COMPOSITE INFLATABLE DOWNHOLE PACKER OR BRIDGE PLUG

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ABSTRACT
Inflatable packer assemblies and bridge plugs that incorporate selective components made of a composite material, thereby providing improvements in weight, drillability and corrosion resistance. A through-tubing packer assembly is described having end sleeves fashioned partially from composite material of high strength fiber and polymer resin. The inflatable packer element has longitudinal ribs fashioned from composite material with a specialized cross-section having a larger cross-section of rib material in locations where additional bending resistance is required and permits additional elastomeric material to be placed about the ribs in sealing areas. An external casing packer is also described having a composite valve assembly and central mandrel formed primarily of composite material. The mandrel includes metallic fittings for threaded attachments to be made.
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[0001] This application claims the priority of U.S. Provisional patent application Ser. No. 60/444,439 filed Feb. 3, 2003.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The invention relates generally to earth boring and deep well completion tools and methods. In certain aspects, the invention relates to fabrication materials and methods for constructing inflatable packers or bridge plugs.

[0004] 2. Description of the Related Art

[0005] A subterranean well annulus is that generally annular space within a wellbore between the inside bore wall or casing and the outer surfaces of a pipe or tube that is suspended within the wellbore. Packers and bridge plugs are well tools that are commonly used to segregate axially adjacent sections of the well annulus to prevent the transfer of fluids, liquid or gas, from flowing or migrating from one earth strata to another. Briefly, the packer is a structural barrier along a short length of the annulus performing the function of erecting a fluid-tight seal at both outer and inner surface perimeters thereby preventing fluid and pressure transfer between axially adjacent well sections. Through-tubing packers and bridge plugs are also known. These devices are disposed within the interior of a string of production tubing or the like, and then set within to provide fluid tight sealing therewith.

[0006] There are numerous mechanisms available to the driller or hydrocarbon producer for erecting a barrier in the form of a packer. One of the several mechanisms is an inflatable packer. Characteristically, inflatable packers comprise an elastomeric boot element around the outer perimeter of a tubular mandrel. Opposite ends of the elastomeric boot are secured to the mandrel. Further, the ends are overlaid by a sleeve structure that is either assembled with or integral with pipe joint structure. The well annulus, or, alternatively, the tubing interior, is obstructed by expansion of the elastomeric boot from the mandrel. A pressurized charge of fluid is expressed from the mandrel flow bore through a valve conduit in the mandrel wall or collar. This expressed fluid is channeled between the sleeve underside and the mandrel outer surface thereby expanding the elastomeric boot against the surrounding well bore or tubing wall.

[0007] When the packer is inflated to expand the elastomeric boot against the inside casing, tubing, or borehole wall, extremely high hoop stress is imposed upon the sleeve. Where the packer confines high-pressure differentials, the hoop stress is even greater. Accordingly, the packer end sleeve is usually fabricated with high strength materials. Unfortunately, many high strength metals are adversely affected by the fluids and gases typically present in a well environment: for example, CO₂, H₂S, and production stimulation acids. Additionally, the use of high strength materials for packer components makes it more difficult to drill out the packer assembly should it become stuck in the wellbore and have to be removed in that manner.

[0008] Packer service conditions, therefore, strongly dictate fabrication material selection in many instances. More exotic materials, such as high-strength Inconel, have traditionally been used for construction of packers to be used in severe condition applications. However, the resulting cost is expensive.

[0009] U.S. Pat. No. 6,269,878, issued to Wyatt et al. relates to the design of an inflatable packer assembly. Wyatt explains that any piece of the packer assembly may be made of “drillable” material, such as fiberglass, drillable plastic, cast iron, aluminum, aluminum alloys, fiber reinforced resin materials and so forth so that the packer assembly may be drilled or milled out of the wellbore. Beyond this general indication, however, there are no specific suggestions as to which packer components should be constructed of drillable materials and which should not. There is also no indication as to which materials out of the list provided are best used for particular components.

[0010] Accordingly, it is an object of the present invention to provide a packer construction from materials that are sufficiently strong for most applications and yet are substantially impervious to the chemistry of most downhole fluids. It is also an object of the present invention to provide a packer device that is both strong and relatively inert to corrosive well fluids. An additional object of the invention is to provide a packer sleeve construction that is substantially comprised of high strength composite materials such as carbon or aramid fiber bound in a polymer composition. A further object of this invention is to provide a packer construction having improved performance and life.

SUMMARY OF THE INVENTION

[0011] Packer assemblies are described that incorporate selective components made of a composite material, thereby providing improvements in weight, drillability, corrosion resistance, and overall packer performance. In one described embodiment, a through-tubing packer assembly is described having end sleeves that are fashioned partially from composite material.

