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(54)

REMOVABLE FLUID BARRIER

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A removable fluid barrier comprises: a generally planar flexible body fabricated of at least one resilient material and having an outer face defining a sealing surface of the removable fluid barrier, the flexible body encapsulating a plurality of permanent magnets and a re-
- inforcement sheet, the reinforcement sheet comprising fibers of a first material and fibers of a second material, the first material having a higher tensile strength than the second material, the second material having a higher toughness than the first material.

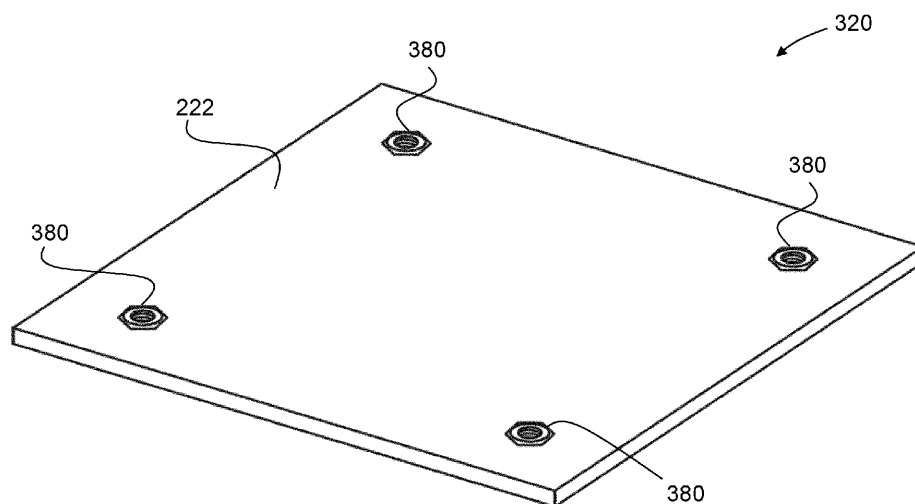


Figure 17

Description**Field**

[0001] The present invention relates generally to fluid containment, and in particular to a removable fluid barrier.

Background

[0002] Storage and transportation of hazardous fluids, such as hazardous liquids and gases, is known to be problematic, as any rupture that occurs in the tank containing the fluid can be difficult to mend quickly while hazardous fluid is still in the tank. Such ruptures typically result in leakage and/or spillage of hazardous fluid from the tank, which can contaminate and damage the surrounding environment.

[0003] For example, in the event of rail accident involving tank cars, it has been found that leakage of fluids from the ruptured tank car(s) into the surrounding environment is not easily prevented. Similar difficulties exist for other for fluid transport vehicles, such as highway tanker trucks, as well as static fluid containers, such as unpressurized fluid storage tanks and 55 gallon (208.2 litre) drums. As most fluid transport vehicles and static fluid containers do not have internal baffles, the amount of fluid leakage in such cases can be significant.

[0004] A conventional approach to deal with such a rupture is to plug the rupture with a wooden peg. However, in many instances, the use of a wooden peg is inadequate to completely stop fluid flow through the plugged rupture.

[0005] Removable fluid barriers have also been considered. For example, International PCT Application No. WO 1992004574 to Goulding describes an apparatus that includes an aluminum backing plate onto which a sponge rubber layer is bonded. The sponge rubber layer has an impervious skin, which is impervious to liquids contained in a transport tanker or tank made of steel or another ferrous material to which the apparatus is to be applied for sealing a rupture therein. At the periphery of the backing plate are a set of eight permanent magnets which are also bonded to the aluminum plate. When a rupture occurs in the tanker or tank, the apparatus may be used to stem the flow of the leak by fastening the magnets to the tanker or tank to thereby compress the sponge rubber layer against the rupture.

[0006] Improvements are generally desired. It is therefore an object at least to provide a novel removable fluid barrier.

Summary

[0007] In one aspect, there is provided a removable fluid barrier, comprising: a generally planar flexible body fabricated of at least one resilient material and having an outer face defining a sealing surface of the removable fluid barrier, the flexible body encapsulating a plurality of permanent magnets and a reinforcement sheet, the reinforcement sheet comprising fibers of a first material and fibers of a second material, the first material having a higher tensile strength than the second material, the second material having a higher toughness than the first material.

[0008] The fibers of the first material may be basaltic fibers. The fibers of the second material may be fibers of a non-olefin thermoplastic material having high crystallinity.

[0009] The flexible body may be formed by a single casting.

[0010] The flexible body may have a single, unitary structure.

[0011] The removable fluid barrier may further comprise one or more connectors at least partially encapsulated within the flexible body. Each of the one or more connectors may be configured to matingly connect to a connecting element to provide a handle for handling the removable fluid barrier. Each of the one or more connectors comprises a threaded nut.

[0012] The outer face of the flexible body may comprise a textured surface, optionally, wherein the textured surface has a non-planar topography.

[0013] The plurality of permanent magnets may comprise one or more rare earth magnets.

[0014] The each of the permanent magnets may comprise an epoxy coating.

[0015] The at least one resilient material may comprise a polymer.

[0016] The flexible body may be fabricated of polyurethane.

Brief Description of the Drawings

[0017] Embodiments will now be described more fully with reference to the accompanying drawings in which:

Figure 1 is a perspective view of a removable fluid barrier;

Figure 2 is a perspective, partially transparent view of the removable fluid barrier of Figure 1;

Figure 3 is an exploded view of the removable fluid barrier of Figure 1;

Figure 4 is a perspective sectional view of a first layer accommodating permanent magnets and forming part of the removable fluid barrier of Figure 1;

Figure 5 is a fragmentary side view of a portion of the first layer and the permanent magnets of Figure 4 indicated by reference numeral 5;

Figure 6 is a perspective view of a permanent magnet forming part of the removable fluid barrier of Figure 1;

Figure 7 is a flowchart of a method of manufacturing the removable fluid barrier of Figure 1;

Figure 8 is a perspective view of a first mold used to form the first layer;

Figure 9 is a perspective view of a second mold used to form a second layer forming part of the removable fluid barrier of Figure 1;

Figure 10 is a perspective view of the second mold of Figure 9, with the first layer accommodating the permanent magnets placed therein;

Figure 11A is a perspective view of another embodiment of a removable fluid barrier;

Figure 11B is a perspective, partially transparent view of the removable fluid barrier of Figure 11A;

Figure 12 is a perspective view of another embodiment of a removable fluid barrier;

Figure 13 is an exploded view of a portion of an assembly used to fabricate the removable fluid barrier of Figure 12, and showing a reinforcement sheet forming part of the removable fluid barrier;

Figure 14 is an enlarged fragmentary, schematic view of a portion of the reinforcement sheet of Figure 13;

Figure 15 is a side sectional view of the removable fluid barrier of Figure 12, during fabrication and taken along the section line indicated in Figure 13;

Figure 16 is a side sectional view of the removable fluid barrier of Figure 15;

Figure 17 is a perspective view of another embodiment of a removable fluid barrier;

Figure 18 is a perspective view of a connector forming part of the removable fluid barrier of Figure 17; and

Figures 19A to 19F are photographic images of examples of the removable fluid barrier of Figure 12, after being subjected to liquid penetration testing in accordance with an example.

Detailed Description of the Drawings

[0018] Turning now to Figures 1 to 6, a removable fluid barrier is shown and is generally indicated by reference numeral 20. Removable fluid barrier 20 is configured to be magnetically fastened to a ruptured fluid vessel made of steel or other ferrous material, such as for example a rail tank car, to cover the rupture for reducing or preventing leakage of fluid therefrom.

[0019] The removable fluid barrier 20 comprises a generally planar flexible body 22 fabricated of one or more resilient materials and encapsulating a plurality of permanent magnets 24. The flexible body 22 comprises a first layer 26 and a second layer 28. In this embodiment, each of the first layer 26 and the second layer 28 is fabricated of polyurethane, and is formed by casting. Also in this embodiment, the flexible body 22 has a generally square shape, and has dimensions of about 30 inches $\times$ about 30 inches $\times$ about 0.5 inches (about 76.2 cm $\times$ about 76.2 cm $\times$ about 1.27 cm) (about 76.2 cm $\times$ about 76.2 cm $\times$ about 1.27 cm).

[0020] The first layer 26 has an array of recesses 32 formed on one side thereof, with each recess 32 being sized and shaped to accommodate a permanent magnet 24. The array of recesses 32 is generally centered on one side of the first layer 26, and covers a large portion thereof, such that a margin 34 extends around its periphery. The recesses 32 are arranged in a densely spaced pattern within the array. In the embodiment shown, the recesses 32 are distributed over about 65% of the area of the first layer, and the recesses 32 are interconnected such that adjacent permanent

magnets 24 abut.

[0021] The second layer 28 has generally identical dimensions as the first layer 26. The second layer 28 is joined to the first layer 26, with the permanent magnets 24 accommodated therein, such that the first layer 26 and the second layer 28 provide an integrated, closed structure encapsulating the permanent magnets 24. The interface between the first layer 26 and the second layer 28 is strong, and has sufficient strength to remain joined during normal use of the removable fluid barrier 20. As a result of this strong interface, and as a result of the first layer 26 and the second layer 28 being fabricated of the same material, the flexible body 22 effectively has a unitary structure.

[0022] Figure 6 shows one of the permanent magnets 24. Each permanent magnet 24 is a rare earth magnet, and is fabricated of an alloy comprising one or more rare earth elements. Rare earth magnets are known to have a high magnetic strength, and more specifically a high energy product. As a result, the array of permanent magnets 24 enables the removable fluid barrier 20 to be very strongly magnetically fastened to ferrous structures.

[0023] Each permanent magnet 24 is shaped so as to have two opposing faces, and is magnetically polarized such that each opposing face provides a respective one of the north pole or the south pole. Each permanent magnet 24 may be, for example, a grade N35 neodymium iron boron magnet, sold by United International Manufacture of Hong Kong.

[0024] Figure 7 is a flowchart showing steps of a method of manufacturing a removable fluid barrier, such as the removable fluid barrier 20. First, the first layer 26 is cast by pouring polyurethane resin 62 into a first mold 64 comprising mold feature 66, as shown in Figure 8. As will be understood, the mold feature 66 is shaped to form the array of recesses 32.

[0025] The polyurethane resin 62 may be, for example, a thermoset polyurethane resin sold by Prothane of Milton, Ontario, Canada. Once the polyurethane resin 62 has cured within the mold 64, the first layer 26 is formed (step 90).

[0026] The first layer 26 is removed from the mold 64. The permanent magnets 24 are then inserted (not shown) into the recesses 32 of the first layer 26 (step 92). In this embodiment, the permanent magnets 24 are inserted such that their magnetic polarities all have the same orientation within the first layer 26.

[0027] The first layer 26, with the permanent magnets 24 accommodated therein, is then placed into a second mold 72 which, in the embodiment shown, comprises four (4) aluminum sheets 74 assembled into a square frame, shown in Figure 9. The second layer 28 is then cast by pouring polyurethane resin 62 into the second mold 72 and over the first layer 26 and the permanent magnets 24, as shown in Figure 10. Once the polyurethane resin 62 has cured within the mold 72, the second layer 28 is formed (step 94).

[0028] In use, the removable fluid barrier 20 is applied to a ruptured ferrous fluid vessel (not shown) such that the removable fluid barrier 20 covers the rupture, and such that the first layer 26 contacts the ferrous fluid vessel around the rupture. The permanent magnets 24 provide a magnetic force of attraction to the ferrous fluid vessel. This magnetic force of attraction, in combination with the flexibility of the fluid barrier 20, causes the removable fluid barrier 20 to conform to and to become magnetically fastened to the ferrous fluid vessel. As will be understood, the flexibility of the removable fluid barrier 20 enables the removable fluid barrier 20 to conform to curvature of the ferrous fluid vessel. Further, the magnetic force of attraction, in combination with the flexibility of the first layer 26, causes the first layer 26 to compress against the ferrous fluid vessel, which thereby enables the removable fluid barrier 20 to effectively provide a fluid seal or an at least partial fluid seal around the rupture, so as to reduce or prevent the outflow of fluid through the rupture. In this manner, the outer surface of the first layer 26 defines a sealing surface of the removable fluid barrier 20.

[0029] It will be understood that the removable fluid barrier may alternatively be applied to the ruptured ferrous fluid vessel such that the second layer 28 contacts the ferrous fluid vessel. In such a case, the outer surface of the second layer defines a sealing surface of the removable fluid barrier.

