, the degree of fluid-resistance required, the material characteristics, aesthetic concerns, and the maximum desired effort in bending.

[0068] After bending into the three-dimensional structure, the structure may be fastened with a fastener 60 and finished at a finishing station. As described above, the structure may be treated with a sealing or layer of coating to further enhance fluid-resistance. The structure may also be fastened with conventional fasteners or welding.

[0069] The above-described method allows for precision-folding of three-dimensional structure with a fluid-resistant bend line from a two-dimensional sheet of material. The sheet of material and method therefor in accordance have other advantages over conventional slitting techniques. The method allow for preparing a two-dimensional for folding into a fluid-resistant three-dimensional structure without the need for complex fluid sealing processes.

[0070] For convenience in explanation and accurate definition in the appended claims, the terms “up” or “upper”, “down” or “lower”, “inside” and “outside” are used to describe features of the present invention with reference to the positions of such features as displayed in the figures. However, any physical orientation is possible, so these terms are used only as a matter of convenience and should not be construed as absolute.

[0071] The foregoing descriptions of specific embodiments of the present invention have been presented for purposes of illustration and description. They are not intended to be exhaustive or to limit the invention to the precise forms disclosed, and obviously many modifications and variations are possible in light of the above teaching. The embodiments were chosen and described in order to best explain the principles of the invention and its practical application, to thereby enable others skilled in the art to best utilize the invention and various embodiments with various modifications as are suited to the particular use contemplated. It is intended that the scope of the invention be defined by the Claims appended hereto and their equivalents.

WHAT IS CLAIMED:

1. A method of preparing a two-dimensional sheet of material for bending along a bend line to form a three-dimensional article having a fluid-resistant bend, the method comprising:

forming at least one bend-controlling displacement in the thickness direction of the sheet of material, a portion of a periphery of the bend-controlling displacement proximate the bend line defining a sheared face directed toward an opposed sheet surface in the sheet of material on an opposite side of the bend line; and

bending the sheet of material whereby a balancing of the forces during bending produces face-to-surface engagement between the sheared face and the opposed sheet surface such that the sheet material is substantially fluid-resistant along the bend line.

2. A method according to claim 1, wherein the forming step includes forming a plurality of bend-controlling displacements having a pair of bending straps in the sheet of material intersecting the bend line and a respective sheared face extending therebetween, and wherein the bending step subjects the straps to tension such that the sheared face closely abuts against the opposed sheet surface when the sheet of material is bent.

3. A method according to claim 2, wherein the plurality of bend-controlling displacements are formed in the sheet of material with a sheared edge extending along a respective sheared face along one side of the bend line, and wherein the forming step defines an opposed face opposite each sheared face such that bending produces edge-to-face engagement of the sheet of material during the bending step.

4. A method according to claim 1, wherein the bending step seals the opposed surface to the sheared face when the sheet of material is bent.
5. A method according to claim 4, wherein the seal is substantially formed by close abutment of the sheared face to the opposed surface.
6. A method according to claim 5, wherein abutment is substantially uniform along the sheared face.
7. A method according to claim 5, wherein the seal is formed with substantially no use of sealing materials.
8. A method according to claim 4, further including after the forming step, adhering a layer of coating material to the sheet of material across the bend-controlling displacements.
9. A method according to claim 8, wherein the adhering step provides a continuous layer of flexible coating material to the sheet of material across the plurality of bend-controlling displacements, which continuous layer remains substantially intact after the bending step.
10. A method according to claim 9, wherein the coating material is paint.
11. A method according to claim 4, further including after the bending step, adhering a layer of coating material to the sheet of material across the bend-controlling displacements.

12. A method according to claim 1, wherein the forming step forms the bend-controlling displacement with a substantially oval-shape and includes a periphery with end portions and a crown portion extending between the end portions.
13. A method according to claim 12, wherein the forming step provides the crown portion of the bend-controlling displacement with an arcuate profile.
14. A method according to claim 12, wherein the crown portion is a large radii arc.
15. A method according to claim 12, wherein the end portions are a small radii arc.
16. A method according to claim 12, the bend-controlling displacement further including transition zones between the crown portion and the end portions.
17. A method according to claim 16, wherein the transition zones have a radius of curvature intermediate the radii of curvature of the end portions and the crown portion.
18. A method according to claim 16, wherein the first order derivative of the radius of curvature of the sheared face along the crown portion, the transition zones and the end portions is substantially uniform.
19. A method according to claim 1, wherein the forming step forms a joggle zone connecting an unsheared portion of the bend-controlling displacement to the sheet material, wherein each end portion includes a portion of the sheared face and a portion of the joggle zone.

20. A method according to claim 1, wherein the sheared edge extends below the opposed sheet surface a distance that is at least 75% the thickness of the material.
21. A method according to claim 1, wherein the sheared edge has a z-depth of between 0.095-0.110 mm.
22. A method according to claim 1, wherein the sheet of material is steel.
23. A method according to claim 1, wherein the sheared face extends to within approximately 40° of a longitudinal axis of the displacement with respect to a radial center of the end portion.
24. A method according to claim 1, wherein the forming is accomplished using one of a stamping process, punching process, a roll forming process, or an embossing process.
25. A method according to claim 1, wherein the three-dimensional article is a NEMA-3 pull box.
26. A method of preparing a two-dimensional sheet of material for bending along a bend line to form a three-dimensional article having a fluid-resistant bend, comprising:
forming at least one bend-controlling displacement in the thickness direction of the sheet of material with a substantially oval shape, the bend-controlling displacement including a periphery with end portions and a curved crown extending between the end portions proximate the bend line, the bend-controlling displacement including a sheared face extending along the crown portion and into the end portions

and facing an opposed sheet surface in the sheet of material on an opposite side of the bend line;

bending the sheet of material about the bend line,

wherein the curved crown portion is dimensioned to produce face-to-surface engagement between the sheared face and the opposed sheet surface.

27. A method according to claim 26, wherein the end portions have a smaller radius of curvature than the crown portions.
28. A method according to claim 26, wherein the crown portion is a large radii arc.
29. A method according to claim 26, wherein the end portions are a small radii arc.
30. A method according to claim 26, the bend-controlling displacement further including transition zones between the crown portion and the end portions.
31. A method according to claim 30, wherein the transition zones have a radius of curvature intermediate the radii of curvature of the end portions and the crown portion.
32. A method according to claim 26, wherein the bend line is substantially fluid-resistant when the sheet of material is bent.
33. A method according to claim 26, wherein a portion of the periphery proximate the bend line defines a sheared face directed toward an opposed sheet surface in the sheet of material on an opposite side of the bend line, whereby during the bending

step a balancing of forces during bending produces face-to-surface engagement between the sheared face and the opposed sheet surface such that the sheet material is substantially fluid-resistant along the bend line.

34. A method according to claim 33, wherein the forming step forms a joggle zone connecting an unsheared portion of the bend-controlling displacement to the sheet material, wherein each end portion includes a portion of the sheared face and a portion of the joggle zone.

35. A method according to claim 33, wherein the sheared face extends to within approximately 40° of a longitudinal axis of the displacement with respect to a radial center of the end portion.

36. A two-dimensional sheet of material formed for bending along a bend line to form a three-dimensional article having a fluid-resistant bend, the sheet of material comprising:

a sheet of material including a bend-controlling displacement in the thickness direction of the sheet of material, a portion of a periphery of the bend-controlling displacement proximate the bend line defining a sheared face directed toward an opposed sheet surface in the sheet of material on an opposite side of the bend line, the sheared face and opposed sheet surface configured and positioned to produce face-to-surface engagement of the sheet of material after bending such the bend is substantially fluid-resistant when bent.

