A liner for emplacement in a conduit in a well penetrating subterranean formations characterized by an annular body portion having substantially cylindrical interior and exterior surfaces that are at least partially coextensive and having an outside diameter less than the inside diameter of the conduit; the liner having a metallurgical composition and dimensions for being expanded to conformingly engage the conduit with a tight frictional engagement. The liner is adapted for use with a wireline setting tool without the necessity for a separate anchor or support. Also disclosed are the method of emplacing the liner in the conduit, specific metallurgical compositions, and specific embodiments and combinations.

21 Claims, 18 Drawing Figures
3,746,091

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CONDUIT LINER FOR WELLBORE
CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of application Ser. No. 878,108, filed Nov. 19, 1969, and now abandoned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to apparatus for use in a well penetrating subterranean formations. More particularly, it relates to liners and combinations of apparatus employing a liner in casing or tubing in an oil well or the like.

2. Description of the Prior Art

The prior art is replete with practical and impractical liners, and methods and apparatus for setting the liners in the casing or tubing in a well. As is well known, the liners are ordinarily set by being expanded outwardly into tight frictional engagement with the conduit; such as the casing or the tubing. The degree and type of tight frictional engagement depends, of course, on the use, or application, for which the liners are intended. For most applications, the liners are set with a tightness that prevents unwanted movement longitudinally of the conduit. Frequently, the liners are set with both tight frictional and sealing engagement, as will be apparent from a description of specific embodiments hereinafter. The tight frictional engagement provides a finite force that is designed for retaining the liner in place to do its job. Obviously, forces larger than design can be generated that are large enough to move the set liner longitudinally of its conduit. Liners or plugs have been set in a well by detonation of explosives within an enclosed chamber, or about a mandrel within a conduit; bridge plugs have been set by drawing a mandrel up within an expansible annular body and leaving the mandrel emplaced within the annular body, and by driving an expanding body upwardly or downwardly into and through an expansible body retained in position by a supplemental anchor or support means; such as, a tubing stop or a string of conduit supported on a platform of the well. Liners have been set by hydraulically forcing a swaging mandrel, or swage means, upwardly through corrugated liners held in place by the tubing string. Liners have also been set by jarring by repeated firing of an explosive jar brought to the surface and reloaded between firings and by explosively driving a swage means upwardly or downwardly through a corrugated liner held in place by a frangible member with a second explosive charge within the frangible member to destroy it. While some of the prior art devices have been useful, they have suffered from one or more of the following disadvantages:

1. they depended upon a separate supplemental support which had to engage the conduit and had to be individually set in the well for satisfactory operation, the supplemental supports were often unreliable and even if successful effected a surface discontinuity that created corrosion problems later;
2. they depended upon an outside coating of resilient material for effecting the sealing;
3. they required two parts; such as, an inner mandrel for setting and retaining the liner in place;
4. they were limited to thin walls because of the relatively large flexure of certain corrugations in the walls;
5. they had regions of relatively low yield strength because of the large amount of flexure induced by corrugations;
6. the resulting structure emplaced in the well-bore had a restricted aperture that was not as smooth as desired therethrough;
7. if they formed seats with a smooth internal diameter they were limited to seating at joints;
8. they required a separate string of pipe for operation; for example, either for rotating or jarring a tool or for conveying a high pressure fluid thereto;
9. they required a plurality of trips into the well to effect passage of the swage means completely through the liner;
10. they destroyed a portion of the equipment and sometimes damaged other equipment in the well by an uncontained explosion; or
11. they employed in the liner materials that were objectionable because of their physical, chemical, or electrochemical properties; for example, they formed galvanic, or electrolytic, cells with the conduit, thereby causing localized corrosion.

It is a primary object of this invention to provide for being set in a conduit in a wellbore penetrating subterranean formations, an improved liner, and combinations of liner and terminal elements that alleviate the disadvantages of the prior art devices and methods, as enumerated hereinbefore.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic elevational view of the liner and apparatus for setting it in a casing in a well penetrating subterranean formations, in accordance with one embodiment of the invention.