[0030] The removable fluid barrier 20 may be removed by pulling an edge of the removable fluid barrier 20 away from the ferrous fluid vessel, and with sufficient force so as to overcome the magnetic force of attraction provided by the permanent magnets 24. The removable fluid barrier 20 may then be cleaned to remove fluid residue, if necessary, and may then be used for another application.

[0031] As an example, the removable fluid barrier 20 may be applied to a rupture any ferrous, low-pressure or unpressurized fluid vessel, such as for example a rail tank car, a highway transport tanker, a fluid storage tank, a drum container such as a 55 gallon drum, a low-pressure pipeline, and the like, so as to limit spillage of fluid from the fluid vessel. In such applications, the removable fluid barrier 20 may be used by emergency personnel, such as for example firefighters, to prevent or reduce leakage of fluid, such as hazardous liquid or gas.

[0032] As another example, the removable fluid barrier 20 may alternatively be applied to a ferrous drain structure, such as for example a sewer grate, a manhole cover, a floor drain cover, and the like, to reduce or prevent entry of fluid into the drain. In such applications, the removable fluid barrier 20 may be used by emergency personnel, such as for example firefighters, to prevent fluid spilled on a floor or ground surface from entering the drain, and to thereby contain the spill of fluid. The fluid may be hazardous liquid or gas.

[0033] As will be appreciated, the permanent magnets 24 fabricated of rare earth alloy advantageously provide a stronger magnetic force of attraction as compared to permanent magnets fabricated of other materials, such as for example ferrous permanent magnets. As will be understood, the stronger magnetic force of attraction provided by the permanent magnets 24 enables the removable fluid barrier 20 to become more strongly magnetically fastened to the

ruptured ferrous fluid vessel, and to thereby withstand greater opposing forces arising from fluid pressure within the fluid vessel, as compared to conventional removable fluid barriers comprising ferrous permanent magnets.

[0034] As will be appreciated, the permanent magnets 24 allow the removable fluid barrier 20 to be magnetically fastened to the ruptured fluid vessel in a facile manner, and without the need to provide an electrical current and means for delivering such a current, as would be required for conventional removable fluid barriers comprising electromagnets. The permanent magnets 24 advantageously enable the removable fluid barrier 20 to be fastened quickly, which is particularly beneficial for emergency situations and situations involving hazardous materials.

[0035] As will be appreciated, the densely spaced configuration of the permanent magnets 24 advantageously enables the permanent magnets 24 to provide a much stronger total magnetic force of attraction over a given area, while allowing to the removable fluid barrier 20 to remain flexible, as compared to conventional fluid barriers comprising non-densely spaced configurations of magnets.

[0036] As will be appreciated, the removable fluid barrier 20 has a generally simple construction and consists of generally only three (3) components, namely the first layer 26, the plurality of permanent magnets 24, and the second layer 28. The simple construction advantageously allows the removable fluid barrier 20 to be manufactured at lower cost, as compared to conventional fluid barriers having more complex construction.

[0037] As will be appreciated, the use of a durable resilient material, such as polyurethane, for the first and second layers 26 and 28 advantageously enables these layers to provide sufficient structural integrity to contain the permanent magnets 24 during use, and to also each provide an outer surface that has sufficient flexibility to form a fluid seal against the fluid vessel.

[0038] As will be appreciated, the inclusion of a margin 34 in the first layer 26 allows the edges of the removable fluid barrier 20 to be easily lifted from the ferrous fluid vessel, which may effectively serve as a handle for facilitating removal of the removable fluid barrier 20.

[0039] Other configurations are possible. For example, although in the embodiment described above, the array of recesses covers only a portion of the first layer such that a margin extends around its periphery, in other embodiments, the removable fluid barrier may alternatively be configured such that substantially no margin extends around the periphery of the first layer. Such configurations may be desirable for removable fluid barriers of smaller size, for which the total magnetic force of attraction provided by the permanent magnets is less, and which therefore may be removed by pulling away from the ferrous fluid vessel using less force.

[0040] For example, Figures 11A and 11B show another embodiment of a removable fluid barrier, which is generally indicated by reference numeral 120. Removable fluid barrier 120 is generally similar to removable fluid barrier 20 described above and with reference to Figures 1 to 6, and comprises a generally planar flexible body 122 fabricated of one or more resilient materials and encapsulating a plurality of permanent magnets 24. The flexible body 122 comprises a first layer 126 and a second layer 128, and in this embodiment, each of the first layer 126 and the second layer 128 is fabricated of polyurethane and is formed by casting. Also in this embodiment, the flexible body 122 has a generally square shape, and has dimensions of about 10 inches $\times$ about 10 inches $\times$ about 0.5 inches (about 25.4 cm $\times$ about 25.4 cm $\times$ about 1.27 cm).

[0041] Similar to first layer 26 described above, the first layer 126 has an array of recesses (not shown) formed on one side thereof, with each recess being sized and shaped to accommodate a permanent magnet 24. The array of recesses is generally centered on the first layer 126. However, unlike the first layer 26 described above, the array of recesses covers generally the entirety of one side of the first layer 126, such that substantially no margin extends around its periphery. The recesses are arranged in a densely spaced pattern within the array. In this embodiment, the recesses are distributed across about 90% of the area of the first layer 126, and the recesses are interconnected such that adjacent permanent magnets 24 abut.

[0042] The second layer 128 has generally identical dimensions as the first layer 126. The second layer 128 is joined to the first layer 126, with the permanent magnets 24 accommodated therein, such that the first layer 126 and the second layer 128 provide an integrated, closed structure encapsulating the permanent magnets 24. The interface between the first layer 126 and the second layer 128 is strong, and has sufficient strength to remain joined during normal use of the removable fluid barrier 120. As a result of this strong interface, and as a result of the first layer 126 and the second layer 128 being fabricated of the same material, the flexible body 122 effectively has a unitary structure.

[0043] Although in the embodiment described above, the first layer and the second layer of the flexible body are both fabricated of polyurethane, in other embodiments, one or both of the first layer and the second layer may alternatively be fabricated of another suitable thermoset resin, from another suitable polymer, or from another suitable material, that provides suitable flexibility and suitable durability. In still other embodiments, an adhesive layer may alternatively be disposed between the first layer and the second layer.

[0044] Although in the embodiment described above, the first layer and the second layer are formed by casting, in other embodiments, one or both of the first layer and the second layer may alternatively be formed by another suitable method, such as for example injection molding, cutting from a slab of material, and the like.

[0045] Although in the embodiment described above, each permanent magnet is a rare earth magnet, in other em-

bodiments, one or more of the permanent magnets may alternatively be ferrous magnets.

[0046] Still other configurations are possible. For example, Figures 12 to 16 show another embodiment of a removable fluid barrier, which is generally indicated by reference numeral 220. Removable fluid barrier 220 is configured to be magnetically fastened to a ruptured fluid vessel made of steel or other ferrous material, such as for example a rail tank car, to cover the rupture for reducing or preventing leakage of fluid therefrom.

[0047] The removable fluid barrier 220 comprises a generally planar flexible body 222 fabricated of one or more resilient materials and encapsulating a plurality of permanent magnets 230. The flexible body 222 has a single, continuous, unitary structure, and this embodiment the flexible body 222 is fabricated of polyurethane and is formed by casting. More specifically, the flexible body 222 is formed by a single casting, during which the permanent magnets 230 are encapsulated, and are thereby enclosed in the flexible body 222. In the example shown, the flexible body 222 has a generally square shape, and has dimensions of about 30 inches $\times$ about 30 inches $\times$ about 0.5 inches (about 76.2 cm $\times$ about 76.2 cm $\times$ about 1.27 cm). The generally planar flexible body 222 has two opposing faces, namely a first face 232 and a second face 234. At least a portion of the first face 232 comprises a textured surface 236, which is formed by casting the flexible body 222 against a textured plate 240 during fabrication, as described below.

[0048] The permanent magnets 230 are encapsulated within the flexible body 222 generally adjacent the first face 232. In this embodiment, the flexible body 222 also encapsulates a reinforcement sheet 242, which is disposed within the flexible body 222 between the permanent magnets 230 and the first face 232. The reinforcement sheet 242 is flexible and resilient, and is configured to provide reinforcement to the flexible body 222 for strengthening the fluid barrier 220.

[0049] In this embodiment, the reinforcement sheet 242 is fabricated of a woven composite cloth comprising fibers 244 of a first material and fibers 246 of a second material that are arranged within the reinforcement sheet 242 in an alternating pattern. The properties of the first material include, among others, very high tensile strength, very high chemical resistance, and very high wettability by polyurethane. The properties of the second material include, among others, very high toughness, very high chemical resistance, and very high wettability by polyurethane. Thus, the fibers 244 of the first material have a higher tensile strength and a higher rigidity than the fibers 246 of the second material, while the fibers 246 of the second material have a higher toughness and a higher resiliency than the fibers 244 of the first material. In this embodiment, the fibers 244 of the first material are basaltic fibers, and the fibers 246 of the second material are wet-spun fibers of a non-olefin thermoplastic material having a high degree of crystallinity. The reinforcement sheet 242 may be, for example, a basaltic/non-olefin thermoplastic woven composite cloth developed specifically by the inventors, and now distributed by Composites Canada, a division of FFB Fiberglass Inc., of Mississauga, Canada, as product serial number BTB83-60.

[0050] The inventors have discovered that the fibers 244 of the first material, namely the basaltic fibers, have the properties of very high tensile strength, very high chemical resistance, and very high wettability by polyurethane. The inventors have also discovered that the fibers 246 of the second material, namely the fibers of the non-olefin thermoplastic material having the high degree of crystallinity, advantageously have the properties of very high toughness, very high chemical resistance, and very high wettability by polyurethane. In particular, the inventors have discovered that the high degree of crystallinity of the fibers of the non-olefin thermoplastic material contributes greatly to the very high wettability by polyurethane. The inventors have discovered that these properties of the first fibers 244 and the second fibers 246 advantageously enable the reinforcement sheet 242 to have the combined properties of high tensile strength, high toughness, very high chemical resistance, and very high wettability by polyurethane.

[0051] In this embodiment, the fibers 244 of the first material are grouped into bundles, and are positioned immediately adjacent to a parallel bundle of the fibers 246 of the second material (which are also grouped into bundles), in an alternating manner within the reinforcement sheet 242, as shown schematically in Figure 14. The inventors have found that by arranging a bundle of fibers 244 of the first material immediately adjacent to a parallel bundle of fibers 246 of the second material in an alternating manner, the fibers 246 of the second material, which have very high toughness, impart a "rip-stop" effect that reduces or impedes the propagation of cracking and/or tearing of fibers 244 of the first material, which advantageously increases the tear resistance of the reinforcement sheet 242.

[0052] The reinforcement sheet 242 is separated from the first face 232 by a thin layer of the one or more resilient materials of which the flexible body 222 is fabricated, as may be seen in Figures 15 and 16. Similarly, the permanent magnets 230 are separated from the reinforcement sheet 242 by a thin layer of the one or more resilient materials of which the flexible body 222 is fabricated, as may be seen in Figures 15 and 16.

[0053] In the example shown, each permanent magnet 230 is disc shaped, and comprises a rare earth magnet body 252 fabricated of an alloy comprising one or more rare earth elements. Rare earth magnets are known to have a high magnetic strength, and more specifically a high energy product. As a result, the array of permanent magnets 230 enables the removable fluid barrier 220 to be very strongly magnetically fastened to ferrous structures. Each permanent magnet 230 may be, for example, a grade N42 neodymium iron boron magnet.

[0054] Each permanent magnet 230 also comprises a ferromagnetic disc 254 that is magnetically fastened to the magnet body 252. It has been found by the inventor that the ferromagnetic disc 254 increases the magnetic force of attraction of the permanent magnet 230, and thereby increases the magnetic force of attraction of the removable fluid

barrier 220 to the fluid vessel. In this embodiment, the ferromagnetic disc 254 is fabricated of a ferromagnetic material, such as steel, for example. Each permanent magnet 230 further comprises a thin epoxy coating 256 disposed on the outer surfaces of the magnet body 252 and the ferromagnetic disc 254, such that the epoxy coating 256 encapsulates the permanent magnet 230. As will be understood, the epoxy coating 256 increases the strength of the interface between the permanent magnet 230 and the one or more resilient materials of which the flexible body 222 is fabricated.

[0055] Figure 13 shows a portion of an assembly 260 used to fabricate the removable fluid barrier 220. The assembly comprises a first face plate 262 fabricated of a ferromagnetic material, a spacer frame 264, and a second face plate 266. In this embodiment, the first face plate 262 is fabricated of steel. The first face plate 262, the spacer frame 264 and the second face plate 266, when assembled, define a mold cavity 268 for fabricating the removable fluid barrier 220. The second face plate 266 has a first aperture 272, through which liquid polymer resin used to fabricate the flexible body 222 is delivered. The second face plate 266 also has a second aperture 274, through which air displaced by the liquid polymer resin flowing through the mold cavity 268 is vented.