37. A sheet of material according to claim 36, the bend-controlling displacement having an oval shape and further including a periphery with end portions and a crown portion extending between the end portions.

38. A sheet of material according to claim 37, wherein the crown portion has an arcuate profile.

39. A sheet of material according to claim 38, wherein the end portions have an arcuate profile with a radius of curvature smaller than a radius of curvature of the crown portion.

40. A sheet of material according to claim 37, the bend-controlling displacement further including transition zones between the crown portion and the end portions.

41. A sheet of material according to claim 40, wherein each of the transition zones have a radius of curvature intermediate the radii of curvature of the end portions and the crown portion.

42. A sheet of material according to claim 37, wherein the bend-controlling displacements further include a joggle zone connecting an unsheared portion of the bend-controlling displacement to the sheet material, wherein each end portion includes a portion of the sheared face and a portion of the joggle zone.

43. A two-dimensional sheet of material formed for bending along a bend line to form a three-dimensional article, the sheet of material comprising:

a sheet of material including a bend-controlling displacement in the thickness direction of the sheet of material with a substantially oval shape, the bend-controlling

displacement including a periphery with end portions and a curved crown extending between the end portions proximate the bend line, the bend-controlling displacement including a sheared face extending along the crown portion and into the end portions and facing an opposed sheet surface in the sheet of material on an opposite side of the bend line;

wherein the curved crown portion is dimensioned to produce face-to-surface engagement between the sheared face and the opposed sheet surface.

44. A method according to claim 43, wherein the end portions have a smaller radius of curvature than the crown portions.

45. A method according to claim 43, wherein the crown portion is a large radii arc.

46. A method according to claim 43, wherein the end portions are a small radii arc.

47. A method according to claim 43, the bend-controlling displacement further including transition zones between the crown portion and the end portions.

48. A method according to claim 47, wherein the transition zones have a radius of curvature intermediate the radii of curvature of the end portions and the crown portion.

49. A rigid three-dimensional article formed by bending a two-dimensional sheet of material along at least one bend line, the article including:

at least one bend-inducing displacement in the thickness direction of the sheet of material, a portion of a periphery of the bend-inducing displacement proximate the bend line defining a sheared face directed toward an opposed sheet surface in the sheet of material on an opposite side of the bend line,

wherein the sheared face and opposed sheet surface are in engagement such that the sheet material is substantially fluid-resistant along the bend line.

50. An article according to claim 52, wherein the sheared face and opposed sheet surface are in close abutment along a periphery of the sheared face.