[0012] A packer end sleeve construction is described that utilizes a composite of high strength fiber and polymer resin. The fibers are formed of high strength aramid or carbon, so that the resulting composite of fiber and resin will have tensile strengths approaching 300 ksi. In forming the end sleeve, the fibers are wrapped in layers and oriented in a manner to address particular expected stress conditions. If high hoop stresses will be imposed upon a particular component, the fibers within the composite material will be primarily oriented in a circumferential direction for maximum hoop strength. If axial strain will be imposed upon the component, a portion of the fibers will be oriented in position that is substantially normal to the circumference in order to increase axial strength. The fibers are bound in a high temperature thermoplastic matrix, such as PEEK (poly-ether-ether-keytone).

[0013] Additionally, the inflatable packer element is surrounded by a plurality of longitudinal ribs that are fashioned from composite material. The ribs have a specialized cross-section that provides for a larger cross-section of rib material in locations where additional bending resistance is required and a smaller cross-section of rib material where such bending resistance is not required. The rib design permits additional elastomeric material to be placed about the ribs in sealing areas. The ribs are constructed of several plies of
varying orientations to address the different stresses encountered throughout the length of a rib.

[0014] A support sleeve fashioned of KEVLAR® or another suitably strong composite material is located at the interface of the expandable bladder and end sleeve in order to provide reinforcement to the composite portions of the end sleeve against expansive forces. This sleeve construction is provided over the rib area of a packer sleeve where a majority of hoop stress is applied. The support sleeve changes the outward radial stress that is applied to the lower portion of the end sleeve by flattening the geometry of rib deployment during inflation of the bladder. Due to the necessity for thread assembly of the packer sleeve to the remaining pipe structure, the composite sleeve construction may be hybridized with threaded steel inserts.

[0015] An exemplary external casing packer is also described that incorporates a central mandrel that is formed primarily of composite material. The mandrel also includes metallic fittings for threaded attachments to be made. If desired, the entire external casing packer assembly can be made of composites, including the valve collar. A valve collar that is fashioned of composite material is more easily manufactured.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] The advantages and further aspects of the invention will be readily appreciated by those of ordinary skill in the art as the same becomes better understood by reference to the following detailed description when considered in conjunction with the accompanying drawings in which like reference characters designate like or similar elements throughout the several figures of the drawing and wherein:

[0017] FIG. 1 is a side view, partially in cross-section, of an exemplary through-tubing bridge plug that incorporates an inflatable packer assembly constructed using composite components in accordance with the present invention.

[0018] FIG. 2 is a side view, partially in cross-section, of the inflatable packer element of the bridge plug of FIG. 1, shown apart from the other components.

[0019] FIG. 3 is a side, cross-sectional detail of an exemplary end sleeve for use in the packer element shown in FIG. 2.

[0020] FIGS. 4A, 4B, 4C, and 4D illustrate an exemplary process for forming a pair of partially composite end sleeves.

[0021] FIG. 5 illustrates, in side cross-section, the annular end cap used with the end sleeve shown in FIG. 3.

[0022] FIG. 6 is an axial cross-section taken along lines 6-6 in FIG. 2 illustrating the overlapping arrangement of ribs.

[0023] FIG. 7 is a side cross-sectional view of an alternative end sleeve for use in the through-tubing packer element shown in FIG. 2.

[0024] FIG. 8 is a side cross-sectional view of a further alternative end sleeve for use in the through-tubing packer element shown in FIG. 2.

[0025] FIG. 9 is a cross-sectional view of a portion of an exemplary end sleeve arrangement also illustrating a method of securing composite ribs within a partially composite end sleeve.

[0026] FIG. 10 is a cross-sectional view of a portion of an alternative end sleeve arrangement also illustrating a method of securing composite ribs within a metallic end sleeve.

[0027] FIG. 11 is a side cross-sectional view of the exemplary composite rib shown in FIG. 11.

[0028] FIG. 12 is an axial cross-sectional view of an exemplary composite rib taken along lines 12-12 in FIG. 11.

[0029] FIG. 13 is an illustrative diagram depicting the overlapping arrangement of a plurality of ribs upon inflation of the bladder element of a packer assembly.

[0030] FIG. 14 is a side cross-sectional view of an external casing packer assembly constructed using composite components in accordance with the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0031] The present invention is directed to designs for inflatable packer assemblies and bridge plugs that utilize non-metallic, lightweight, composite materials to form for certain components. The resulting packer assemblies or bridge plugs are lighter in weight and easier to drill or mill out of the wellbore than conventional packer assemblies. Additionally, the composite portions of the packer or plug assemblies will be more resistant to corrosive downhole chemicals, such as CO₂ and H₂S, than conventional packer assemblies. At the same time, the packer or plug assemblies will have the hardness and durability necessary to provide adequate threaded connections to other components within a drill string. A suitable composite material for use in forming the components described herein is a carbon fiber/PEEK matrix.

[0032] Referring first to FIG. 1, there is shown an exemplary through-tubing bridge plug 10 that incorporates an inflatable packer assembly. The bridge plug 10 is typically carried on wireline or coiled tubing, in a manner known in the art, and disposed downwardly through production tubing (not shown). When the plug 10 is lowered to a desired location, the plug 10 is set by inflating the inflatable packer element. The mechanics of such setting and inflation are well known and, thus, will not be described in detail here.