[0056] During fabrication of the removable fluid barrier 220, the assembly 260 is assembled by placing the spacer frame 264 onto first face plate 262. The textured plate 240 is then disposed on the first face plate 262, generally centered within the area bordered by the spacer frame 264, and the reinforcement sheet 242 is then disposed on the textured plate 240. The textured plate 240 has non-planar surfaces and is fabricated of a non-ferromagnetic material. As will be understood, the non-planar surfaces of the textured plate 240 provide conduits through which the liquid polymer resin can flow during casting of the flexible body 222, so as to enable the reinforcement sheet 242 and the permanent magnets 230 to be encapsulated. In the embodiment shown, the textured plate 240 has dimpled surfaces, and is fabricated of an aluminum alloy. The permanent magnets 230 are then disposed on the portion of the reinforcement sheet 242 covering the textured plate 240, such that the textured plate 240 is interposed between each of the permanent magnets 230 and the first face plate 262. Each of the permanent magnets 230 is disposed on the reinforcement sheet 242 such that the ferromagnetic disc 254 is oriented away from the reinforcement sheet 242, as shown in Figures 14 to 16. As will be understood, placement of the permanent magnets 230 in this manner causes the permanent magnets 230 to be magnetically attracted to the first face plate 262 through the textured plate 240 and the reinforcement sheet 242. The second face plate 266 is then placed onto the spacer frame 264 to define the mold cavity 268.

[0057] The first face plate 262, the spacer frame 264 and the second face plate 266, with the reinforcement sheet 242, the textured plate 240 and the permanent magnets 230 inside, are then removably fastened together using one or more suitable fasteners (not shown). In this embodiment, the fasteners are C-clamps (not shown). The flexible body 222 is then cast by injecting the liquid polymer resin, which is delivered from a source (not shown) of liquid polymer resin via a suitable conduit (not shown), through the first aperture 272 into the mold cavity 268. Air in the mold cavity displaced by the advancing liquid polymer resin is vented through the second aperture 274. The liquid polymer resin fills the mold cavity and encapsulates the permanent magnets 230 and the reinforcement sheet 242 by flowing around the permanent magnets 230, between the permanent magnets 230 the reinforcement sheet 242, and between the reinforcement sheet 242 and the textured plate 240. The liquid polymer resin is then allowed to cure. Once cured, the flexible body 222, which encapsulates the permanent magnets 230 and the reinforcement sheet 242, is formed. The first face plate 262, the spacer frame 264 and the second face plate 266 are then unfastened, and the flexible body 222 with the textured plate 240 attached thereto are removed. The textured plate 240 is then separated from the flexible body 222, as shown in Figure 16, yielding the removable fluid barrier 220.

[0058] In use, the removable fluid barrier 220 is applied to a ruptured ferrous fluid vessel (not shown) such that the removable fluid barrier 220 covers the rupture, and such that the first face 232 contacts the ferrous fluid vessel around the rupture. The permanent magnets 230 provide a magnetic force of attraction to the ferrous fluid vessel. This magnetic force of attraction, in combination with the flexibility of the fluid barrier 220, causes the removable fluid barrier 220 to conform to and to become magnetically fastened to the ferrous fluid vessel. As will be understood, the flexibility of the removable fluid barrier 220 enables the removable fluid barrier 220 to conform to curvature of the ferrous fluid vessel. Further, the magnetic force of attraction, in combination with the flexibility of the first face 232, causes the first face 232 to compress against the ferrous fluid vessel, which thereby enables the removable fluid barrier 220 to effectively provide a fluid seal or an at least partial fluid seal around the rupture, so as to reduce or prevent the outflow of fluid through the rupture. In this manner, the surface of the first face 232 defines a sealing surface of the removable fluid barrier 220.

[0059] It will be understood that the removable fluid barrier may alternatively be applied to the ruptured ferrous fluid vessel such that the second face 234 contacts the ferrous fluid vessel. In such a case, the surface of the second face 234 defines a sealing surface of the removable fluid barrier.

[0060] The removable fluid barrier 220 may be removed by pulling an edge of the removable fluid barrier 220 away from the ferrous fluid vessel, and with sufficient force so as to overcome the magnetic force of attraction provided by the permanent magnets 230. The removable fluid barrier 220 may then be cleaned to remove fluid residue, if necessary, and may then be used for another application.

[0061] As an example, the removable fluid barrier 220 may be applied to a rupture in any ferrous, low-pressure or unpressurized fluid vessel, such as for example a rail tank car, a highway transport tanker, a fluid storage tank, a drum

container such as a 55 gallon drum, a low-pressure pipeline, and the like, so as to limit spillage of fluid from the fluid vessel. In such applications, the removable fluid barrier 220 may be used by emergency personnel, such as for example firefighters, to prevent or reduce leakage of fluid, such as hazardous liquid or gas.

[0062] As another example, the removable fluid barrier 220 may alternatively be applied to a ferrous drain structure, such as for example a sewer grate, a manhole cover, a floor drain cover, and the like, to reduce or prevent entry of fluid into the drain. In such applications, the removable fluid barrier 220 may be used by emergency personnel, such as for example firefighters, to prevent fluid spilled on a floor or ground surface from entering the drain, and to thereby contain the spill of fluid. The fluid may be hazardous liquid or gas.

[0063] As will be appreciated, the permanent magnets 230 fabricated of rare earth alloy advantageously provide a stronger magnetic force of attraction as compared to permanent magnets fabricated of other materials, such as for example ferrous permanent magnets. As will be understood, the stronger magnetic force of attraction provided by the permanent magnets 230 enables the removable fluid barrier 220 to become more strongly magnetically fastened to the ruptured ferrous fluid vessel, and to thereby withstand greater opposing forces arising from fluid pressure within the fluid vessel, as compared to conventional removable fluid barriers comprising ferrous permanent magnets.

[0064] As will be appreciated, the permanent magnets 230 allow the removable fluid barrier 220 to be magnetically fastened to the ruptured fluid vessel in a facile manner, and without the need to provide an electrical current and means for delivering such a current, as would be required for conventional removable fluid barriers comprising electromagnets. The permanent magnets 230 advantageously enable the removable fluid barrier 220 to be fastened quickly, which is particularly beneficial for emergency situations and situations involving hazardous materials.

[0065] As will be appreciated, the removable fluid barrier 220 has a generally simple construction and consists of generally only three (3) components, namely the flexible body 222, the plurality of permanent magnets 230, and the reinforcement sheet 242. The simple construction advantageously allows the removable fluid barrier 220 to be manufactured at lower cost, as compared to conventional fluid barriers having more complex construction.

[0066] As will be appreciated, the flexible body 222, which is formed by a single casting during which the permanent magnets 230 are encapsulated, has a single, unitary structure, and therefore lacks a seam surface or weld surface that would otherwise be present in conventional fluid barriers comprising flexible bodies that are fabricated by more than one (1) casting and that comprise multiple layers. As will be understood, the single, unitary structure of the flexible body 222 improves the structural integrity of the fluid barrier 220, as compared to conventional fluid barriers comprising multiple layers.

[0067] As will be appreciated, the inclusion of a margin in the flexible body 222 allows the edges of the removable fluid barrier 20 to be easily lifted from the ferrous fluid vessel, which may effectively serve as a handle for facilitating removal of the removable fluid barrier 220.

[0068] Other configurations are possible. For example, although in the embodiment described above, the fibers 244 of the first material are grouped into bundles, and are positioned immediately adjacent to a parallel bundle of the fibers 246 of the second material (which are also grouped into bundles), in an alternating manner within the reinforcement sheet 242, in other embodiments, each single fiber 244 of the first material may alternatively be positioned immediately adjacent to a parallel single fiber 246 of the second material in an alternating manner within the reinforcement sheet.

[0069] Still other configurations are possible. For example, Figures 17 and 18 show another embodiment of a removable fluid barrier, which is generally indicated by reference numeral 320. Removable fluid barrier 320 is generally identical to removable fluid barrier 220 described above and with reference to Figures 12 to 16 and comprises the flexible body 222 fabricated of the one or more resilient materials and encapsulating the plurality of permanent magnets 230. The flexible body 222 has the single, continuous, unitary structure, and this embodiment the flexible body 222 is fabricated of polyurethane and is formed by casting. More specifically, the flexible body 222 is formed by a single casting, during which the permanent magnets 230 are encapsulated, and are thereby enclosed in the flexible body 222. In the example shown, the flexible body 222 has a generally square shape, and has dimensions of about 30 inches $\times$ about 30 inches $\times$ about 0.5 inches (about 76.2 cm $\times$ about 76.2 cm $\times$ about 1.27 cm). The generally planar flexible body 222 has the two opposing faces, namely the first face 232 and the second face 234. At least a portion of the first face 232 comprises the textured surface 236, which is formed by casting the flexible body 222 against the textured plate 240 during fabrication, as described below.

[0070] The permanent magnets 230 are encapsulated within the flexible body 222 generally adjacent the first face 232. In this embodiment, the flexible body 222 also encapsulates the reinforcement sheet 242, which has been described above for removable fluid barrier 220 and with reference to Figures 12 to 16. The reinforcement sheet 242 is disposed within the flexible body 222 between the permanent magnets 230 and the first face 232.

[0071] In this embodiment, the removable fluid barrier 320 also comprises one or more connectors 380, which are partially encapsulated within the flexible body 222. Each connector 380 is configured to matingly engage a connecting element (not shown), which together provide a handle for facilitating removal of the removable fluid barrier 320 from the ferrous fluid vessel. In the example shown, the removable fluid barrier 320 comprises four (4) connectors 380, each of which is positioned at a respective corner of the flexible body 222.

[0072] In the example shown, each connector 380 comprises a nut 382 that is affixed to a flange 384 by a suitable joining method, such as welding. The threaded nut 382 defines a threaded bore 386 that extends fully through the nut 382, and through the flange 384. Each connector 380 is oriented in the flexible body 222 such that the threaded bore 386 defines a bore axis (not shown) that is perpendicular to the second face 234. The flange 384 has a plurality of apertures 388 formed therein, which provide conduits through which the liquid polymer resin can flow during casting of the flexible body 222, to enable the flange 384 of the connector 380 to be encapsulated.

[0073] As will be understood, the threaded bore 386 is configured to matingly receive a threaded portion of a bolt (not shown). In this manner, the matingly-engaged connector 380 and bolt (not shown) together provide a handle for facilitating removal of the removable fluid barrier 320 from the ferrous fluid vessel.

[0074] Each connector 380 has a height that is slightly less than the thickness of the flexible body 222. Preferably, the height of the connector 380 is between 0.90 times and 0.99 times the thickness of the flexible body 222, more preferably between 0.92 times and 0.98 times, still more preferably between 0.93 times and 0.97 times, and most preferably about 0.95 times the thickness of the flexible body 222. Each connector 380 is positioned in the flexible body 222 such that a top portion of the nut 382 is visible on the second face 234, and such that no portion of the connector 380 is visible from the first face first face 232.

[0075] The removable fluid barrier 320 can be fabricated using the assembly 260 described above and with reference to Figures 12 to 16. Fabrication of the removable fluid barrier 320 is otherwise identical to the fabrication of the removable fluid barrier 220, but further comprises disposing the one or more connectors 380 on the reinforcement sheet 242 which is disposed on the textured plate 240. The permanent magnets 230 are then disposed on the portion of the reinforcement sheet 242 covering the textured plate 240 in the manner described above, and such that the textured plate 240 is interposed between each of the permanent magnets 230 and the first face plate 262. The second face plate 266 is then placed onto the spacer frame 264 to define the mold cavity 268.