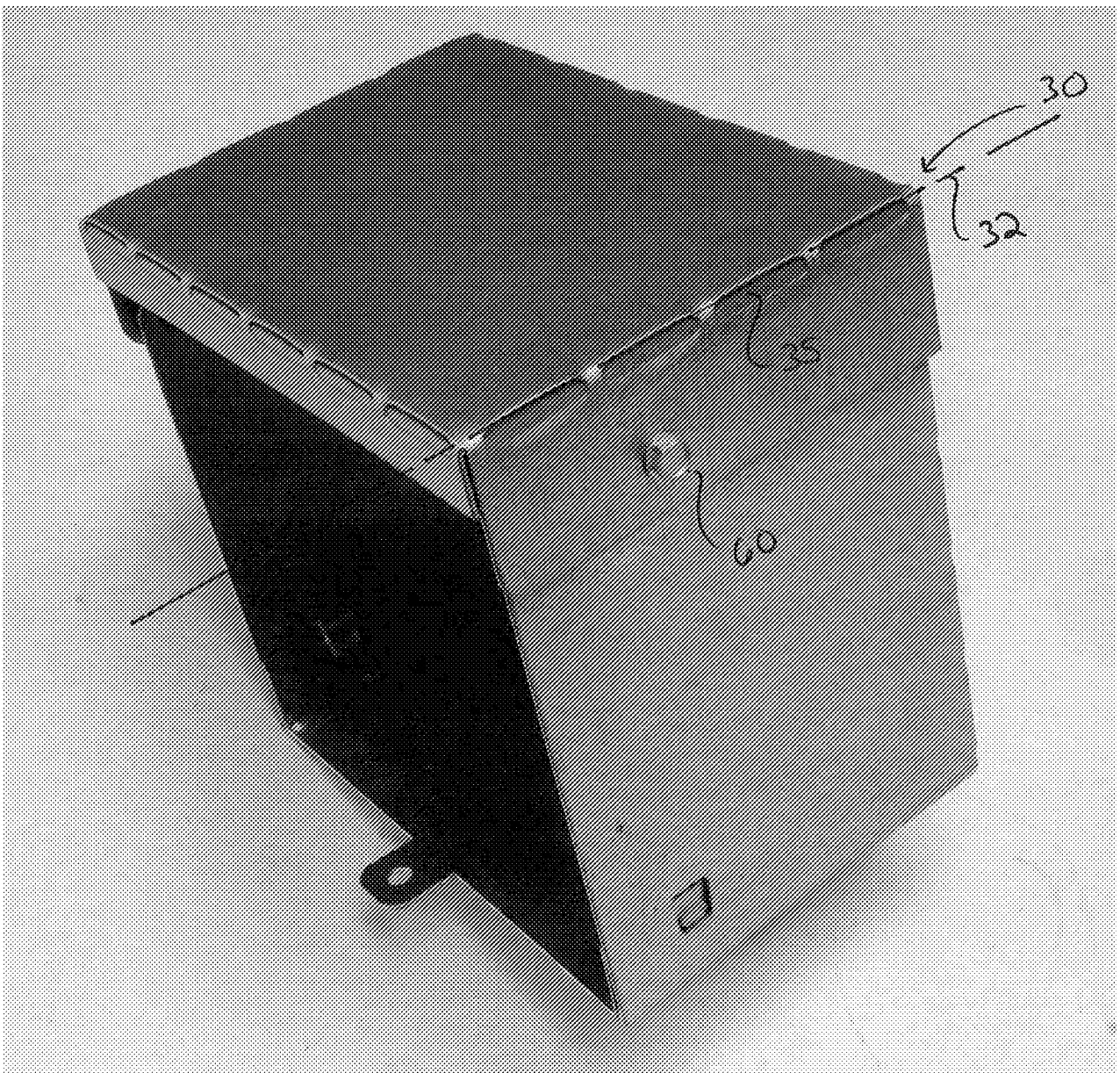


FIG. 1

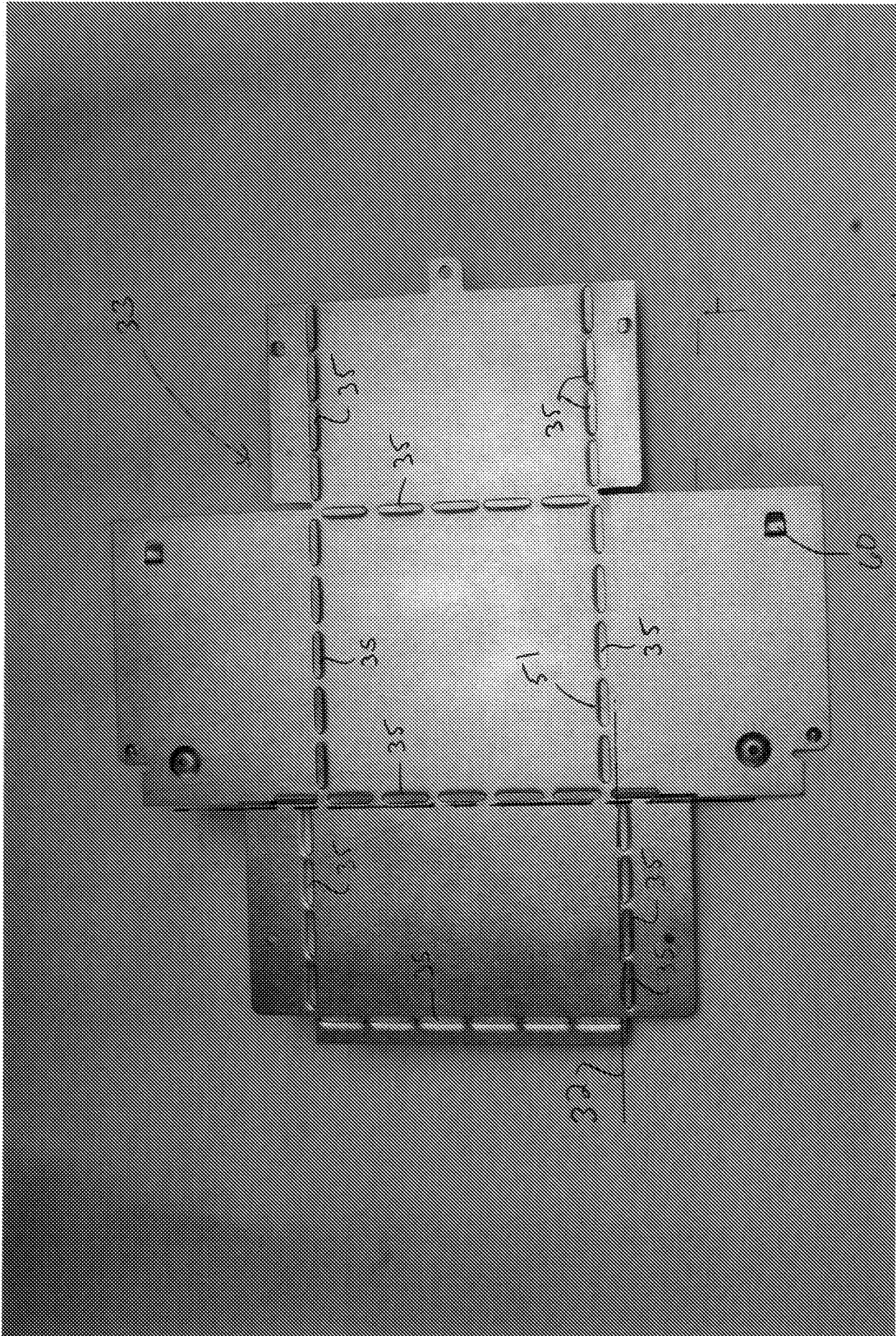