FIGS. 2 and 3 are fragmentary longitudinal sectional views of, respectively, the upper and lower parts of the device of FIG. 1, showing the device in one operative position.

FIGS. 4 and 5 are fragmentary longitudinal sectional views of, respectively, the upper and lower parts of the device of FIG. 1, showing the device in another operative position.

FIGS. 6 and 7 are fragmentary longitudinal sectional views illustrating another embodiment of the invention employed in hanging a production liner within a casing in a well.

FIGS. 8 and 9 are fragmentary longitudinal sectional views of another embodiment of the invention employed in emplacing a bull plug seal means in a casing in a well.

FIGS. 10, 11 and 12 are fragmentary longitudinal sectional views illustrating another embodiment of the invention employed in emplacing a straddle pack a casing in a well.

FIG. 13 is a fragmentary longitudinal sectional view of another embodiment of this invention employed in emplacing a seal sub in a casing in a well.

FIG. 14 is an elevational cross sectional view of a seal nipple for emplacing in the seal sub of FIG. 13.

FIG. 15 is a cross sectional view of a multiple bore packer emplaced in the embodiment of FIG. 13.

FIG. 16 is a fragmentary longitudinal sectional view taken along the line XVI — XVI of FIG. 15.
FIGS. 17 and 18 are fragmentary longitudinal sectional views illustrating another embodiment of this invention effecting a straddle patch in a casing in a well.

DESCRIPTION OF PREFERRED EMBODIMENTS

Referring now to the drawings, FIG. 1 illustrates a setting tool device 11, having liner 13 disposed between swage means 15 and setting sleeve means 17, all suspended from a wire line 19 at a given depth in a section of casing 21 in wellbore 23 penetrating subterranean formations 25. A collar locator and cable head assembly 27 is ordinarily included to facilitate accurate emplacement of the liner and withdrawal of the setting tool device.

The setting tool device which is illustrated in cross section in FIGS. 2 and 3 is described in detail in U. S. Pat. No. 3,186,485, "Setting Tool Devices," Harrold D. Owen. Reference is made to that patent for a detailed description of the operation of the setting tool. Broadly, the setting tool is a type of force generating means wherein a piston assembly and a cylinder assembly are powered for movement relative to each other by an ignitable charge in the tool. Briefly, setting tool device 11 includes fluid actuated means comprising a head assembly including igniter means, a cylinder assembly and a piston assembly within the cylinder assembly, with the piston assembly being slideable relatively to the cylinder assembly; and means including a combustion chamber adapted for receiving a combustible material power charge and disposed within the cylinder assembly for imparting motion to the cylinder assembly relative to the piston assembly to move the swage means upwardly through the liner, movement of which is opposed by the setting sleeve means. For ease of explanation the setting tool is illustrated herein as having its piston assembly connected with the swage means and its cylinder assembly connected with the setting sleeve means. Adapter means are available to effect the reverse connection in which the cylinder assembly is connected with the swage means and the piston assembly is connected with the setting sleeve means if desired.

Referring to FIGS. 2 and 3, liner 13 is accurately positioned at a given depth; for example, by use of collar locator 27. The given depth may include a section of casing 21 having a leak such as formed by an aperture 28 therein. Liner 13 includes an annular body portion having interior and exterior surfaces that define cylinders that are at least partially coextensive. The body portion has an outside diameter less than the diameter of the casing, or conduit; has sufficient malleability for and is adapted for being expanded to conformingly engage the casing; and has a wall thickness sufficient to effect a wall after expansion capable of withstanding differential pressure between the inside and outside of the casing. The body portion of the liner has a modulus of elasticity in compression sufficient to retain tight frictional engagement with the conduit after being expanded thereagainst and prevent being displaced upwardly or downwardly by forces normally expected to be imposed on the liner. Liner 13 is disposed between swage means 15 and setting sleeve means 17. Expressed otherwise, swage means 15 is disposed below liner 13 for moving through and expanding the liner outwardly and into contact with the casing, the external dimensions of the swage means having been preselected in accordance with the internal dimensions of the casing and the diameters and wall thickness of the liner to effect the necessary frictional engagement and the necessary thickness of the wall after expansion into engagement with the casing.