The plug 10 includes, at its upper end, a fishing neck portion 12 having a reduced diameter external latching profile 14 by which a fishing tool (not shown) may be secured for removal of the plug 10 from the production tubing. Below the fishing neck portion 12 is an upwardly and outwardly directed shoulder 16 which transitions to an expanded diameter portion 18. A valve assembly sub 20 is located directly below the expanded diameter portion 18. The valve assembly sub 20 houses fluid valving used in inflation of the inflatable packer assembly of the plug 10. The lower end of the valve assembly sub 20 presents an annular ring portion 22 having internal threads 24 and external threads 26.

[0033] Conventionally, the fishing neck portion 12 and valve assembly sub 20 have consisted of metallic components that are threadedly connected to one another. In the plug 10, however, the fishing neck portion 12 and valve assembly sub 20 are unitarily formed as a single top sub component fashioned of composite material. The use of composite material permits the top sub portion of the plug 10 to be easily drilled or milled away in the event that the plug 10 becomes stuck within the production tubing and cannot
be removed using a fishing tool. Composite material also provides for a plug 10 that is lighter in weight and, therefore, more desirable and easily used in situations where the wellbore is angled or substantially horizontal in orientation.

[0034] Below the unitary top sub, a poppet housing 28 is secured by threading to the exterior threads 26 and encloses poppet 30 and compression spring 32. The poppet housing 28 is secured by threading at its lower end to spring housing 34. These components operate in a well-known manner to assist inflation of the bladder element of the plug 10. A central mandrel 36 is secured at its upper end to the threaded connection 24 of the top sub described previously and extends downwardly. At its lower end, the mandrel 36 is secured to a bullnose 38 by threaded connection 40. The mandrel 36 defines a central bore 42 along its axial length. Surrounding the mandrel 36 below the spring housing 34 is an inflatable packer element 44, the details of which will be described in detail shortly. The lower end of the inflatable packer element 44 is secured by threading to a bottom sub 46, which is fitted with a bleed plug 48. The bottom sub 46 also supports a shear ring 50, shear adapter 52 and shear screw 54 that are used for normal operation of the inflatable packer element 44, in a manner that is well understood by those of skill in the art, if removal of the plug 10 is required after setting.

[0035] FIG. 2 illustrates the inflatable packer element 44 of the plug 10 apart from the other components of the plug 10 so that its structure and operation is more easily seen. As best seen there, the packer element 44 includes an upper end sleeve 56, packer element portion 58 and lower end sleeve 60. The packer element portion 58 includes a bladder element 62 that is fashioned of nitrile rubber, as is known in the art. The bladder element 62 radially surrounds the central mandrel 36, shown in FIGS. 1 and 6. An annular space 63 is schematically illustrated in FIG. 1 as being defined between the bladder element 62 and the mandrel 36. As is known in the art, the bladder element 62 maybe radially inflated to set the packer element 44 by disposing fluid, under pressure, into the annular space 63, thereby inflating and radially expanding the bladder element 62. The bladder element 62 is retained within the upper and lower end sleeves 56, 60 by metallic retaining rings 64 and 66 which seat inside of the end sleeves 56, 60, respectively, thereby trapping the axial ends of the bladder element 62 between the retaining rings 64, 66 and the end sleeves 56, 60.

[0036] Several longitudinal reinforcing ribs 68 are arranged circumferentially about the outer surface of the bladder element 62 in an overlapping fashion. The overlapping arrangement of ribs 68 is best seen by reference to FIG. 6. The ribs 68 are fashioned of composite material and will be described in greater detail shortly.

[0037] Referring once again to FIGS. 1 and 2, a pair of enlarged elastomeric sealing elements 70, 72 is shown surrounding the ribs 68. These sealing elements 70, 72 provide contact surfaces that contact and engage the interior of a production tubing string when the bladder element 62 is inflated. The sealing elements 70, 72 provide for a resilient and fluid tight seal against the interior of the production tubing. If a larger version of the packer element 44 were to be integrated into a production tubing string, sealing would occur against the casing wall or open hole wall of the well. It is noted that, while the sealing elements 70, 72 are illustrated as covering only a portion of the axial length of the ribs 68, the packer element 44 may also be formed so that a sealing element surrounds essentially the entire radial exterior surface of the ribs 68.

[0038] The upper and lower end sleeves 56, 60 are partially comprised of a composite material and partially comprised of standard metal, such as steel. FIG. 3 depicts an exemplary design for the upper end sleeve 56. It will be understood, however, that the same construction may be used for the lower end sleeve 60. As shown, the end sleeve 56 includes a first, upper portion 74 that is fashioned of metal, typically steel, and a second, lower portion 76 that is fashioned of composite material. Additionally, an annular end cap 78 is secured to the lower end of the second portion 74. The annular end cap 78 functions to provide a resilient and strong lower shoulder for the upper end sleeve 56 and, similarly, a resilient and strong upper shoulder for the lower end sleeve 60. The end caps 78 also provide optimal resistance to hoop stress forces that are imposed upon the lower end of the upper end sleeve 56 and the upper end of the lower end sleeve 60 during inflation of the bladder element 62. It is noted that the first, metallic portion 74 of the end sleeve 56 is overlapped by and affixed to the second portion 76 over a contact area 80, which is depicted in FIG. 3. The first, upper portion 74 includes a threaded box-type connector 80 that is used to affix the end sleeve 56 to the spring housing 34.