[0076] The first face plate 262, the spacer frame 264 and the second face plate 266, with the reinforcement sheet 242, the textured plate 240, the one or more connectors 380, and the permanent magnets 230 inside, are then removably fastened together using one or more suitable fasteners (not shown). In this embodiment, the fasteners are C-clamps (not shown). The flexible body 222 is then cast by injecting the liquid polymer resin, which is delivered from a source (not shown) of liquid polymer resin via a suitable conduit (not shown), through the first aperture 272 into the mold cavity 268. Air in the mold cavity displaced by the advancing liquid polymer resin is vented through the second aperture 274. The liquid polymer resin fills the mold cavity and encapsulates the permanent magnets 230, the reinforcement sheet 242, the entire flange 384 and a portion of the nut 382 of each of the one or more connectors 380, by flowing around the permanent magnets 230, around the one or more connectors 380, between the one or more connectors 380 and the reinforcement sheet 242, between the permanent magnets 230 the reinforcement sheet 242, and between the reinforcement sheet 242 and the textured plate 240. The liquid polymer resin is then allowed to cure. Once cured, the flexible body 222, which encapsulates the permanent magnets 230 and the reinforcement sheet 242, and which partially encapsulates the one or more connectors 380, is formed. The first face plate 262, the spacer frame 264 and the second face plate 266 are then unfastened, and the flexible body 222 with the textured plate 240 attached thereto are removed. The textured plate 240 is then separated from the flexible body 222. The threaded bore 386 of each connector is then opened by a suitable method, such as drilling, to remove cured liquid polymer resin therein, and to simultaneously form a correspondingly-sized hole through the reinforcement sheet 242, each drilled hole extends from the first face 232 to the second face 234 and through the flexible body 222, yielding the removable fluid barrier 320.

[0077] Although in the embodiments described above, the removable fluid barrier 320 comprises four (4) connectors 380, in other embodiments, the removable fluid barrier 320 may alternatively comprise fewer than four (4) connectors 380, such as one (1), two (2) or three (3) connectors, or alternatively more than four (4) connectors.

[0078] Although in the embodiments described above, the flexible body 222 comprises a textured surface 236 that is formed by casting the liquid polymer resin against a textured plate 240, in other embodiments, the textured surface 236 may alternatively be formed by casting the liquid polymer resin against any surface having a non-planar topography, so as to create a textured surface having a non-planar topography. In one such embodiment, the surface having the non-planar topography may be, for example, a plate having a one or more of a grooved surface, a ridged surface, a dimpled surface, a perforated surface, a scored surface, and the like. As will be understood, the non-planar topography may comprise a patterned topography or a non-patterned topography.

[0079] Although in the embodiments described above, the permanent magnet 230 comprises a ferromagnetic disc 254 that is magnetically fastened to the magnet body 252, in other embodiments, two or more of the magnet bodies 252 may alternatively be magnetically fastened to a single ferromagnetic plate fabricated of a ferromagnetic material. In one such embodiment, the single ferromagnetic plate may be a steel sheet, a steel plate, and the like, to which the plurality of magnet bodies 252 are magnetically fastened.

[0080] The following example illustrates various applications of the above-described embodiments.

EXAMPLE

[0081] Samples of the removable fluid barrier 220 were subjected to liquid penetration testing in accordance the ASTM F903 test standard ("Standard Test Method for Resistance of Materials Used in Protective Clothing to Penetration by Liquids").

[0082] Generally, in this testing, samples of the removable fluid barrier, each of which was an entire removable fluid barrier 220, were put into a test cell. A circular area having a diameter of one (1) inch (2.54 cm) on the first face 232 of each sample was then brought into contact with and exposed to a liquid at atmospheric pressure for a time period. Although the time period specified by the ASTM F903-10 standard is four (4) hours, the time period used in the testing was eight (8) hours, or four-hundred and eighty (480) minutes, to better simulate the conditions experienced by the removable fluid barrier 220 during a real-life application, such as by emergency personnel.

[0083] The liquids used in the testing are generally classified as hazardous liquid chemicals. The concentrations of the liquid chemicals used in the testing were those commonly used for transport of the liquid chemicals by rail or truck in North America.

[0084] Five (5) different samples were exposed to each liquid. During each test, the second face 234 of each sample was assessed for liquid penetration. The test ended either when liquid penetration was detected on the second face 234 of the sample or, if no liquid penetration was detected, when the end of the time period (namely, four-hundred and eighty (480) minutes) was reached. The test time was recorded as a "penetration time" and was then averaged for the five (5) samples. At the end of each test, the first face 232 of each sample was visually inspected and photographically imaged.

[0085] The results of the testing are presented in Table 1, below. Selected photographic images are shown in Figures 19A to 19F:

TABLE 1

Test No.	Liquid	Avg. Penetration Time (mins)	Result	Figure of Representative Photo Image
1	acetonitrile (99.0%)	>480	pass	
2	ethyl acetate ($\geq 99.8\%$)	>480	pass	
3	calcium hypochlorite (10%)	>480	pass	
4	dimethylformamide ($>99\%$)	>480	pass	19A
5	methanol (100%)	>480	pass	
6	sodium hydroxide (50%)	>480	pass	
7	hexane ($\geq 95\%$)	>480	pass	
8	sulfuric acid (96%)	>480	pass	19B
9	tetrahydrofuran (99%)	>480	pass	19C
10	diethylamine ($\geq 99.5\%$)	>480	pass	
11	hydrogen peroxide (15% w/w)	>480	pass	
12	nitrobenzene (99%)	>480	pass	
13	aniline ($>99\%$)	>480	pass	19D
14	phenol (90%)	>480	pass	19E
15	toluene ($\geq 99.5\%$)	>480	pass	
16	chlorobenzene ($\geq 99.5\%$)	>480	pass	
17	formaldehyde (37%)	>480	pass	
18	unleaded gasoline (mixture)	>480	pass	
19	phosphoric acid (85%)	>480	pass	

(continued)

Test No.	Liquid	Avg. Penetration Time (mins)	Result	Figure of Representative Photo Image
20	acetic acid, glacial (100%)	>480	pass	
21	nitric acid (70%)	294	FAIL	19F
22	acetone (99.8%)	>480	pass	
23	carbon disulfide (99%)	>480	pass	
24	dichloromethane (99.6%)	>480	pass	
25	hydrochloric acid (32%)	>480	pass	
26	ammonium hydroxide (30%)	>480	pass	
27	diesel fuel (mixture)	>480	pass	

[0086] As can be seen, during the eight (8) hour time period, the removable fluid barrier 220 prevented penetration of all liquids tested, with the exception of nitric acid (see test number 21 and Figure 19F). In the nitric acid tests, penetration into and through the removable fluid barrier 220 to the second face 234 was observed for all five (5) samples.

[0087] Further, although some liquids were observed to dissolve at least a portion of the thin layer of the flexible body 222 between the first face 232 and the reinforcement sheet 242 (see, for example, Figures 19A to 19E), none of the liquids was observed to dissolve any portion of the reinforcement sheet 242, again with the exception of nitric acid. In the case of nitric acid, it is believed that the resultant penetration of the reinforcement sheet 242 was caused by chemical reaction with one or both of the fibers 244 of the first material, which were basaltic fibers, and the fibers 246 of the second material, which were wet-spun fibers of the non-olefin thermoplastic material having the high degree of crystallinity. This penetration of the reinforcement sheet 242, in turn, allowed the penetrating nitric acid to reach and chemically react with one or more metallic materials of the permanent magnets 230, which resulted in the orange discoloration and foaming visible in Figure 19F.

[0088] The results of this test demonstrate, among other findings, the high chemical resistance of the reinforcement sheet 242, which comprised the fibers 244 of the first material, which were basaltic fibers, and the fibers 246 of the second material, which were wet-spun fibers of the non-olefin thermoplastic material. In particular, both the fibers 244 and the fibers 246 were observed to retain their integrity and resist dissolution by all of the 27 liquids tested, which are all generally classified as hazardous liquid chemicals, with the exception of one liquid (namely, nitric acid). As will be understood, this chemical resistance advantageously allows the reinforcement sheet 242 to retain its mechanical integrity and continue to provide reinforcement to the flexible body 222 for strengthening the fluid barrier 220 during use.

[0089] Although embodiments have been described above with reference to the accompanying drawings, those of skill in the art will appreciate that variations and modifications may be made without departing from the scope thereof as defined by the appended claims.

Claims

1. A removable fluid barrier, comprising:
a generally planar flexible body fabricated of at least one resilient material and having an outer face defining a sealing surface of the removable fluid barrier, the flexible body encapsulating a plurality of permanent magnets and a reinforcement sheet, the reinforcement sheet comprising fibers of a first material and fibers of a second material, the first material having a higher tensile strength than the second material, the second material having a higher toughness than the first material.
2. The removable fluid barrier of claim 1, wherein the fibers of a first material are basaltic fibers.
3. The removable fluid barrier of claim 1 or 2, wherein the fibers of the second material are fibers of a non-olefin thermoplastic material having high crystallinity.
4. The removable fluid barrier of any preceding claim, wherein the flexible body is formed by a single casting.

5. The removable fluid barrier of any preceding claim, wherein the flexible body has a single, unitary structure.
6. The removable fluid barrier of any preceding claim, further comprising one or more connectors at least partially encapsulated within the flexible body.
7. The removable fluid barrier of claim 6, wherein each of the one or more connectors is configured to matingly connect to a connecting element to provide a handle for handling the removable fluid barrier.
8. The removable fluid barrier of claim 6 or 7, wherein each of the one or more connectors comprises a nut defining a threaded bore.
9. The removable fluid barrier of any preceding claim, wherein the outer face of the flexible body comprises a textured surface, optionally, wherein the textured surface has a non-planar topography.
10. The removable fluid barrier of any preceding claim, wherein the plurality of permanent magnets comprises one or more rare earth magnets.
11. The removable fluid barrier of any preceding claim, wherein each of the permanent magnets comprises an epoxy coating.
12. The removable fluid barrier of any preceding claim, wherein the at least one resilient material comprises a polymer.
13. The removable fluid barrier of any preceding claim, wherein the flexible body is fabricated of polyurethane.