FIG. 2

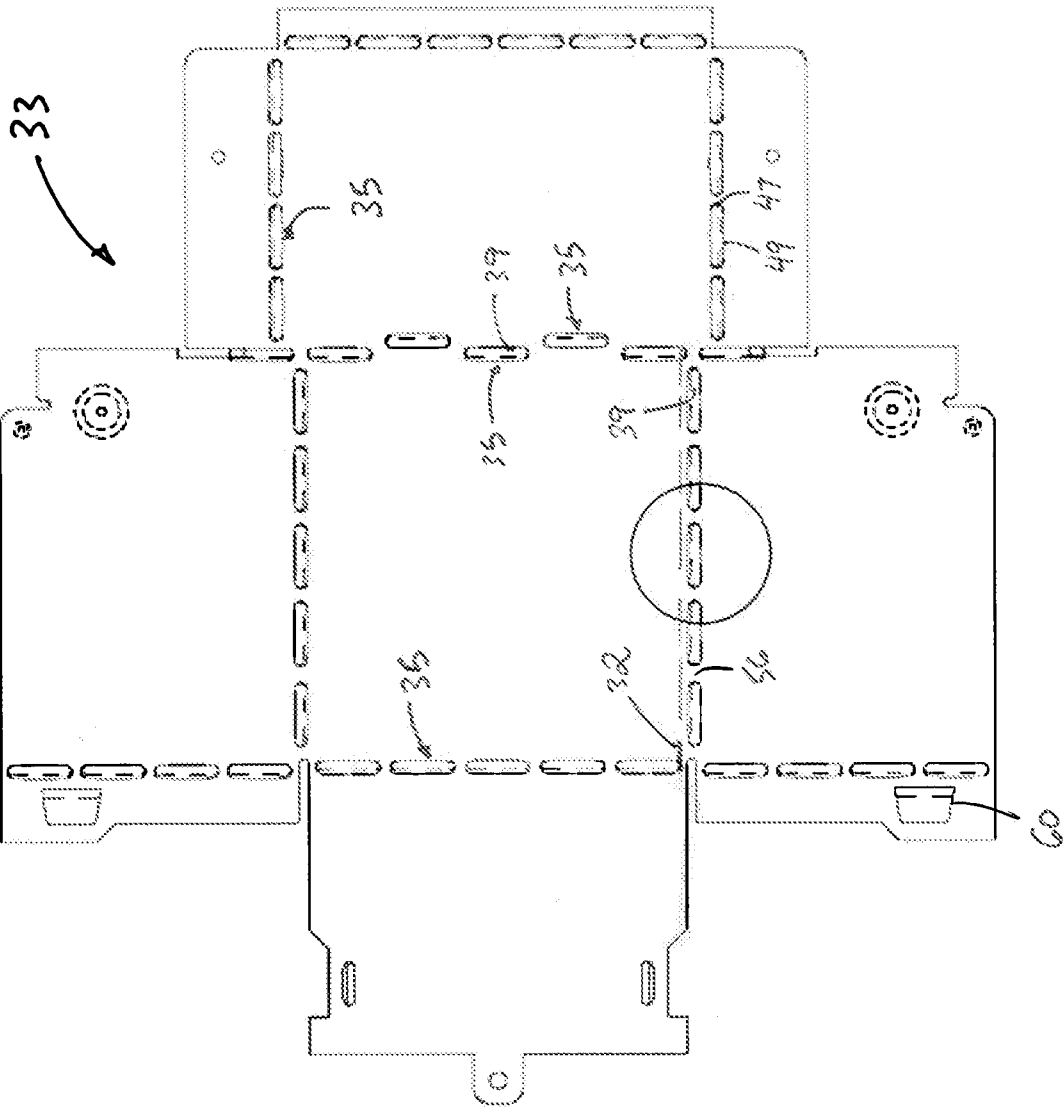


FIG. 3

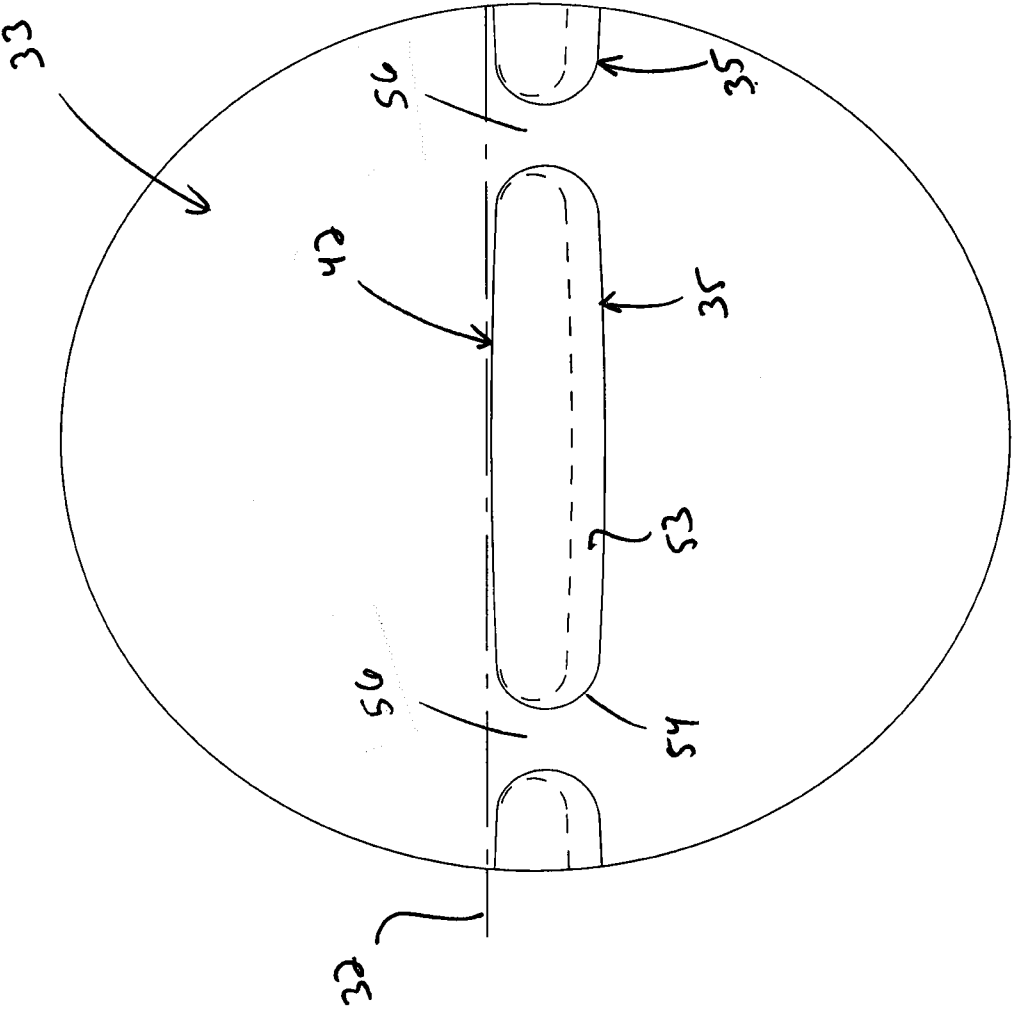