[0039] In currently preferred embodiments, the composite used to form the second portion 76 of the end sleeve 56 consists of high strength fiber and polymer resin. The fibers are preferably formed of aramid (KEVLAR®) or carbon and, when formulated together with the resin, provide tensile strengths approaching 300 ksi. As will be described in greater detail shortly, a plurality of layers of the fibers are wrapped circumferentially about the end sleeve 18 for maximum hoop strength and bound in a high temperature thermoplastic matrix. PEK (poly-ether-ether-keytone) provides a suitable thermoplastic matrix, although other suitable matrices may be used. An important advantage to the use of composite material in forming portions of the end sleeves 56, 60 is that reinforcing ribs 68 that are formed of a composite material may be more easily and securely affixed to the composite portions of the end sleeves 56, 60, as will be described in greater detail shortly, with respect to FIG. 9.

[0040] The second, lower portion 76 is preferably formed by winding a number of layers of composite material onto the overlap portion 81 of the first, upper portion 74. Referring now to FIGS. 4A, 4B, 4C and 4D, an exemplary, and currently preferred, method of forming a pair of composite end sleeves, such as end sleeves 56 and 60, is illustrated. FIG. 4A is a side cross-sectional view that depicts a pair of metallic end pieces 82, 84 removably disposed upon a tubular section 86 to form a unitary workpiece 88. The metallic end pieces 82, 84 correspond to the upper portion 74 of an end sleeve 56 or 60 as described above. The exterior radial surface of the overlap portion 81 of each of the metallic end pieces 82, 84 is knurled, grooved or otherwise roughened to help the layers of composite material to adhere and become securely affixed to the end pieces 82, 84. FIGS. 4B and 4C are external views of the workpiece 88 illustrate the application of different layers of composite material. In FIG. 4B, a first layer 90 of composite material is being
wound onto the workpiece 88 as the workpiece 88 is being rotated about its longitudinal axis 92. The layer is placed onto the workpiece 88 with an in-situ melting and bonding process without curing. The first layer 90 includes a resin matrix base coating a plurality of fiber strands 94 that are oriented generally parallel to one another. The currently preferred composite material layer is formed of high strength carbon fibers and a PEEK resin matrix. For clarity, only a few of the strands 94 are depicted in FIG. 4B. However, in practice, there are numerous such strands within the first layer 90. FIG. 4B illustrates the winding deposition of the first layer 90 of composite material wherein the strands 94 are oriented approximately perpendicular to the axis 92 of the workpiece 88. This fiber orientation allows the first layer 90 to provide maximum resistance to hoop stresses that would act radially outwardly upon the second, lower portion 76 of an end sleeve. It is noted that the first layer 90 is deposited circumferentially along each of the overlap portions 81 of the end pieces 82, 84 as well as the tubular section 86. FIG. 4C illustrates the deposition of a second layer 96 of composite material after the first layer 90 has been fully deposited onto the workpiece 88. The second layer 96 also includes a resin matrix coating a plurality of substantially parallel fibers 98. However, the second layer 96 is applied so that the fibers 98 are oriented at an angle α that is less than 90° degrees with the axis 92.

Additional layers are applied to the workpiece 88 until an annular wall of composite material is built upon the workpiece 88. It may be necessary to adjust the amount of deposition upon various portions of the workpiece 88 in order to provide the annular composite wall (indicated as 100 in FIG. 4D) with an outer surface of substantially uniform diameter. Such adjustments are within the skill of those in the art. Additionally, as the layers of composite material are wound and deposited onto the workpiece 88, the winding should be done so that the fibers of the composite material making up the second portion 76 are oriented so as to maximize the resistance to stress and strain forces that are expected to act upon the second portion 76. In a currently preferred construction, the workpiece 88 is wound with layers of composite material so that approximately ½ of the layers have strands of reinforcing fibers that are oriented approximately in the axial direction and approximately ½ of the layers have strands of reinforcing fibers that are oriented generally in the circumferential direction. It has been found that this construction provides optimum resistance to both hoop stress and axially induced forces.

FIG. 4D depicts the completed workpiece 88 after the wall 100 of desired thickness of composite material has been deposited. Once this has occurred and the composite material has adequately set and cured, the workpiece 88 is then cut along an axial centerline 102 (shown in FIG. 4D). The tubular section 86 may be removed or destroyed, thereby leaving two members formed partially of composite material and partially of metallic material. An annular end ring 78 may then be secured to the composite end of each of the members to result in a pair of end sleeves, such as end sleeves 56, 60 described earlier. The annular end rings 78 are preferably formed of a high-strength steel and are currently preferred to offer improved resistance to hoop stresses proximate the end of the end sleeves 56, 60 as well as preventing delamination of the composite portions of the end sleeves 56, 60.