Adapter rod 29 passes through the liner and is connected at one end portion with swage means 15 and is adapted for connection at the other end with a force generating means for subjected the swage means to a force acting upwardly for pulling the swage means upwardly through the liner.

Setting sleeve means 17 encircles the adapter rod 29 and has its lower end portion expandably engaging the top of the liner and being adapted at its upper end portion for connection with the force generating means for opposing upward movement of the liner by transmission of a downwardly acting a reactive force from the force generating means.

When setting tool device 11 is employed as the force generating means, adapter rod 29 is connected at its upper end with bottom piston 31 of the piston assembly of setting tool device 11. Setting tool device 11 also includes a top piston 33, a top piston connecting rod 35, a top piston extension rod 37, and a firing head 39 mounted by a quick change assembly 41. Setting sleeve means 17 is connected with bottom cylinder 43 of the cylinder assembly of setting tool device 11. The cylinder assembly also includes top cylinder 45 and top sub 47.

A shear plug 49, having a predetermined shear value, is threadedly inserted into matched holes in the upper cylindrical portion 51 and lower body portion 53. Upon ignition of the ignitable charge in the setting tool, shear plug 49 is sheared and a force generated to pull swage means 15 through liner 13. Movement of liner 13 is opposed by the downwardly acting reactive force via the cylinder assembly and setting sleeve means 17 and another operative position, illustrated in FIGS. 4 and 5, is assumed as the swage means 15 is pulled through liner 13 to expand it out into frictional and sealing engagement with casing 21.

Specifically, setting sleeve means 17 expandably engages the top of the liner via adapter means; such as, flexible spring fingers 55. The flexible spring fingers 55 are ordinarily of steel. The flexible spring fingers 55 retain the liner in place during setting but are adapted to flex outwardly to allow passage of the swage means therethrough, as illustrated in FIG. 5, and spring back into position after the swage means has passed therethrough.

To allow the flexible spring fingers to transmit the reactive force and oppose the force pulling swage means 15 through liner 13, an expander support ring 57 is employed in the setting sleeve means 17 and is held in place adjacent liner 13 and within the flexible spring fingers with a shearable means; such as, shear pins 59; for supporting the fingers during the interaction of the large force and reactive force pulling the swage means through the liner. Expander support ring 57 has an annular shoulder 61 for conformingly engaging a shoulder portion 63 of the swage means after the swage means has passed through the liner for moving the expander support ring upwardly as the swage means passes upwardly out of the liner.

The swage means is connected with the adapter rod by a tension release portion 65 having a weak point to facilitate removal of the setting tool device in the event
malfunction occurs to prevent removal of te liner and the swage means.

Swage means 15 is illustrated as a ball swage in which the exterior surfaces form a circle such that upon being pulled through liner 13 an interior cylindrical surface is generated. Any other swage means capable of generating a smooth, cylindrical interior surface and having the requisite strength to expand liner 13 out against the conduit with the force available in the force generating means can be employed.

Swage means 15 contains a central passageway 83 and branch passageways 85 and 86 to facilitate flow of fluids therethrough. In this way the liner and the setting apparatus can be run rapidly down casing 21 to reach the proper depth more quickly. Swage means 15 contains threaded apertures 87 at each end for receiving a tension release portion 65 and allow interconnecting it with adapter rod 29, as well as other adapter rods. Threaded aperture 87 is merely illustrative of a satisfactory interconnection means. Any other interconnection means can be employed if desired.