FIG. 3A

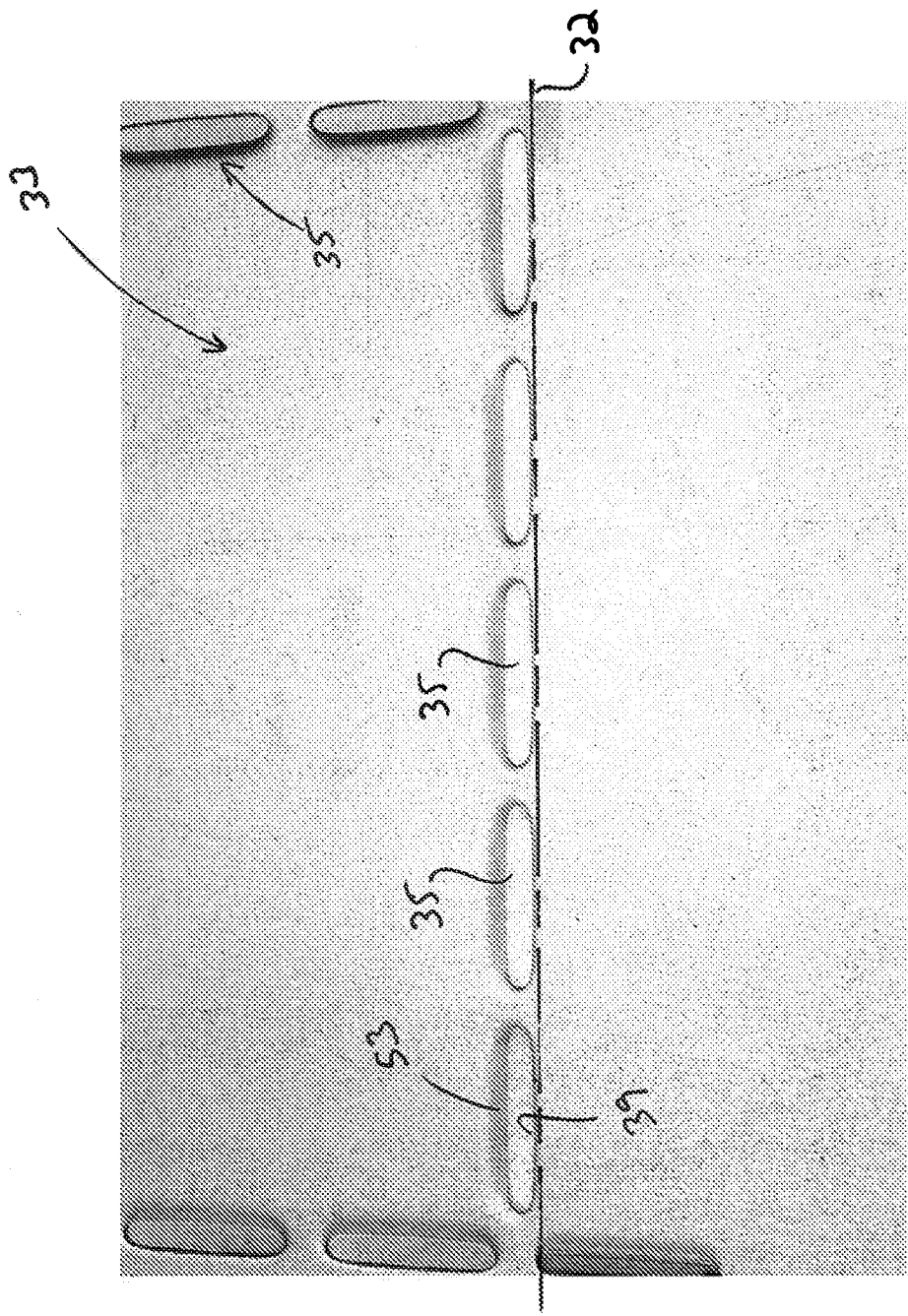
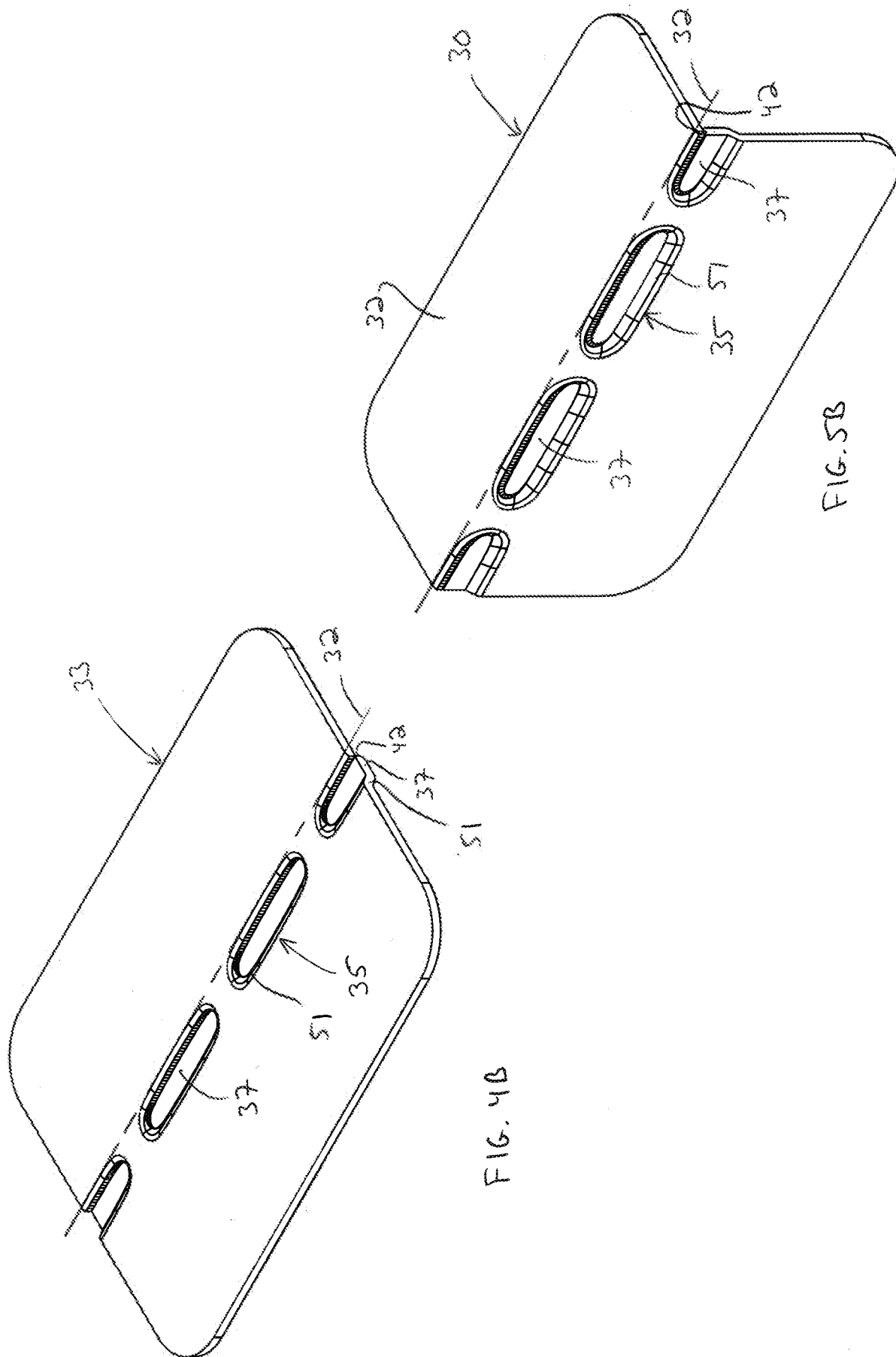