Referring now to FIGS. 7 and 8, two alternative constructions for an end sleeve are shown. In the construction depicted in FIG. 7, an end sleeve 56 features first, upper portion 74 that is fashioned of metal and a second, lower portion 76 that is formed of composite material and is approximately one half of the longitudinal length of the end sleeve 56. The lower portion 76 presents an annular shoulder 104.

FIG. 8 illustrates an alternative construction for the end sleeve 56 wherein the second portion 76 makes up the majority of the end sleeve 56. The first portion 74 consists of an annular ring containing threaded connector 80. The first portion ring 74 is embedded on the interior wall of the second portion 76. It is noted that each of the constructions depicted provide for the threaded connection of end sleeve 56, 56, or 56′ to be located on the first, or metal, portion of the end sleeve. Because the composite material used to make up the second portion is excellent in resisting tension forces, but provides weak interlaminar shear strength, the threaded connection 20 should not be formed into the second portion, i.e., the composite material is preferably not threaded.

In the constructions of end sleeves 56 and 56′, the annular shoulder 104 is formed of composite material rather than metal. In order to ensure that this construction provides adequate hoop strength and resistance to wear and hoop stress during inflation of the bladder element 62, a support sleeve is used. The arrangement depicted in FIG. 9, illustrates an annular braided KEVLAR® support sleeve 106 being used in conjunction with the end sleeve 56′ described earlier. The support sleeve 106 surrounds that ribs 68 proximate the annular shoulder 104. The KEVLAR® support sleeve 106 reduces the radially outward load applied to the annular shoulder 104 during inflation of the bladder element 62 by flattening the geometry of deployment of ribs 68 during expansion of the bladder element 62. The use of composite ribs 68, a KEVLAR® support sleeve 106, and partially composite end sleeve 56 has the advantage of better resisting wear that results from repeated inflation and deflation of the bladder element 62, as might occur if the bridge plug 10 is cyclically loaded or moved from location to location within a tubing string.

FIG. 9 is also illustrative of a method of securely affixing the composite ribs 68 to the second, composite portion 76′ of the end sleeve 56′. A series of fusion welds are used to create a secure connection. At a primary weld point, indicated at 108 in FIG. 9, the composite ribs 68 are fused together and to the composite portion 76′ of the end sleeve 56′. This fusion is accomplished by melting the matrix material within the composite material. Additional, secondary fusion points 110 are shown as well. Still referring to FIG. 9, it is noted that, alternatively, the second, composite portion 76′ of the end sleeve 56′ might be disposed over and directly secured to the ribs 68 during fabrication using the rotational winding technique described above with respect to FIGS. 4A-4C. In this instance, the ribs 68 would be arranged about the tubular section 86 and rotated while layers of composite material are wound about them. During the fabrication process for the end sleeve 56′, most of the composite layers are wound so that the carbon fibers embedded within the composite material are oriented primarily in the radial direction. The circumferential orientation of the fibers within the composite material maximizes that hoop strength that will be provided by the final end sleeve 56′.
Because multiple layers of composite material are used to construct the end sleeve 56, some layers of composite material may be oriented so that the fibers within are oriented at an angle (such as a 45 degree angle) with respect to the longitudinal axis 92 as required to resist expected stress forces. The use of high-strength, carbon fiber-reinforced composite ribs 68 eliminates the plastic deformation or yielding found in traditional steel ribs. The ribs 68 are important load-bearing components in an inflatable through-tubing packer assembly and bear combined loading in high tensile, bending and twisting when the bladder element of the assembly is inflated. Traditional ribs are made of a high-strength stainless steel and may be stressed to yielding beyond its elastic limit when the bladder element is highly inflated to set the assembly. This yielding may prevent the packer assembly or bridge plug from being effectively released from setting so that it can be removed from the tubing string or reset in another location. The inventors have recognized that a composite that includes a PEEK matrix reinforced with advanced high-strength carbon fiber, such as that commercially known as “IM7,” can provide a full elastic deformation that will be recovered after releasing the inflation pressure within the bladder element.

FIG. 10 illustrates a method of securely affixing the composite ribs 68 to a portion of an end sleeve 112 that might be fashioned of metal or of composite material. As shown there, the ribs 68 are fused together at their upper ends to an annular composite load-bearing ring 114. The composite ring 114 is formed to present an outwardly and downwardly facing shoulder 116 that contacts and rests upon a complimentary inwardly and upwardly facing shoulder 118. During inflation of the bladder element, tension forces are applied to the ribs 68, generally in the direction shown by arrow 120. These forces are transmitted to the composite ring 114 and, in turn, applied to the shoulder 118 of the end sleeve 112, as indicated by arrow 122, thereby ensuring a secure connection of the ribs 68 to the end sleeve 112.