As can be seen in FIGS. 4 and 5, when the combustible charge is nearly spent, the piston assembly including bottom piston 31, top piston 33, top piston connecting rod 35, and top piston extending rod 37, firing head 39, and quick change assembly 41 will have moved upwardly with respect to the cylinder assembly including bottom cylinder 43, top cylinder 45 and top sub 47. As swage means 15 moves out of the top portion of liner 13, its shoulder portion 63 engages annular shoulder 61 of expander support ring 57, shearing shear pins 59 and moving expander support ring 57 upwardly. Spring fingers 55 move outwardly to allow swage means 15 to pass therethrough, retaining engagement with the top edge of liner 13.

The liner is placed in the well by the following procedure. The liner and its setting apparatus, setting tool and any accessory equipment are inserted through conventional wellhead and lubricator equipment; and lowered to the desired depth on wire line 19. As indicated hereinbefore, once the liner is accurately positioned at the desired depth in the conduit in the well the force generating means comprising an ignitable charge in the setting tool is accuated, thereby, normally in a single stroke, pulling the swage means upwardly through the liner and expanding the liner outwardly into physical contact with the conduit with sufficient force to retain it in place. In detailed operation, as relative longitudinal movement starts to occur between the liner 13 and the swage means 15 in response to the upwardly and downwardly acting forces from the force generating means, the liner is forced outwardly to engage the casing 21. The engagement of the liner 13 with the casing 21 stops downward movement of the liner, obviating the need for an anchor of any sort. Thereafter, for all practical purposes, the force of the setting tool is directed to pulling the swage means 15 upwardly through the liner 13 which has been immobilized in tight frictional engagement with the casing 21. Subsequently, the setting tool, the swage means and the setting sleeve means and accessories are removed from the well, leaving the liner in place having an unusually large aperture penetrating longitudinally therethrough.

The liner remaining emplaced in the casing has uniform crystallographic structure since it has been substantially uniformly expanded outwardly to engage the casing, or other conduit, into which it is emplaced. The liner has a smooth bore which will serve as a seat against which to seal other elements.

The liner may be formed of any material having the requisite malleability and modulus of elasticity in compression after expansion against the conduit. Ordinarily, the liner will be a metallic liner. For example, alloys of copper, magnesium, aluminum or iron may be employed. The soft steels form satisfactory liners, since they have the requisite properties and do not set up any galvanic cells, regardless of the fluid in the conduit or outside the conduit in the well. A surprising and particularly preferred material of construction is commercially pure iron such as is employed in magnetic inductors for making iron cores of electromagnets, relays, and the like. The commercially pure iron is a highly refined open hearth grade of low-carbon, low-manganese iron. It has less than one percent by weight of alloy constituents, or other elements. Ordinarily, the commercially pure iron has less than 0.5 percent by weight of alloy constituents. For example, a typical ladle analysis and analysis in sheet form of the other elements in Armco magnetic ingot iron, which has been found to be satisfactory, is given in Tables I and II. The symbols of the Periodic table of elements are used in Tables I and II for the respective elements and the numerals represent concentrations in percent by weight.

### TABLE I
Ladle Analysis

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Mn</th>
<th>P</th>
<th>Si</th>
<th>Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>0.10%</td>
<td>max</td>
<td>0.010%</td>
<td>max</td>
<td>0.030%</td>
</tr>
<tr>
<td>C</td>
<td>0.015</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mn</td>
<td>0.028</td>
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</tr>
<tr>
<td>P</td>
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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### TABLE II
Typical Analysis in Sheet Form

<table>
<thead>
<tr>
<th>C</th>
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<th>S</th>
<th>.025</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mn</td>
<td>.028</td>
<td>Si</td>
<td>.003</td>
</tr>
<tr>
<td>P</td>
<td>.005</td>
<td>Total</td>
<td>.076</td>
</tr>
</tbody>
</table>