FIG. 4 A



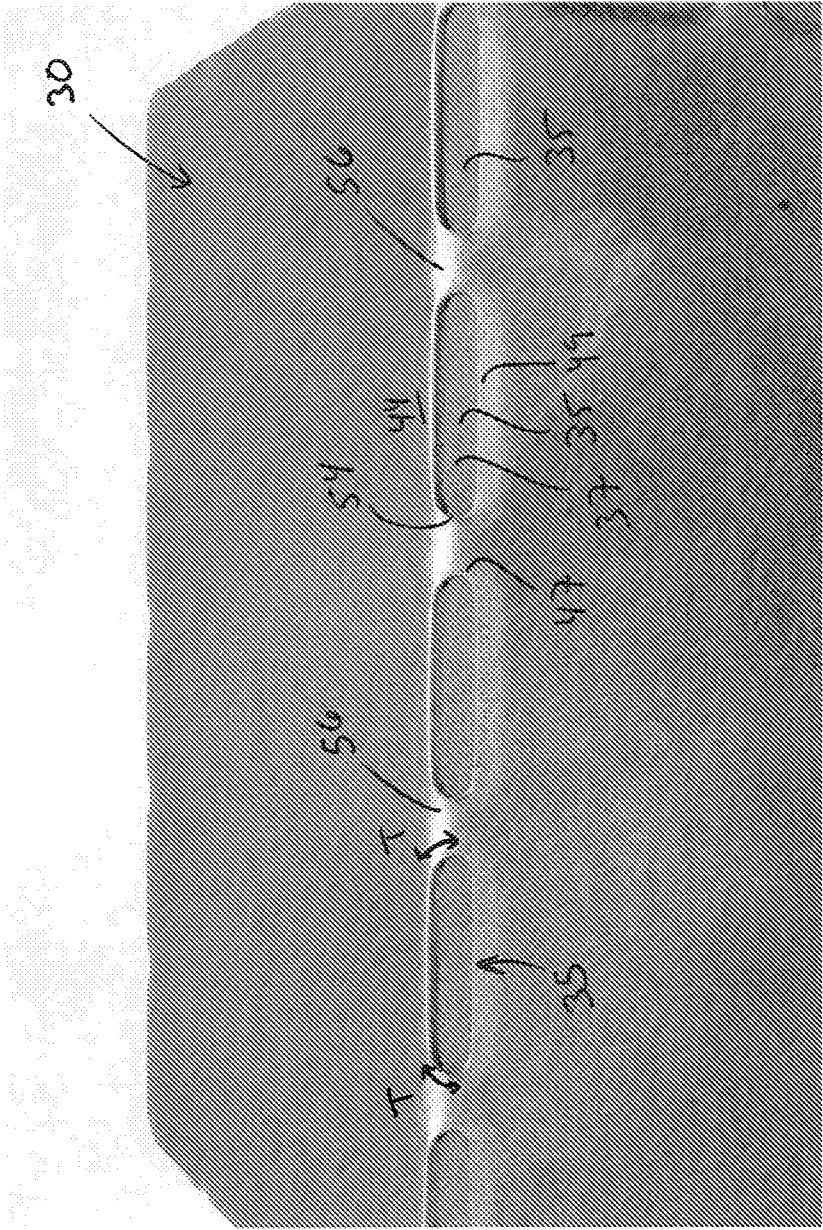


FIG. 5A

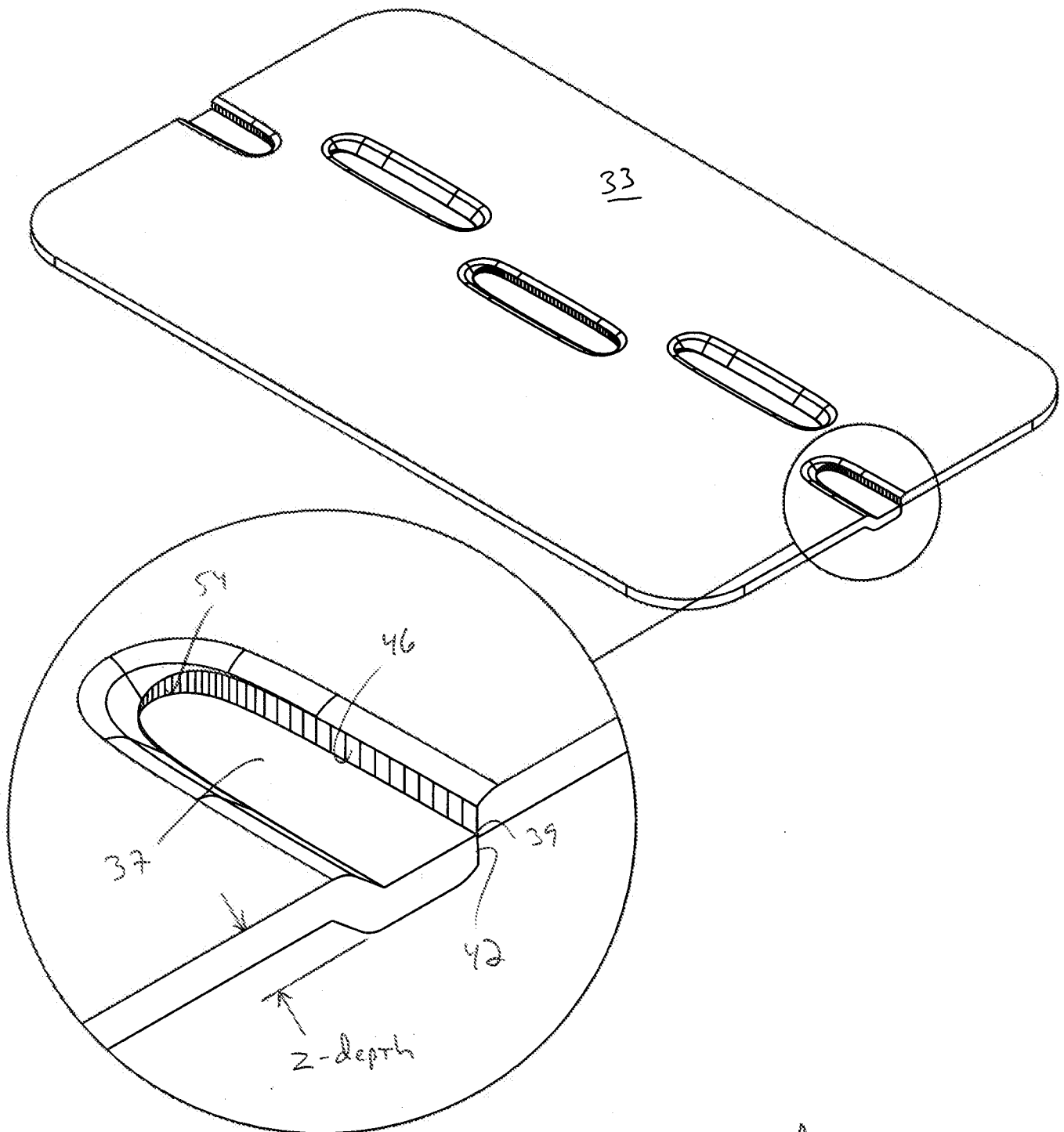
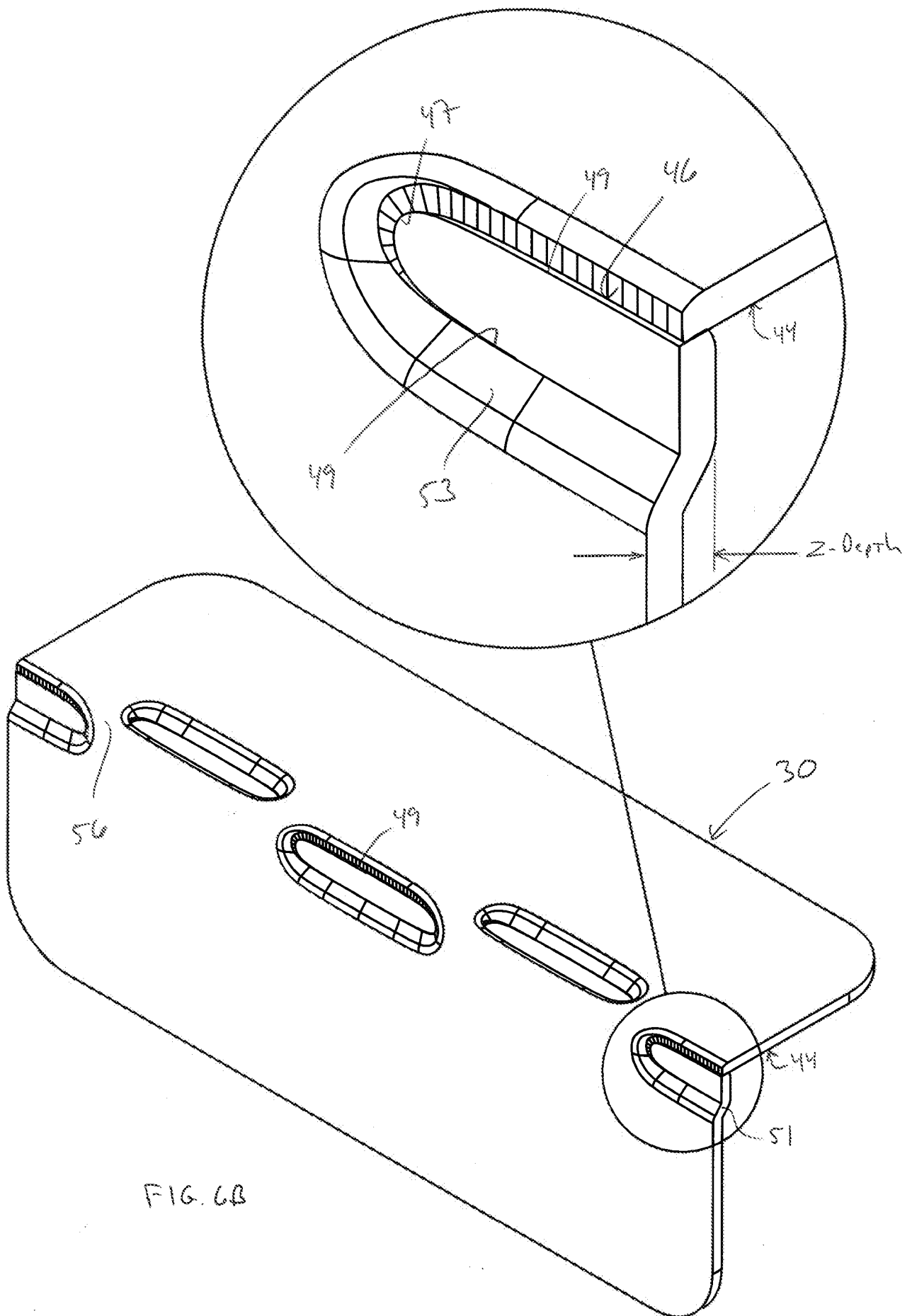