The composite ribs 68 have a varying cross-section that places a greater number of fibers and less elastomer in those areas that are subjected to greater tensile stress. Conversely, fewer fibers and a greater amount of elastomer is provided in areas that are used to create sealing contact (i.e., where the sealing elements 70, 72 will be located). FIG. 11 illustrates a side, or edgewise, view of a single exemplary composite rib 68, which is shown apart from other components of the bridge plug 10. As shown there, the rib 68 includes two opposite end portions 124, 126 and a central portion 128. A typical rib 68 might be about 48 inches in total length. The central portion 128 has a thickness that is less than the thickness of the two end portions 124, 126. The thickness of the end portions 124, 126 is approximately 0.016 inches while the thickness of the central portion 128 is approximately 0.011 inches. As noted, the ribs 68 are formed from a composite material. Preferably, a rib 68 is fabricated by cutting it from a sheet of suitable composite material. One suitable composite material for this application is a woven lay of fiber and resin matrix of the type described previously.

FIGS. 11 and 12 also illustrate a currently preferred construction for the composite ribs 68 wherein three plies 130, 134, and 138 of reinforced composite material are laminated onto one another. As seen there, the first ply 130 extends along the entire length of the rib 68. The inset drawing illustrates that the reinforcing fibers 132 of the first ply 130 are oriented generally parallel to the longitudinal axis 135 of the rib 68. A second ply 134 has fibers 136 that are oriented at an angle with respect to the axis 135. It is currently preferred that the angle of the fibers 136 approach 90 degrees from the axis 135. It is pointed out that the second ply 134 is present on both end portions 124, 126 of the rib 68, but it is not present in the central portion 128 of the rib 68. The absence of the second ply 134 in the central portion 128 results in the central portion 128 being thinner than the end portions 124, 126, which are made up of three plies 130, 134, and 138. The third ply 138 also extends along the entire length of the rib 68 and, as shown in the inset in FIG. 11, has reinforcing fibers 140 that are oriented to lie generally along the axis 135. The fact that the first and third plies 130 and 138 both extend along the entire length of the rib 68 and that both have reinforcing fibers 132, 140, respectively, that are oriented generally along the axis 135 of the rib 68 provides high axial tensile strength to the rib 68 and structural stability when the rib 68 is twisted or bent in use. Additionally, the advanced thermoplastic resin PEEK can provide a high fracture toughness and excellent down-hole environmental and heat resistance, which are important to overall packer life and performance.

The composite ribs 68 provide improved response and resistance to tensile and bending forces, which will be experienced at or around flex points. Thus, the ribs 68 are less likely to fail than ribs of conventional metallic construction. Additionally, the ribs 68 are of a unique cross-sectional design. During inflation of the bladder element 62, the thicker end portions 124, 126 of the ribs 68 will receive radially inward loading by the shoulders 104 of the end sleeves 56, 60. Because there is a greater cross-section of composite material at this flex point, the rib 68 will be more resistant to failure due to bending forces. At the same time, the thinner central portion 128 of the ribs 68 remains suitably strong in resistance of tensional loading. The ribs 68 while allowing additional elastomeric material, such as that making up the sealing elements 70, 72, to be placed upon the outside of the ribs 68. The increase in elastomeric material permits a more secure fluid-tight seal to be formed by the bridge plug 10.

FIG. 12 is an axial cross-section taken along lines 12-12 of FIG. 11 and illustrates that a rib 68 contains a pair of arcuate portions 142, 144 that extend laterally outwardly from a central point 146. The arcuate portions 142, 144 are nestable with like arcuate portions (see FIG. 13) when the bladder element 62 is inflated and expanded radially. FIG. 13 illustrates portions of three exemplary ribs 68a, 68b, and 68c that are arranged in an arcuate fashion and may, in fact be considered an enlarged view of three of the ribs 68 shown arranged in overlapping fashion about the circumference of a circle in FIG. 6, albeit after the bladder element 62 has been inflated and radially enlarged so that the ribs 68 are accurately spread apart from one another about the entire circumference of that circle. The ribs 68a, 68b, and 68c are shown apart from other components of a packer assembly for clarity. Each of the ribs 68a, 68b, and 68c has an arcuate portion 142 that is shaped and sized to easily reside within the arcuate portion 144 of a neighboring rib. In this configuration, the ribs 68 may be spread out relatively uniformly about the circumference of the circle illustrated in FIG. 6, as will be necessary upon inflation of the bladder element 62.
It will be appreciated, then, that the dual arcuate portion construction of the ribs 68 is desirable.