Typical of commercially available pure iron are Swedish iron and Armco magnetic ingot iron. The commercially pure iron is annealed to have a low yield strength in the range of 15,000–30,000 pounds per square inch and to have an elongation in the range of 37 percent – 41 percent in 2 inches, in accordance with standard tests. In this way the commercially pure iron effects sufficient malleability in the liner, as described hereinbefore. Moreover, the commercially pure iron is annealed to have a strength in the range of 39,000–43,000 pounds per square inch so that it will have sufficient strength after expansion to contain the pressures without unusually thick walls. Other physical properties of a satisfactory commercially pure iron may be obtained by reference to the brochure "The Use of Armco Magnetic Ingot Iron and Magnetic Components" by Robert W. Easton, Armco Steel Corporation, Middletown, Ohio.

When softer metals; such as, aluminum, magnesium, or alloys of copper; are employed as the body portion of the liner, it is preferable to include a top portion integrally connected with the body portion. The top portion should have a plurality of notches in its top edge to afford niches into which the metal can extrude when the swage means is pulled upwardly through the body portion of the liner. In this way, the metal does not extrude between the spring fingers of the setting sleeve.
When the liner is to be employed as other than a patch for the conduit, it is preferable to include integrally connected with the body portion of the liner a top portion that has an inner inverted frusto-conical section to form a stabbing section to facilitate entry of other elements into the liner once emplaced in the well. If desired, a coating of a supplementary material may be employed on the exterior surface of the liner to facilitate effecting a seal with the conduit into which the liner is emplaced. When such an external coating is employed, care should be taken that the material of which the coating is made does not extrude from between the liner and the conduit under the differential pressures that may exist thereacross and that the material is not soluble in fluid in contact with it so as to be dissolved from between the liner and the conduit.

In other embodiments, the liner can be employed with a connector means for connecting with a terminal element. The connector means is connected at one of its ends with the body portion of the liner and at the other of its ends with the terminal element. The terminal element may comprise conventional or newly developed downhole equipment; and, typically, includes equipment such as a production liner; a bull plug seal means; a seal sub for a seal nipple or packer; or an intermediate conduit of a straddle patch. Preferably for most downhole applications, the connector means is sealingly connected with the liner and with the terminal element; and has an expansible portion for retaining the sealing interconnection after the body portion of the liner has been expanded outwardly into tight frictional engagement with the conduit in the well. The connector means may be connected with either the top or the bottom of the respective liner, as most expeditiously in connecting with the terminal element. The connector means may be connected with the terminal element by conventional means; such as, a threaded connection; or by an expansible portion, depending upon the nature of the terminal element. The connector means may be integral with or carried by either the terminal element or the liner, or it may be detachably connected with either or both, as by threaded connection. A variety of typical connector means are illustrated in the figures herinafter. referred to and the accompanying descriptive matter.

Referring to FIG. 6, liner 13 is connected at its lower extremity with connector means 67. The expansible connector portion of the connector means 67 is illustrated as being integrally formed with liner 13. If desired, and as implied hereinbefore, it may be affixed by any suitable expansible joint; for example, it may be thermally joined thereto; as by welding, or silver soldering. At its other end, or lower end portion 69, connector means 67 may be threaded to facilitate joining with sub 71 onto which at least a section 73 of a production liner is affixed. While threaded connections between connector means 67, sub 71 and production liner 73 are illustrated, any suitable means can be employed for such interconnection.

The liner 13 of FIG. 6 is arranged and employed similarly as described hereinbefore. Specifically, the liner 13 is disposed between swage means 15 and setting sleeve means 17 for accurate placement within the conduit when swage means 15 is pulled through liner 13. The adapter rod 29 is connected with a force generating means for pulling swage means 15 through liner 13 and setting sleeve means 17 is connected with the force generating means for imparting an opposing, or reactive, force to retain the liner accurately positioned and oppose its being displaced upwardly by the movement of swage means 15 therethrough. The force generating means is actuated to pull swage means 15 through liner 13 and expand it out into frictional and sealing engagement with conduit 75 which may be the same as casing 21. The force generating means pulls swage means 15 through liner 13, effecting simple, rapid, long lasting emplacement of the liner. Thereafter, the force generating means, swage means 15, and setting sleeve means 17, as well as intermediate connections, are removed from the well.