FIG. 1A



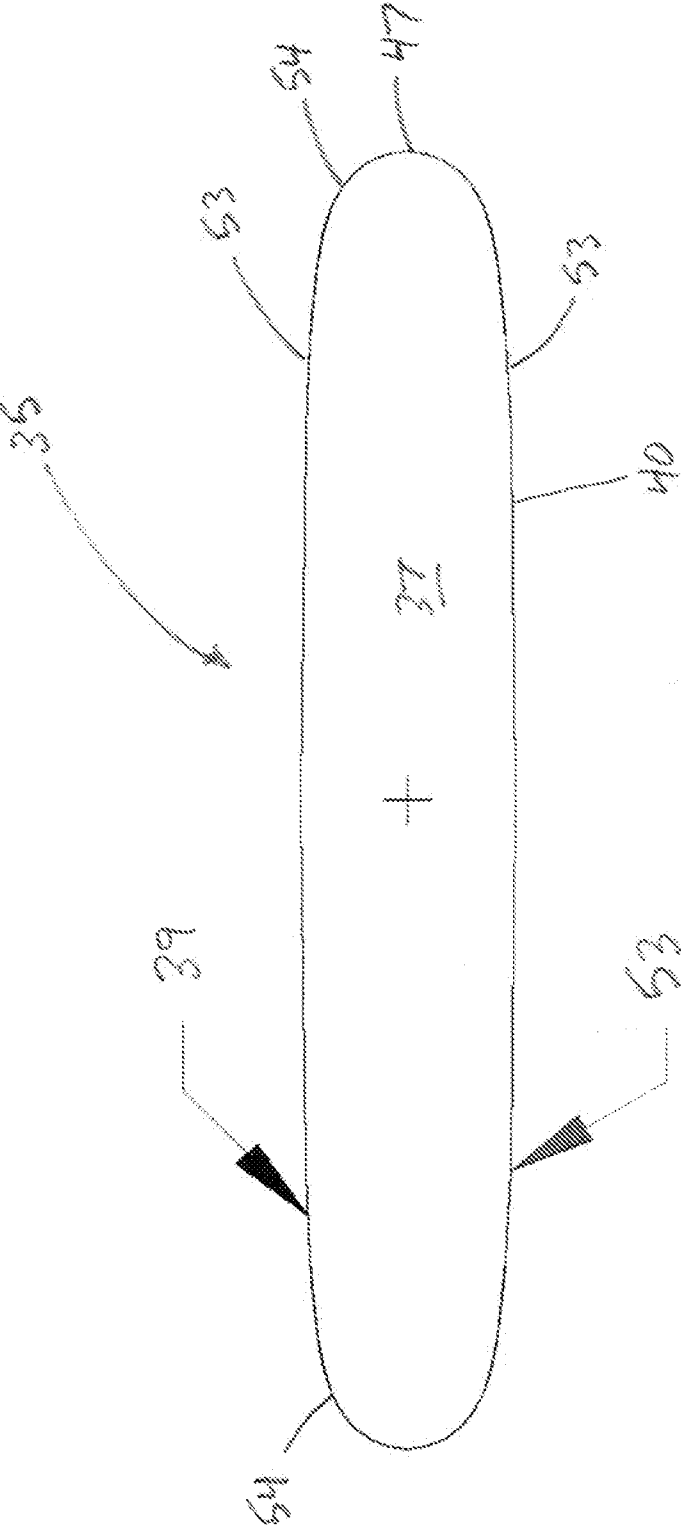


FIG. 7

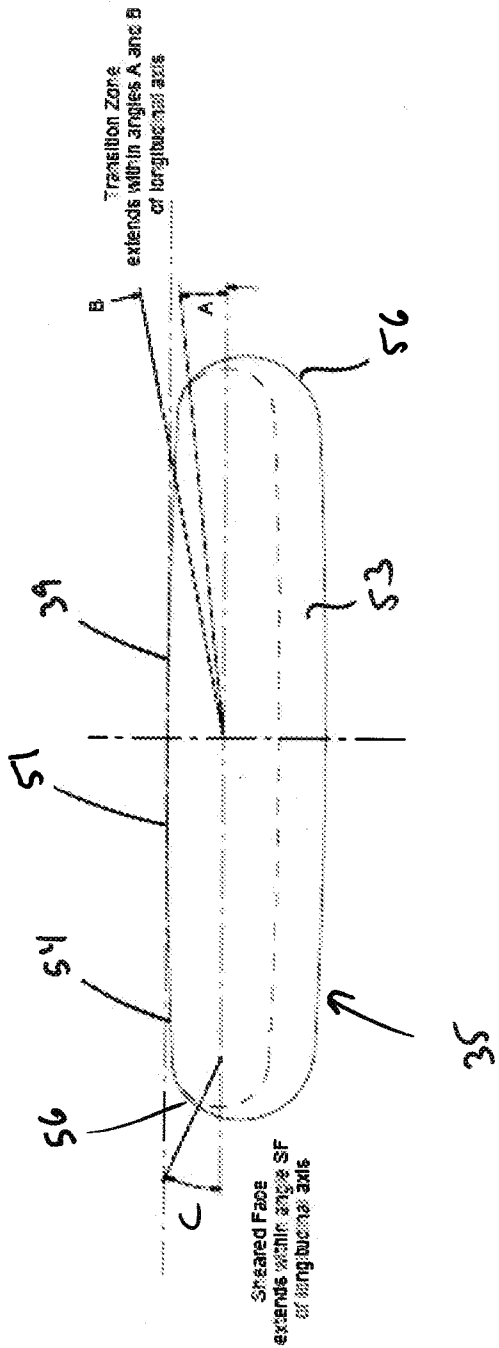


FIG. 8