[0052] Turning now to FIG. 14, there is shown an exemplary inflatable external casing packer (ECP) assembly 200 that includes components fashioned from composite materials. ECP assembly 200 is typically incorporated within a casing string, in a manner well known in the art, and disposed into and then set within an open and uncased borehole (not shown). The ECP assembly 200 includes a central tubular mandrel 202 that defines an axial casing bore 204 therein. In a currently preferred embodiment, the central mandrel 202 includes a tubular mandrel body 206 that is fashioned from composite material. It is noted that the tubular mandrel body 206 may be formed from layers of circumferentially wound reinforced composite material, in a manner similar to that described earlier for the formation of the composite portions of the workpiece 88.

[0053] Following creation of the composite mandrel body 206, externally threaded metal end pieces 208, 210 are secured to both the upper and lower axial ends of the mandrel body 206. The end pieces 208, 210 are preferably fabricated in place upon the mandrel body 206, although other suitable ways of joining such members together may be used. Alternatively, the composite mandrel body 206 might be integrally formed onto the two metal end pieces 208, 210 in the same manner in which the composite portions of the workpiece 88 were built upon the end pieces 82, 84.

[0054] Secured to the outer radial surface of the composite mandrel body 206 are a pair of metallic rings 212, 214. The metallic rings 212, 214 reside within recessed grooves (visible in FIG. 14) within the composite mandrel body 206.

[0055] An inflatable nitrile bladder assembly, shown generally at 216, radially surrounds the central mandrel 202. The bladder assembly 216 includes a radially outer elastomeric cover 218 that surrounds a plurality of longitudinal supporting ribs 220. The ribs 220 may be constructed of a composite material, like ribs 68 described earlier, or they may be conventional metallic ribs. End sleeves 222 and 224 secure the bladder assembly 216 to the mandrel 202. The end sleeves 222, 224 are preferably fashioned of a suitably strong and durable metal, such as steel, and are secured onto the rings 212, 214 of the mandrel 202. The end sleeves 222, 224 also securely retain the bladder assembly 216.

[0056] Upper and lower collars 226, 228 are secured by threading to the end pieces 208, 210, respectively. The upper collar 226 is also a valve collar, which is used to selectively express hydraulic fluid into the ECP assembly 200 and inflate the bladder assembly 216 and set the ECP assembly 200 within a wellbore. Both the upper and lower collars 226, 228 present box-type threaded connectors 230, 232 for securing the ECP assembly 200 within a casing string (not shown). The upper valve collar 226 is formed of a fiber-reinforced composite material. The valve collar 226 has a generally cylindrical body with both the upper box-type threaded connector 230 and a lower box-type threaded connector 234 at its lower end. The lower threaded connector 234 is used to securely affix the valve collar 226 to the upper end piece 208 of the central mandrel 202. The valve collar 226 also has a lateral inflate port 236 that is located just beneath the upper threaded connector 230 and positioned to receive fluid from the lateral exterior of the valve collar 226. The lateral inflate port 236 is interconnected to an axial fluid passage 238 that extends downwardly from the lateral inflate port 236 and opens at the lower end 240 of the valve collar 226. When the valve collar 226 is securely affixed to the end piece 208 of the central mandrel 202, the axial fluid passage 238 will become aligned with an adjoining fluid passage 242 housed within the end sleeve 222. The valve collar 226 thus houses a valve assembly wherein the adjoining fluid passage 242 is hydraulically interconnected with the bladder assembly 216 and, as a result, fluid may be selectively expressed into the lateral inflate port 236 under pressure and then transmitted through the fluid passages 238 and 242 to inflate the bladder assembly 216, thereby setting the ECP assembly 200 within an uncased or cased wellbore.

[0057] During operation, the ECP assembly 200 is operated in a manner typical of inflatable ECP assemblies. However, the construction of the central mandrel 202 is highly advantageous. First, the composite material is easier to drill or mill away than steel or other metals typically used to construct a casing mandrel. Thus, the use of composite material in the central mandrel 202 ensures that the ECP assembly 200 is easier to drill or mill out of the borehole should such become necessary. The use of metallic end sleeves 208, 210 and rings 212, 214 ensures that secure threaded connections between components are provided. In addition, the composite material renders the central mandrel 202 substantially inert and, thus, relatively impervious to corrosion from wellbore fluids including, for example, CO₂ and H₂S production stimulation acids.

[0058] Additionally, the use of composite materials to form the valve collar 226 is highly advantageous. Valve collars have heretofore been formed from steel or a similar metal or metal alloy. Because the valve collar 226 is located at the uppermost end of the ECP assembly 200, it will ordinarily be the first part of the assembly 200 that is encountered by a drill in the event that the assembly 200 must be drilled out of the wellbore. Thus, the use of composite material to create the valve collar 226 is particularly advantageous. When the valve collar 226 is fashioned from composite material, it may be much more easily drilled away and, as a result, the ECP assembly released from its wellbore setting. The valve collar 226 may be formed by using any of the techniques previously described to wind layers of fiber-reinforced composite material onto another to construct a tubular element. In addition, the valve collar 226 might be cast as a single component of fiber reinforced composite material. The use of composite materials in the manner described herein may also result in lower manufacture and assembly costs.