FIG. 7 illustrates the liner 13 expanded into place against conduit 75, the connector means 67 with its upper expansible portion expanded with liner 13, the sub 17, and the production liner 73 emplaced in a conduit 75 in the wellbore. The production liner may be employed as a sand screen, or in connection with a gravel pack. Such production liners are frequently employed in wells operating under secondary recovery techniques; such as, flooding or thermal recovery. While the liners are ordinarily of steel, in certain instances, such as thermal recovery, they may be of stainless steel, titanium or other oxidation resistant metals or metallic alloys. The tough metals such as titanium require greater forces in setting, however, when they are employed in liner 13. Production liners are well known in the technology of producing oil from subterranean formations and need not be described in great detail herein.

When emplaced with liner 13, the production liner does not move downwardly from its own weight. Neither is it moved upwardly by any pressure differential. Ordinarily, there is relatively small differential pressure between the inside and the outside of a production liner.

FIG. 8 illustrates liner 13 and connector means 67 employed to support a bull plug seal means 79 within conduit 75 inside a wellbore. In this embodiment of the invention, the liner is run downwardly through conduit 75 relatively slowly to allow fluids within the conduit to flow past the bull plug seal means 79 and liner 13. Threaded connections are illustrated as the means by which bull plug seal means 79 is connected with the connector means 67. Any other suitable means may be employed to interconnect the two.

After the desired depth has been achieved in the wellbore, operation of the setting apparatus is effected by actuation of the force generating means as described hereinbefore. Upon actuation of the force generating means, swage means 15 is pulled upwardly through liner 13, expanding the liner outwardly and into frictional and sealing engagement with conduit 75. Setting sleeve means 17 is also connected with the force generating means for opposing the relatively upward movement of swage means 15 with downwardly acting reactive force to retain liner 13 at the desired depth in conduit 75 for emplacement.

FIG. 9 illustrates the liner 13 emplaced in conduit 75, the upper, or expansive, portion 81 of connector means 67 being expanded outwardly to accommodate the increased diameter of liner 13, and the lower portion retaining the original diameter and threadedly and sealingly connected with bull plug seal means 79.

In FIG. 9 spring fingers 55 are seen clearly after swage means 15 has passed upwardly therethrough,
moving expander support ring 57 upwardly from within fingers 55. Setting sleeve means 17, swage means 15, as well as the remainder of the force generating means are removed from conduit 75 to leave bull plug seal means 79 firmly emplaced via liner 13 in conduit 75. Liner 13 sealingly and frictionally engages conduit 75 with sufficient force to prevent movement of bull plug seal means 79 upwardly or downwardly by the force of any differential pressure across it normally expected to be encountered. Such differential pressure may be appreciable since the purpose of the bull plug seal means is for isolating a zone of a particular fluid pressure from the remainder of conduit 75. For example, the differential pressure may run as high as 1,000 to 3,000 pounds per square inch, or higher. It is apparent, therefore, that the frictional engagement of liner 13 with conduit 75 must resist displacement with a large frictional force. In some instances where a large differential pressure is expected, the force generating means may generate a force sufficient to expand the liner outwardly to the extent that conduit 75 is also distorted slightly to increase the force resisting movement upwardly or downwardly.

FIG. 10 illustrates another embodiment of the invention in which the connector means 67 is sealingly connected with liner 13, includes an elongate sleeve portion 93, and is sealingly connected at its other end with the annular body portion of a second liner 99 to form a straddle patch for emplacing in the conduit for blocking a communicating passageway between the interior of the conduit 75 and the exterior of the conduit 75.