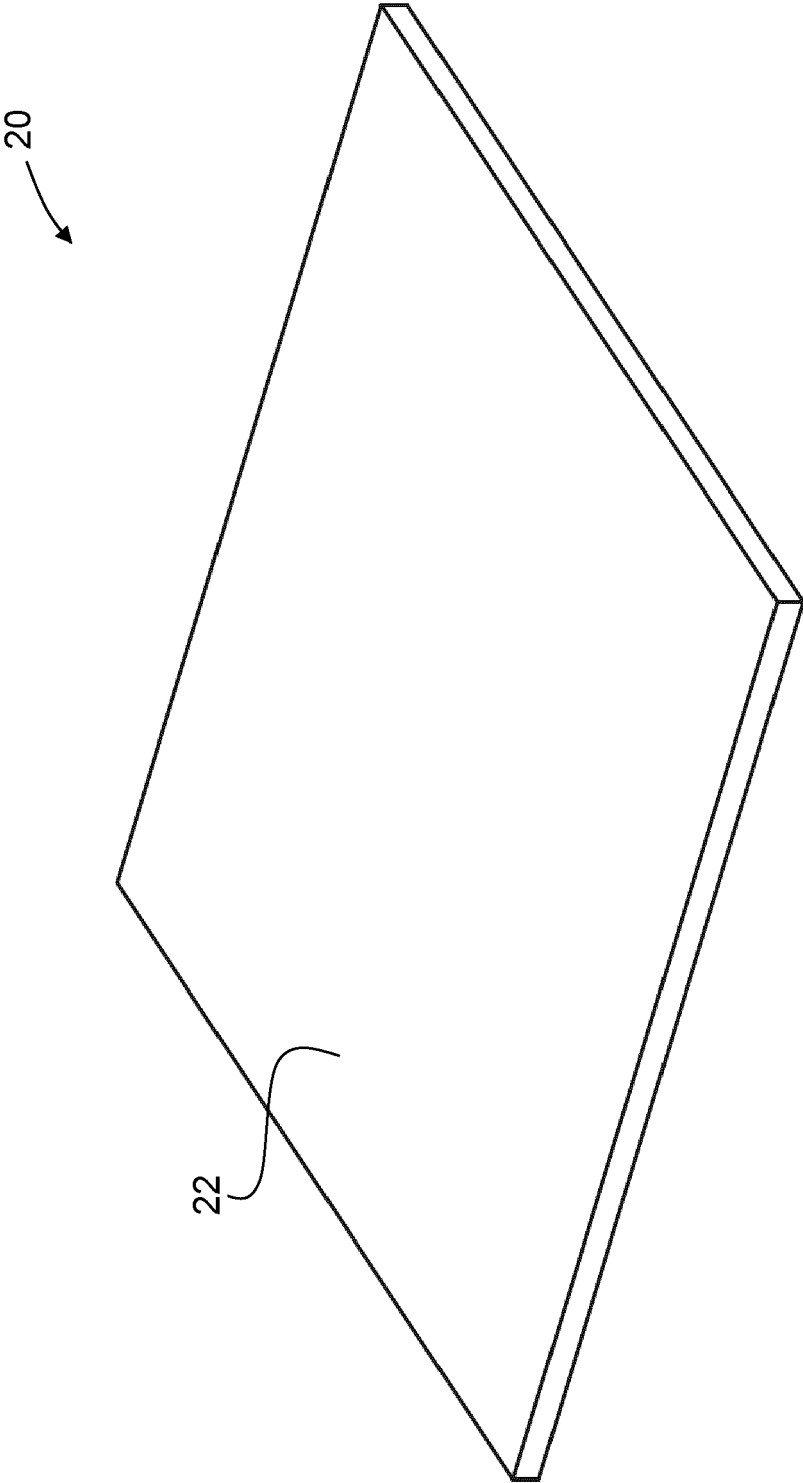


Figure 1

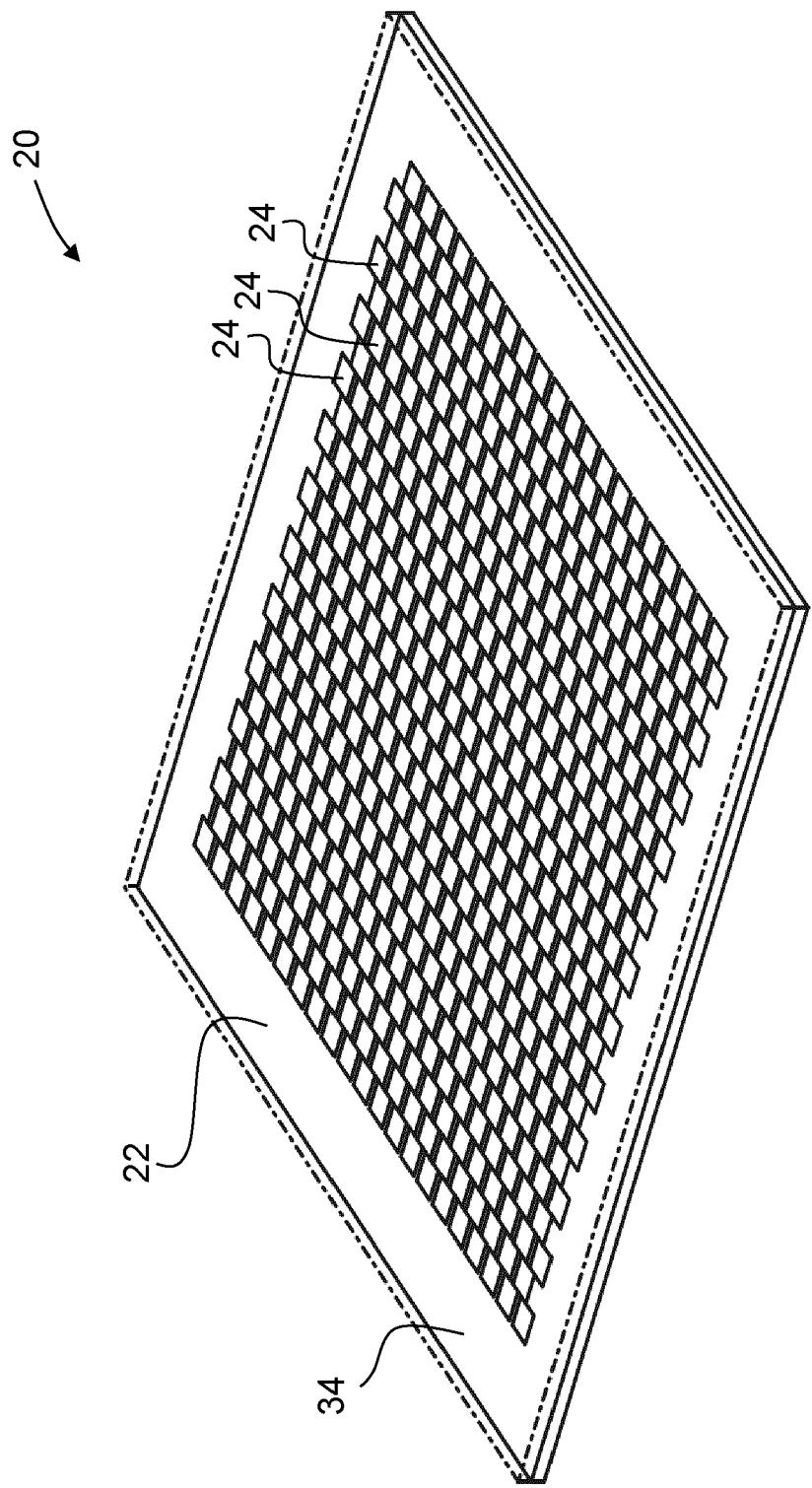


Figure 2

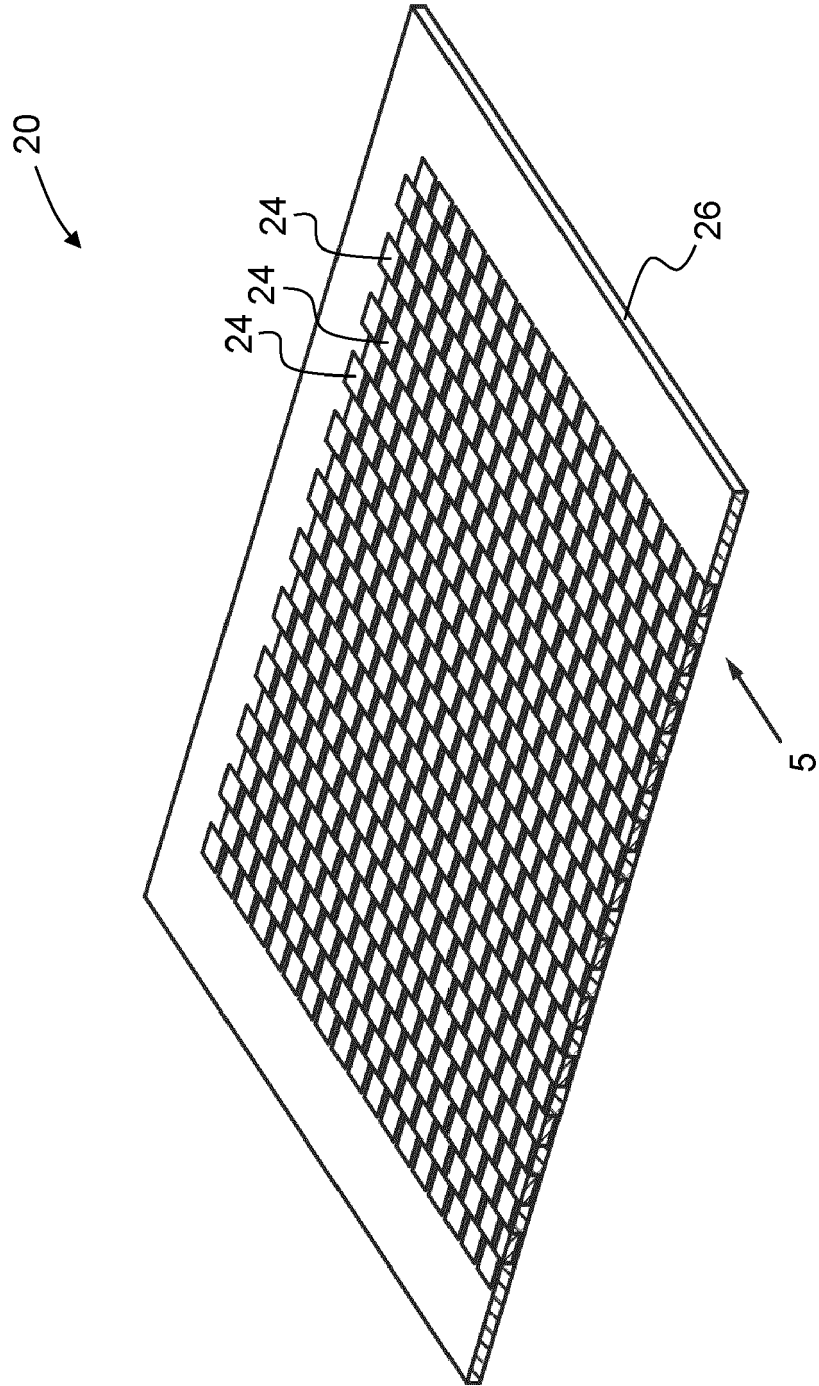


Figure 4

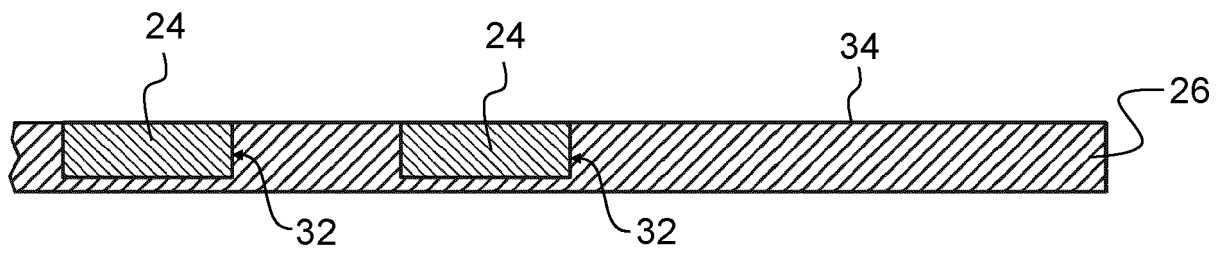


Figure 5

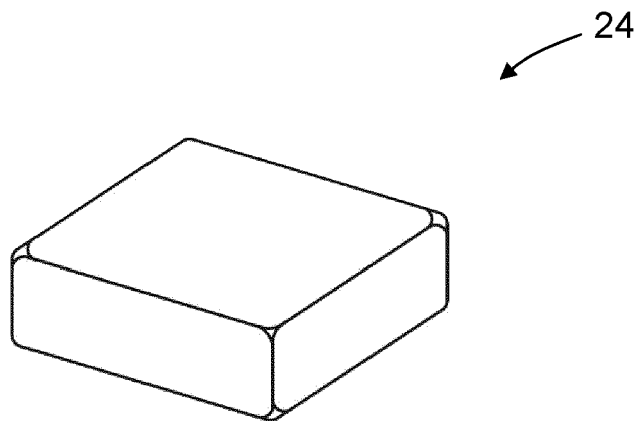


Figure 6

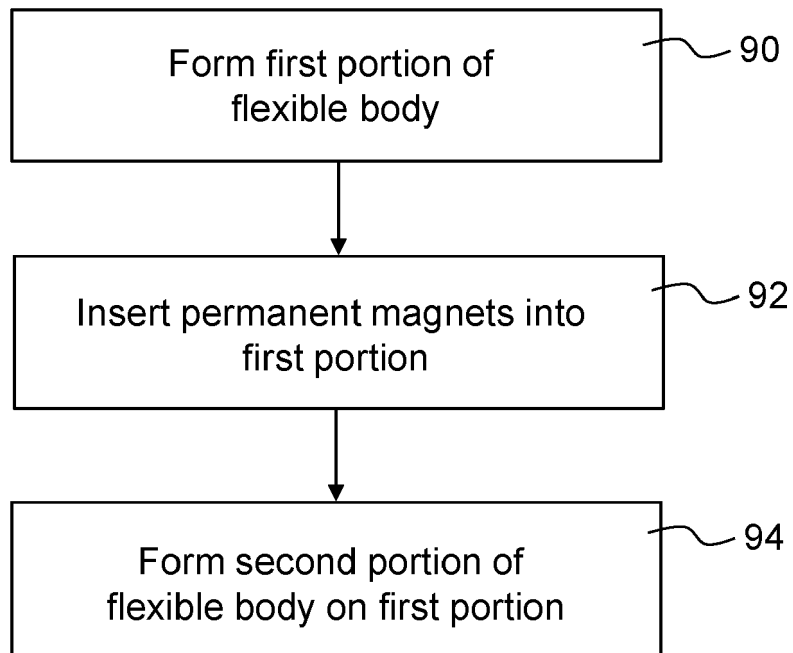


Figure 7

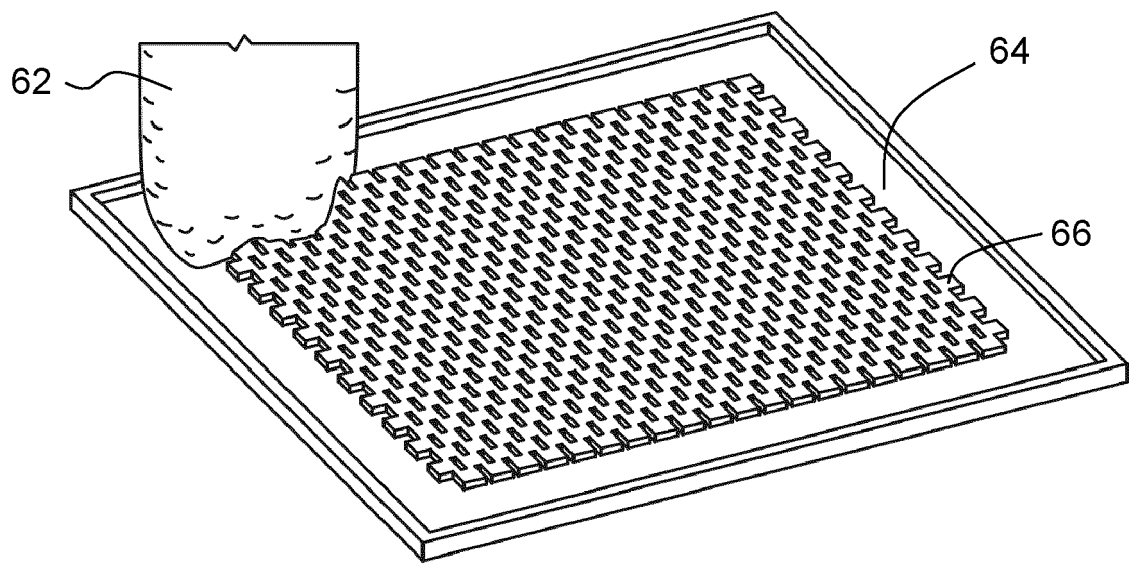


Figure 8

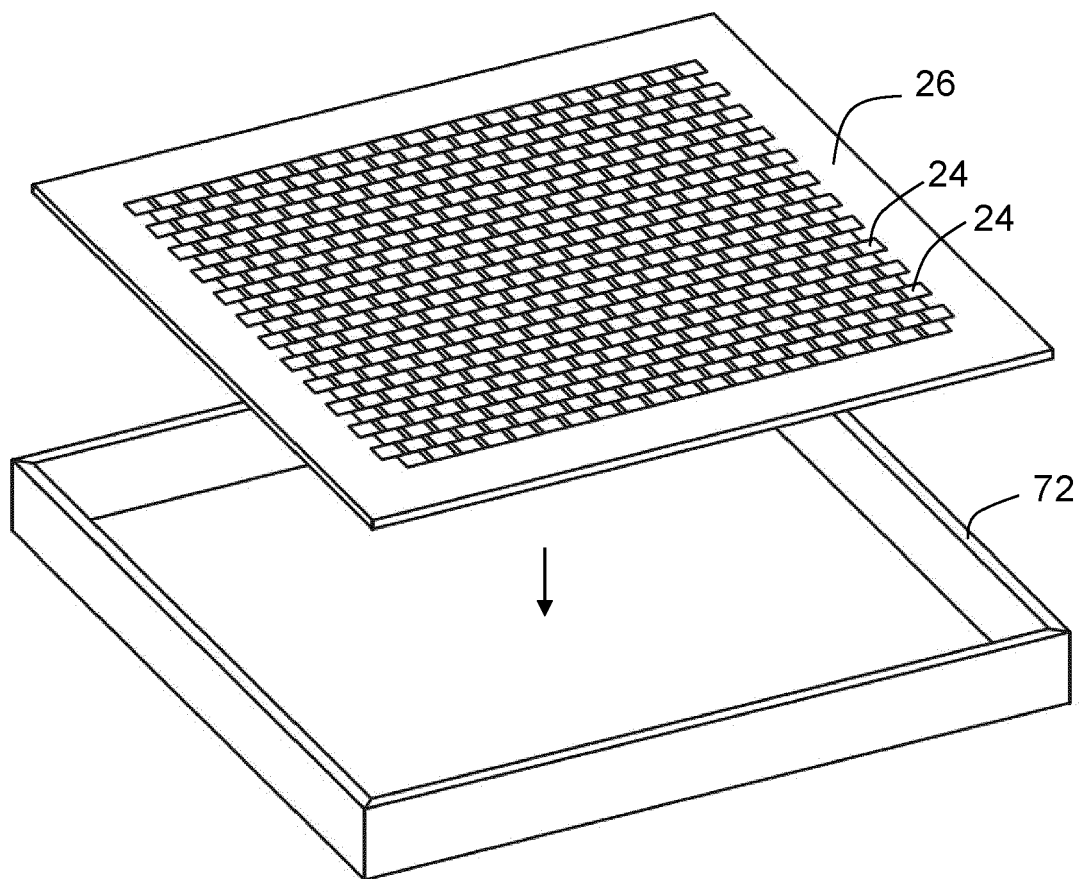


Figure 9

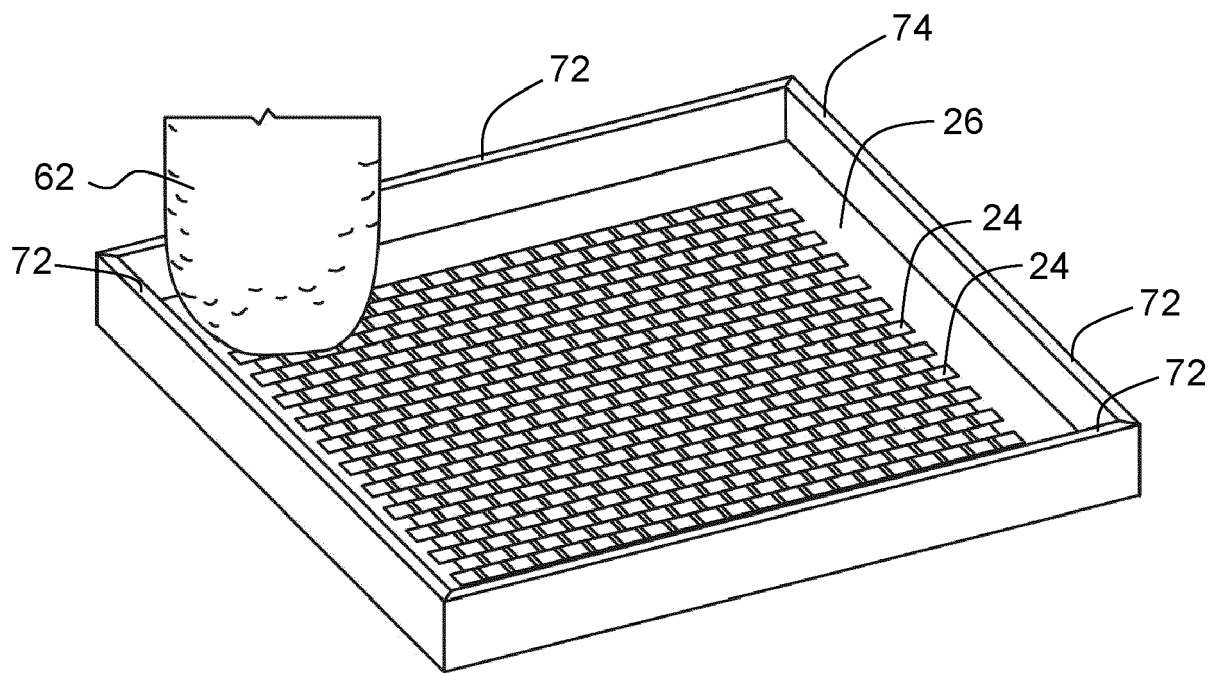


Figure 10

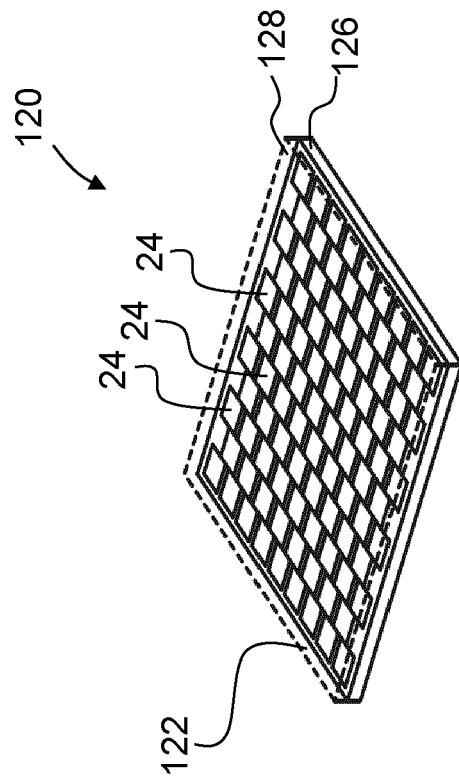


Figure 11B

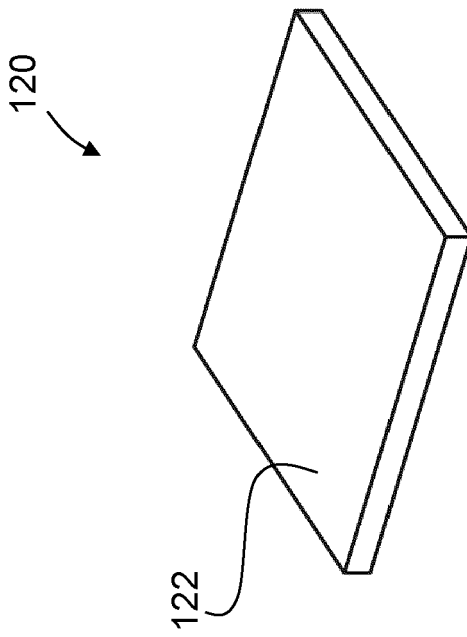


Figure 11A

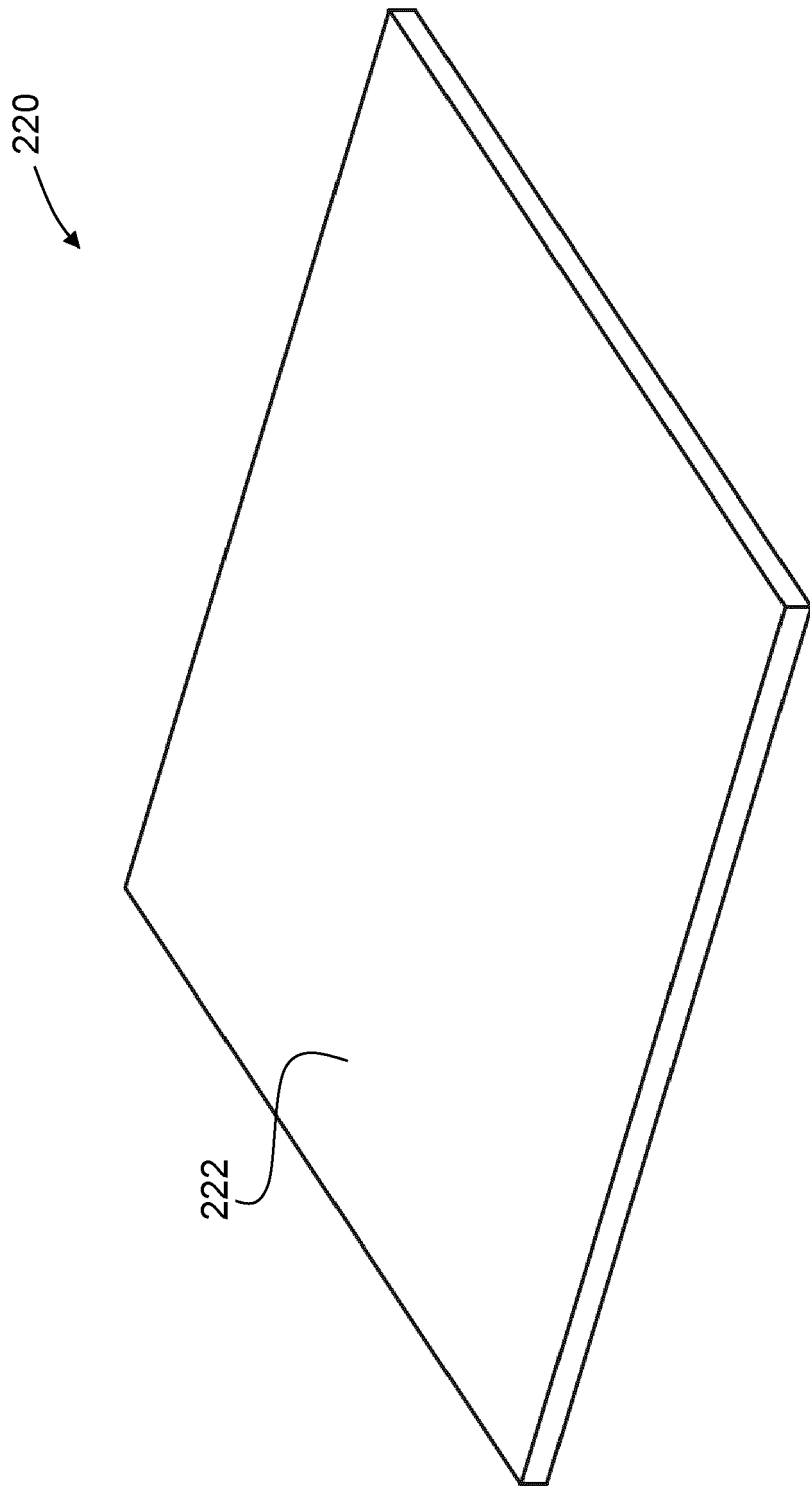