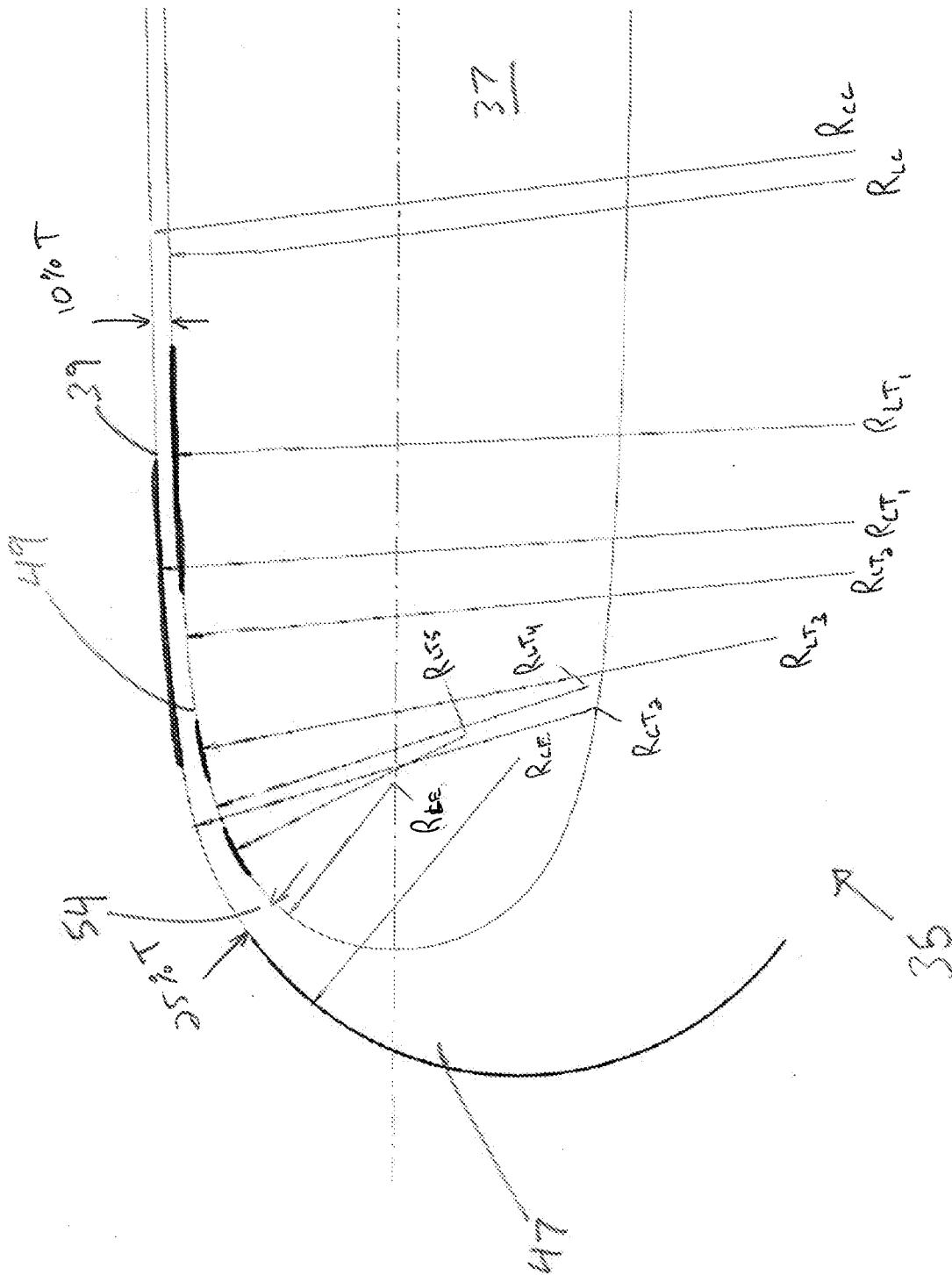


FIG. 9

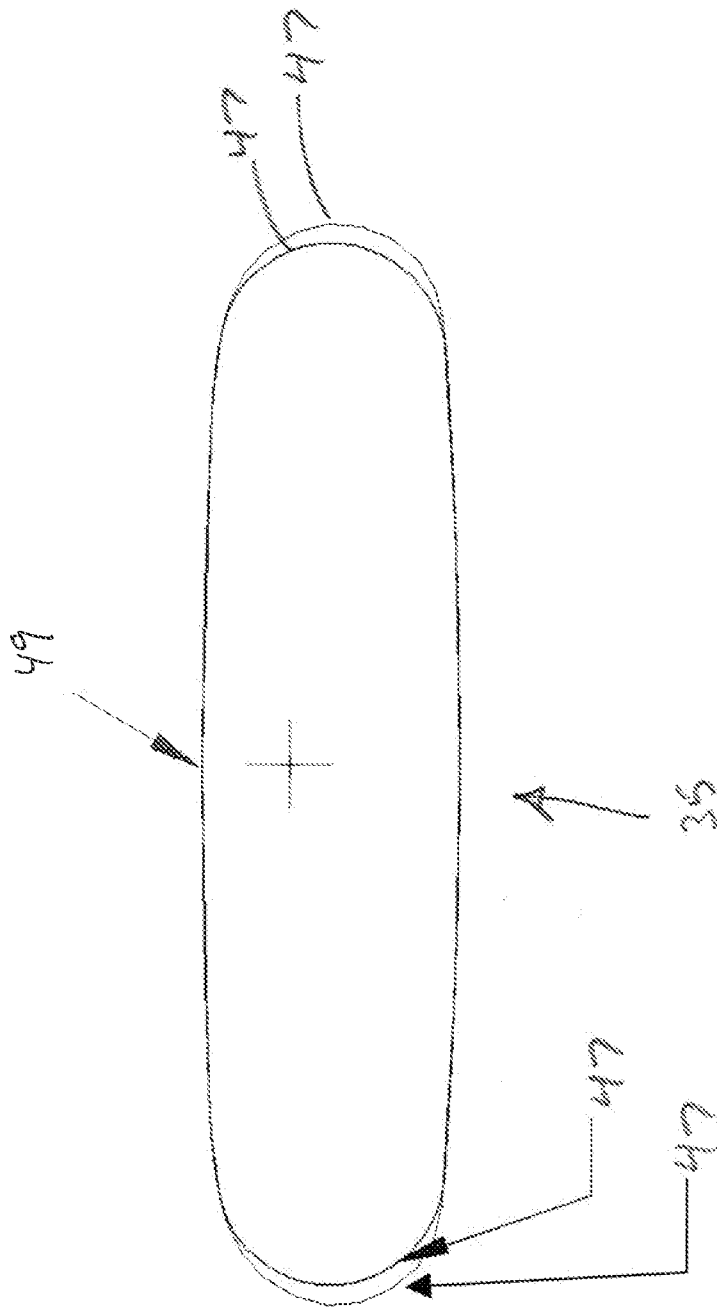


FIG. 10

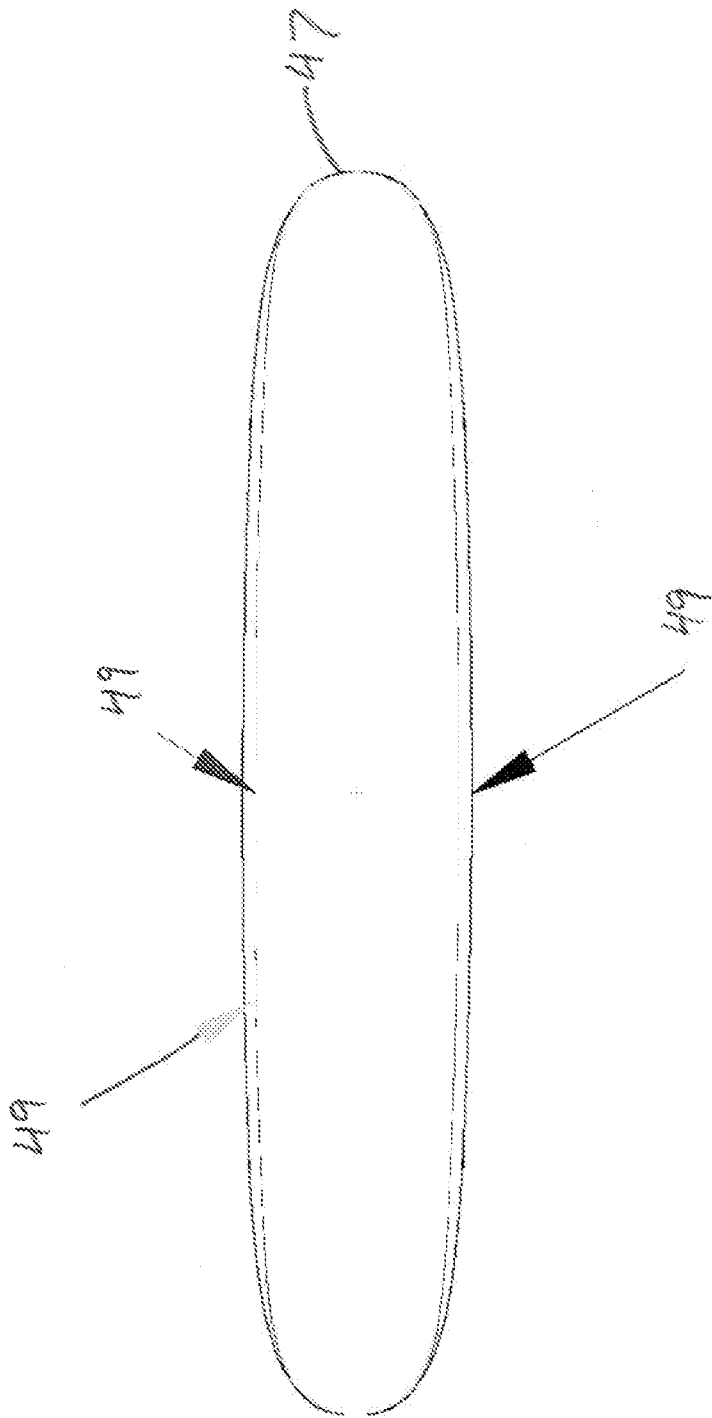


FIG. 11