[0059] Those of skill in the art will recognize that numerous modifications and changes may be made to the exemplary designs and embodiments described herein and that the invention is limited only by the claims that follow and any equivalents thereof.

What is claimed is:

1. An inflatable packer assembly comprising:
   a central mandrel;
   an inflatable bladder element surrounding the central mandrel;
   a longitudinal rib member disposed adjacent the bladder element;
an end sleeve radially surrounding said central mandrel, bladder element and rib member, said end sleeve having a first portion comprised of composite material and a second metallic portion.

2. The inflatable packer assembly of claim 1 wherein the composite material of the first portion of the end sleeve comprises high strength fibers and polymer resin.

3. The inflatable packer assembly of claim 1 wherein the rib member is also comprised of composite material.

4. The inflatable packer assembly of claim 1 further comprising a support sleeve disposed between the end sleeve and the rib member, the support sleeve acting to reduce hoop stress forces applied to portions of the end sleeve during inflation of the bladder element.

5. The inflatable packer assembly of claim 4 wherein the support sleeve is formed substantially of KEVLAR.

6. The inflatable packer assembly of claim 1 wherein the rib member includes a pair of end portions having a first thickness and a central portion having a second thickness and wherein the second thickness is less than the first thickness.

7. The inflatable packer assembly of claim 1 wherein there is a plurality of longitudinal rib members that are disposed circumferentially about the bladder element and wherein each of the rib members is secured to the end sleeve by at least one fusion weld point.

8. The inflatable packer assembly of claim 1 wherein there is a plurality of longitudinal rib members that are disposed circumferentially about the bladder element and wherein each of the rib members is securely affixed to an annular load bearing ring that presents an engagement shoulder, the engagement shoulder being in load-transmitting contact with a portion of the end sleeve.

9. The inflatable packer assembly of claim 1 wherein the composite material forming the first portion of the end sleeve comprises circumferentially wrapped layers of high strength fibers in a resin matrix, the layers having been applied such that the fibers in at least one of said layers are oriented circumferentially.

10. An inflatable packer assembly comprising:

   a central mandrel having:

   a mandrel body comprised of composite material; and

   a metallic portion integrally formed within the mandrel body;

   an inflatable bladder element surrounding the central mandrel;

   a longitudinal rib member disposed adjacent the bladder element; and

   an end sleeve radially surrounding said central mandrel, bladder element and rib member.

11. The inflatable packer assembly of claim 10 wherein the metallic portion comprises a metallic end piece that is secured to an axial end of the mandrel body.

12. The inflatable packer assembly of claim 10 wherein the metallic portion comprises a metallic ring having a radially external surface with threads thereupon, the metallic ring being disposed upon an outer radial surface of the mandrel body.

13. The inflatable packer assembly of claim 12 wherein the metallic ring is disposed within a recessed groove upon the mandrel body.

14. The inflatable packer assembly of claim 10 wherein the composite material of the mandrel body comprises high strength fiber within a resin matrix.

15. The inflatable packer assembly of claim 14 wherein the resin matrix comprises PEEK.

16. An inflatable packer assembly comprising:

   an inflatable bladder assembly; and

   an end sleeve located at one axial end of the bladder assembly to secure the bladder assembly to a mandrel, wherein the end sleeve comprises:

   a first portion comprised of a composite material consisting essentially of high strength fiber in a resin matrix; and

   a second, metallic portion.

17. The inflatable packer assembly of claim 16 wherein the resin matrix comprises PEEK.

18. The inflatable packer assembly of claim 16 wherein the inflatable bladder assembly comprises a plurality of longitudinal rib members for reinforcement of the bladder element, at least one of said plurality of longitudinal rib members being substantially formed of composite material.

19. The inflatable packer assembly of claim 18 wherein the rib members further comprise a pair of end portions having a first thickness and a central portion having a second thickness wherein the second thickness is less than the first thickness.

20. The inflatable packer assembly of claim 16 wherein the composite material forming the first portion of the end sleeve comprises circumferentially wrapped layers of high strength fibers in a resin matrix, the layers having been applied such that the fibers in at least one of said layers are oriented circumferentially.

21. An inflatable packer assembly comprising:

   a central mandrel having a pair of axial ends;

   an inflatable bladder element surrounding the central mandrel;

   a valve collar secured to one axial end of the central mandrel, the valve collar being constructed of composite material and retaining a valve assembly for selective transmission of fluid to the inflatable bladder element for inflation of the bladder element.

22. The inflatable packer assembly of claim 21 wherein the central mandrel further comprises a generally cylindrical central portion that is formed of composite material.

23. The inflatable packer assembly of claim 22 wherein the composite material of the generally cylindrical central portion further comprises a plurality of circumferentially wound fiber-reinforced layers of composite material.

24. The inflatable packer assembly of claim 22 wherein the central mandrel further comprises a threaded metallic end piece secured to at least one axial end.

25. The inflatable packer assembly of claim 22 wherein the central mandrel further comprises at least one threaded metallic ring secured upon an outer radial surface of the composite central portion.

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