Figure 12

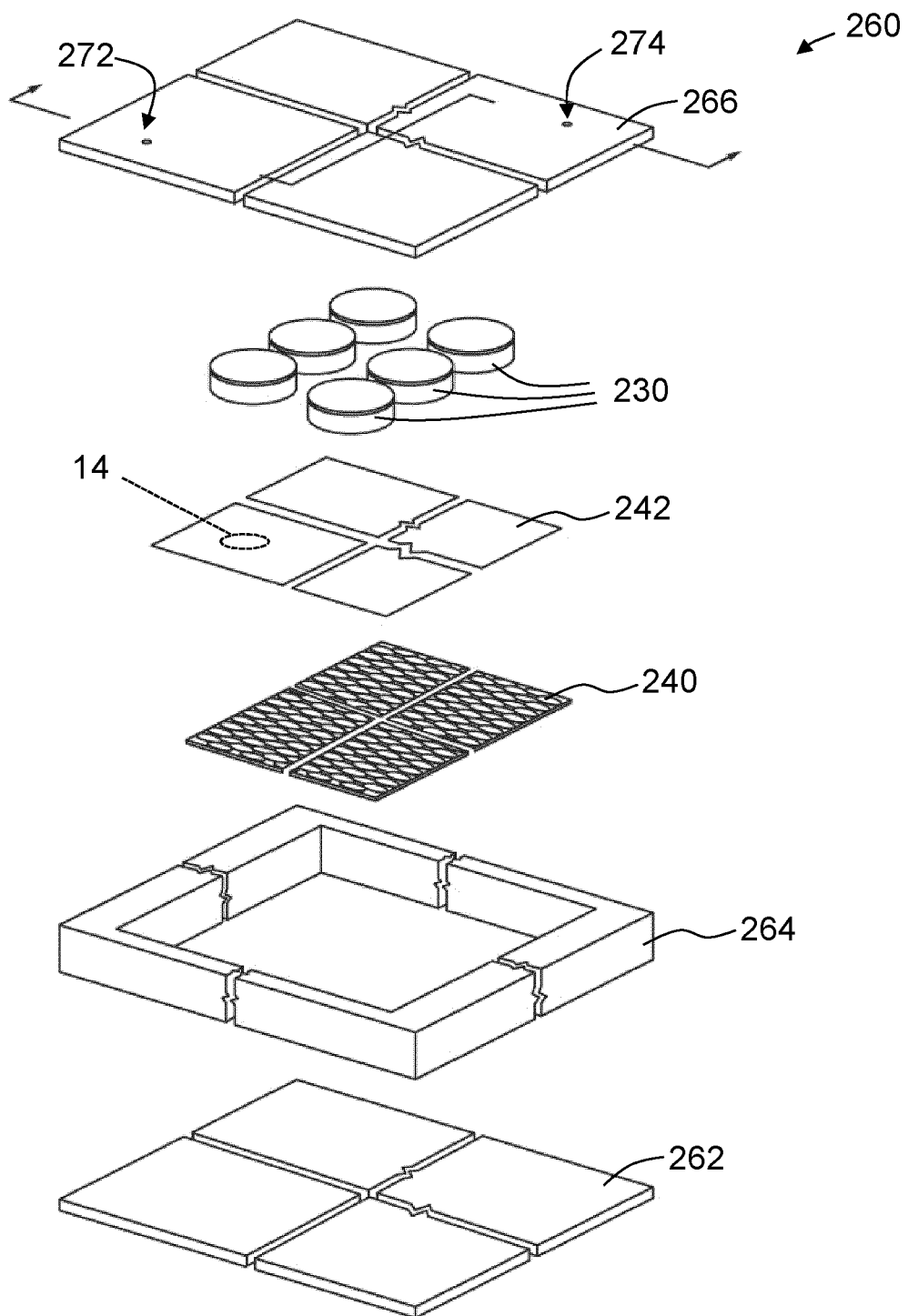


Figure 13

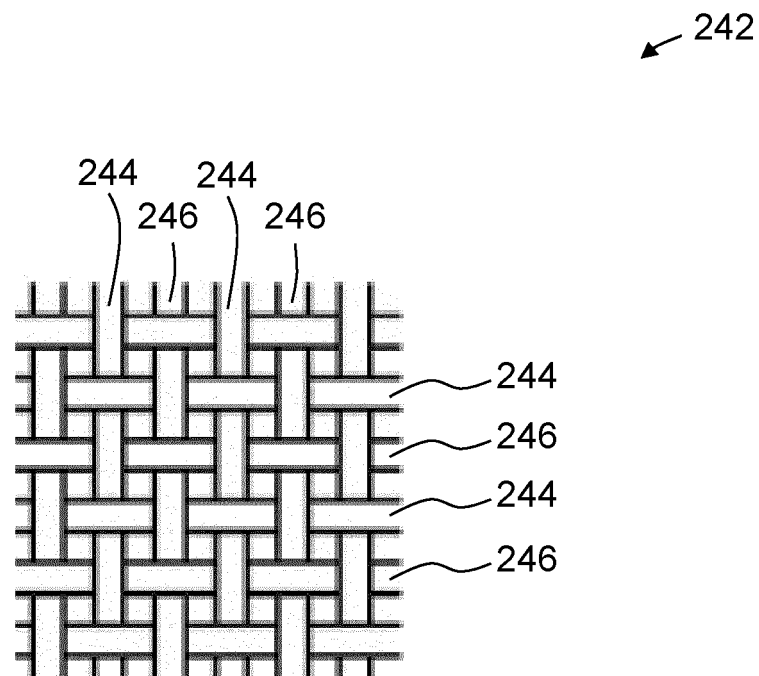


Figure 14

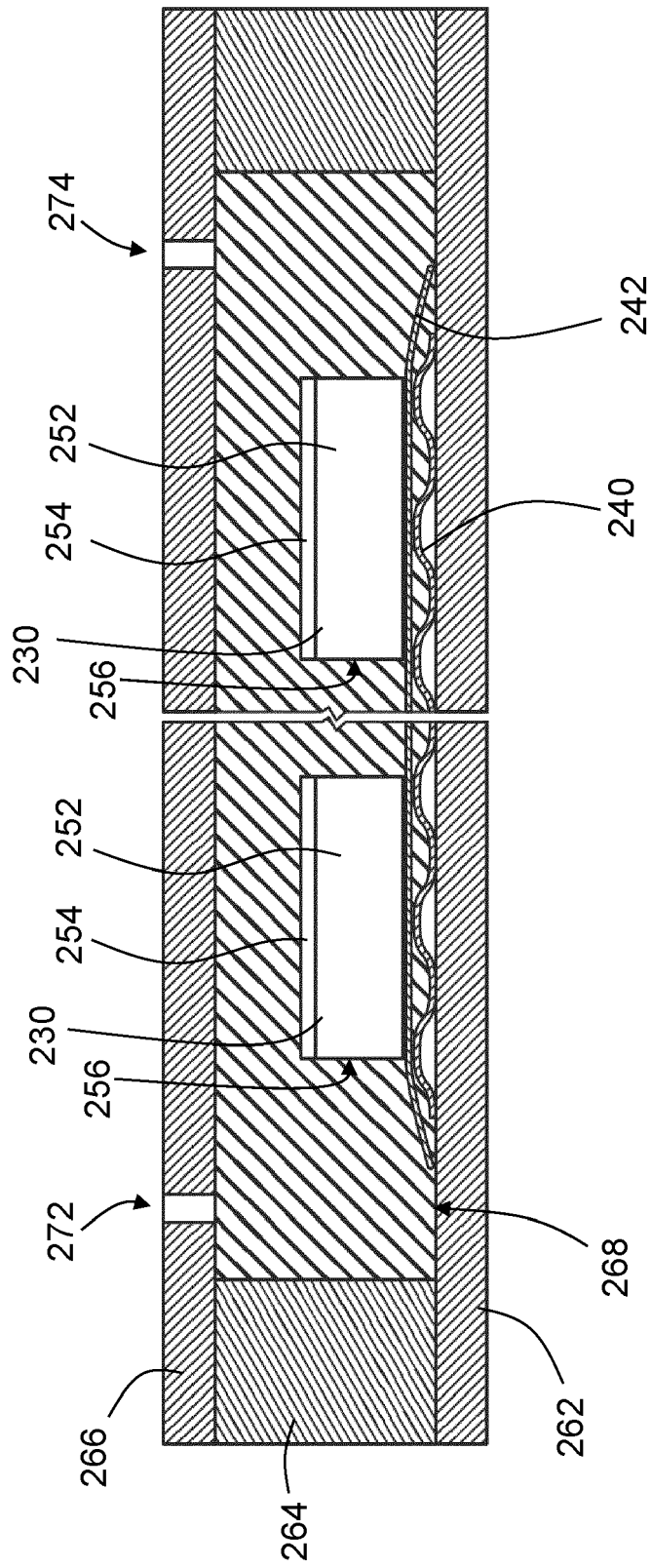


Figure 15

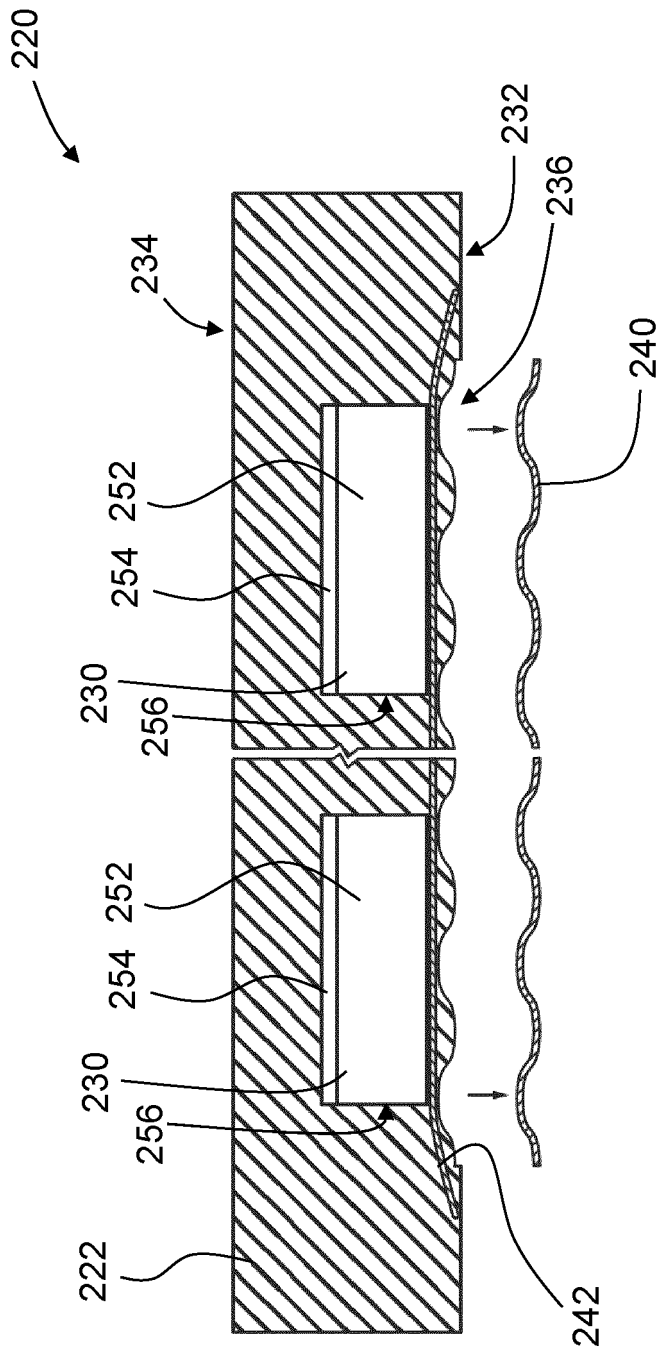


Figure 16

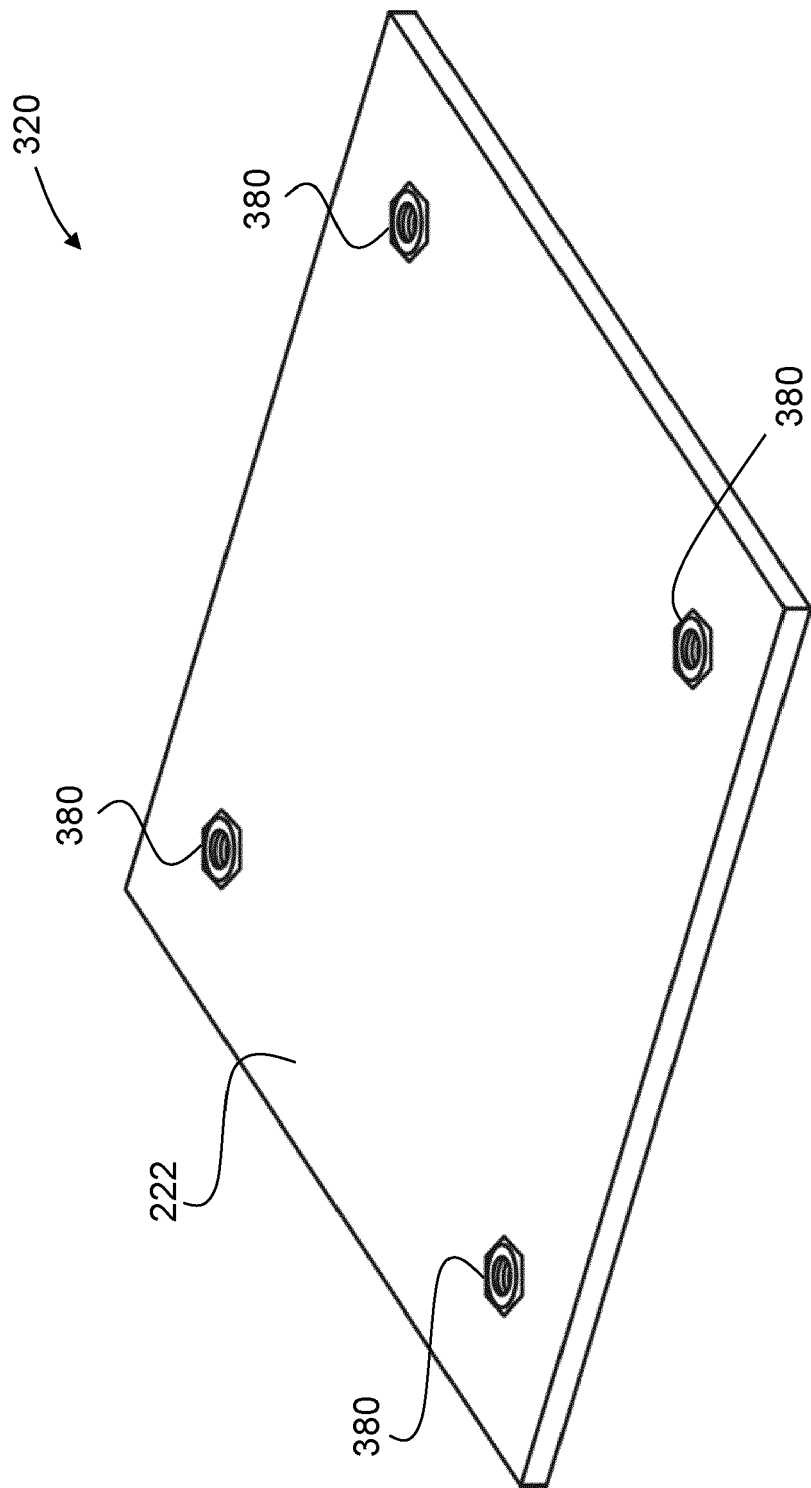


Figure 17

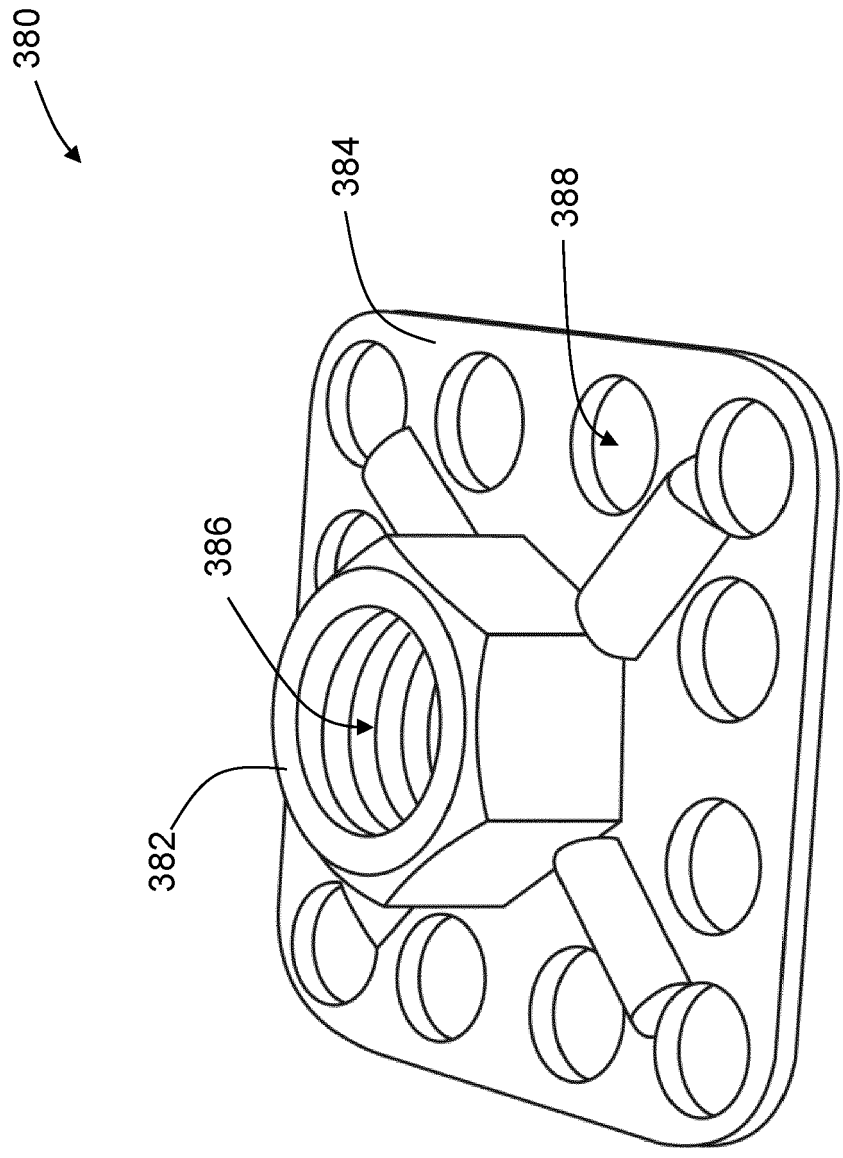


Figure 18

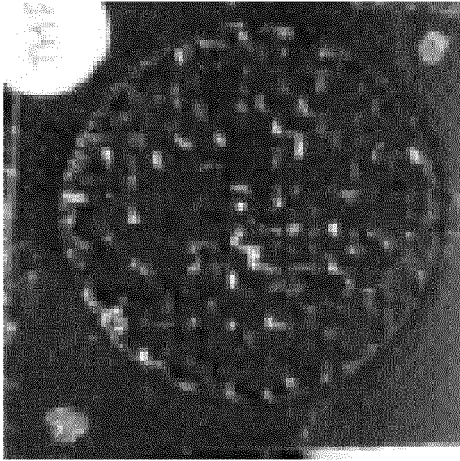


Figure 19C

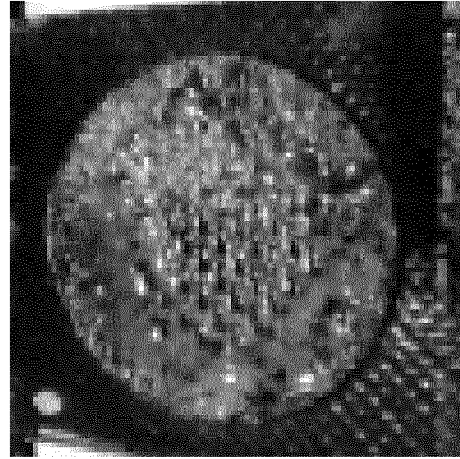


Figure 19F

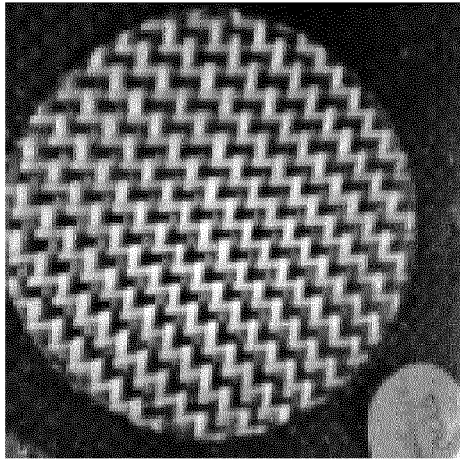


Figure 19B

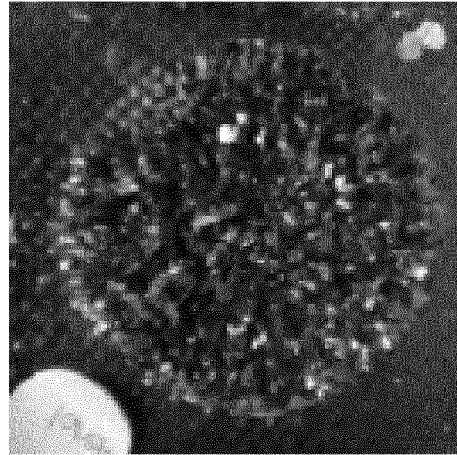


Figure 19E

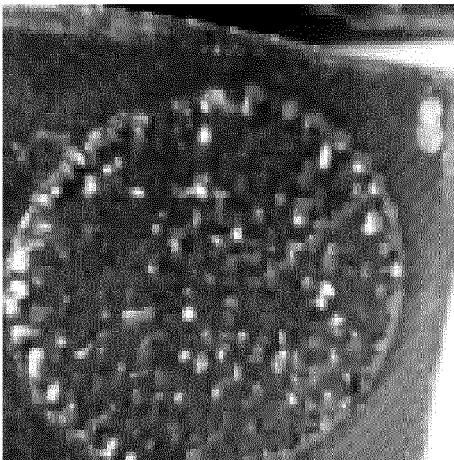


Figure 19A

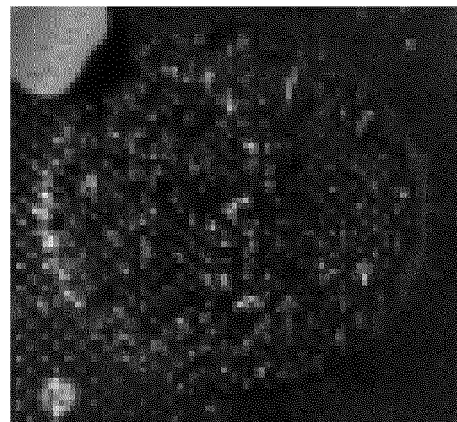


Figure 19D



EUROPEAN SEARCH REPORT

Application Number

EP 22 18 8163

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	CA 2 974 816 A1 (CHEWINS ELLIOTT [CA]) 28 January 2019 (2019-01-28) * column 32 - column 79; figures 1-16 *	1-13	INV. B65D90/24
X	DE 691 20 825 T2 (ENV EMERGENCY SEALS PTY LTD [AU]) 23 January 1997 (1997-01-23) * page 5, line 19 - page 10, line 3; figures 1-6 *	1-13	
X	US 5 165 356 A (WILLIAMS WILLARD E [US]) 24 November 1992 (1992-11-24) * column 3, line 50 - column 6, line 18; figures 1-5 *	1-13	
X	CA 2 865 156 A1 (CHEWINS ELLIOTT [CA]) 26 March 2016 (2016-03-26) * paragraph [0026] - paragraph [0048]; figures 1-12 *	1-13	
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			B65D
The present search report has been drawn up for all claims			
Place of search		Date of completion of the search	Examiner
Munich		19 December 2022	Lämmel, Gunnar
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T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

EPO FORM 1503 03/82 (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 22 18 8163

5 This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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19-12-2022

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