Specifically, liner 13 is threadedly connected with the connector means 67 via an expansible portion comprising conforming threaded section 89 and 91, and sealing means; such as, O-rings 95; that are employed to ensure that liner 13 is sealingly connected with connector means 67 after expansion.

Similarly, the lower end portion 97 incorporates threaded sections 89 and 91 with O-rings 95 to form a second expansible portion 97 that sealingly connect the connector means 67 with the second liner 99. As illustrated, the connector means 67, incorporating its elongate sleeve portion 93 and two expansible portions, is connected with the bottom of the top liner 13 and the top of the bottom liner 99 to form the straddle patch.

Swage means 15 is connected with a second swage means 101 below second liner 99. Second swage means 101 has a diameter slightly less than the diameter of swage means 15 so that it will freely pass through the aperture left in liner 13 by the passage of swage means 15 therethrough. Moreover, the diameter of the second swage means 101 and the diameters and wall thickness of second liner 99 are selected so that they cooperate to effect sealing engagement of second liner 99 with conduit 75 when second swage means 101 is drawn upwardly through second liner 99 expanding it outwardly into sealing and frictional engagement with conduit 75.

It is important that the swage means pass through the associated liners to expand them outwardly into engagement with conduit 75 singly rather than simultaneously. In this way, setting sleeve means 17 is not required to supply the large force that would be required by simultaneous passage of both swaging means through both liners. It is not critical which swage means is pulled through its associated liner first.

As illustrated, second swage means 101 is immediately below and contiguous with second liner 99 and swage means 15 is spaced a distance below liner 13 sufficient to enable second swage means 101 to traverse through second liner 99 before swage means 15 starts its traverse of liner 13.

Swage means 15 is connected via adapter rod 29 with the force generating means and setting sleeve means 17 is connected with the force generating means as described hereinbefore.

Swage means 15 is connected with second swage means 101 by a second adapter rod 107 and a second tension release means 109. Second tension release means 109 enables removal of the portion of the apparatus thereabove in the event there is a malfunction which prevents removal of the second swage means from the conduit 75 within the well.

The straddle patch formed by the two liners and the intermediate second conduit will straddle passageways communicating with an undesired strata by emplacing the straddle patch at the appropriate depth in conduit 75.

The force generating means is actuated to pull second swage means 101 through second liner 99 and swage means 15 through liner 13.

An intermediate position in which second swage means 101 has passed through second liner 99 and in which swage means 15 is in the process of being passed upwardly through liner 13, is illustrated in FIG. 11. Therein, second liner 99 has been expanded outwardly to sealingly and frictionally engage conduit 75. Lower expansible end portion 97 of connector means 67 has been expanded with the body portion of second liner 99. The conforming threaded sections 89 and 91 are expanded outwardly to retain sealing engagement. O-rings 95 also retain sealing engagement and ensure there is no leakage.

It may be advantageous to employ a connector means wherein the elongate sleeve portion 93 is threadedly and sealingly connected at each end portion to the respective expansible portions, in the manner as sub 71 was engaged in FIG. 6. In this way, the threaded sealed portions of the connector means are not expanded, thus lessening the chances of a leak.

As swage means 15 is pulled upwardly through liner 13, spring fingers 55 engage the top portion 105 of the liner and resist its being displaced upwardly. Moreover, as swage means 15 passes through the lower portion of the liner 13 and the upper portion of connector means 67, they are expanded outwardly to frictionally and sealingly engage a portion of conduit 75, and help to retain the liner in place. Expander support ring enables spring fingers 55 to withstand the large force engendered by the interaction between the upward acting force on adapter rod 29 and the downward acting reactive force on setting sleeve means 17 without bowing or otherwise distorting.

FIG. 12 illustrates the straddle patch emplaced within conduit 75. Therein, liner 13 and second liner 99 are sealingly and frictionally emplaced in conduit 75 and co-act with connector means 67 to effect a straddle patch which isolates passageway 103 from the interior of conduit 75. Liner 13 has a stubbing section 111 comprising an inverted frusto-conical section. As illustrated, top portion 111 has notches 113 to allow room for extrusion of metal thereinto during the passage of the swage means through liner 13. Notches 113 are not ordinarily necessary in second liner 99 since there are no adjacent spring fingers 55 into which metal will ex-
Moreover, extrusion of metal in second liner 99 by passage of second swage means 101 therethrough, is of less significance than at the top of liner 13.

A variety of other applications, or uses, of the liner 13 will be apparent once this invention becomes known. Illustrative of such other uses is the use of a seal sub as the terminal element, the seal sub being used to sealingly receive a "large bore packer," or the like. The term "large bore packer" is used in its broad sense to include single bore packers and similar devices such as seal nipples, as well as packers having a plurality of bores. The liner 13 connected via connector means 67 having an expansible portion 131 with a seal sub 133 is illustrated emplaced in casing 21 in FIG. 13. The connector means is connected with the body portion of the liner 13 via threaded connection 135 and suitable sealing means 137; such as, an O-ring in an annular recess. On the other hand, the connector means 67 is integrally formed with the seal sub 133. As illustrated, the liner 13 contains suitable seal means 139 for ensuring a fluid impermeable interconnection between it and the casing 21. For example, the seal means 139 may comprise a plurality of O-ring type seals disposed in grooves 141 extending peripherally around the liner 13. The seal sub 133 has a seal surface 145 defining an internal bore and extending longitudinally thereof. The seal surface 145 is provided with a smooth finish for sealing engagement with the seal nipple, packer, or the like, that is to sealingly receive.

A seal nipple 147 suitable for emplacing within the seal sub 133 is illustrated in FIG. 14. The seal nipple 147 is provided with a top and bottom connection means such as female threads 149 for sealingly receiving male threads on a compatible element; such as, a joint of pipe in a string of conduit. In this way, the joint of pipe, or conduit, may be screwed into the seal nipple 147 and lowered until the seal nipple 147 is emplaced within the seal sub 133. If desired, suitable seal means 151 such as O-ring type seals may be emplaced in grooves 153 extending peripherally around the seal nipple 147. An undercut portion 155 is provided for being gripped with a wrench or the like in order to hold the seal nipple 147 while screwing the respective joints of pipe or conduit 159 together.

A packer 159 emplaced in the seal sub 133 is illustrated in FIGS. 15 and 16. Whereas the seal nipple 147, FIG. 14, had a single aperture 161, the packer 159 has a plurality of apertures 163-165 for receiving respective strings of conduit such as tubing and spaghetti strings. Such supplemental strings of conduit may be necessary in the production of a plurality of zones or in operating supplemental downhole equipment such as gas lift valves or gas operated devices in which the gas is injected through the spaghetti strings. On the other hand, the spaghetti strings may be employed for injection of chemicals; such as, corrosion inhibitors; paraffin deposition suppression chemicals; or the like. In any event, the packer has a sealing surface 167 for being disposed adjacent the seal surface 145 of the seal sub 133. If desired, suitable seal means 151 may be provided also in the body of the packer 159. The seal means 151 may be disposed in suitable grooves 153 extending peripherally around the body of the packer 159, similarly as described with respect to the seal nipple 147.

In operation, the liner 13 is set in the casing 21 as described hereinbefore. Specifically, the liner is emplaced at the desired depth and the setting tool activated to pull the swage means upwardly through the liner to expand it out into tight frictional engagement with the casing 21. The expansible portion of the connector means 67 expands outwardly to retain sealing engagement with the liner 13 as it is expanded. Consequently, the seal sub 133 is sealingly connected with the liner 13. When the respective elements such as the seal nipple 147 or the packer 159 is thereafter emplaced sealingly within the seal surface 145 of the seal sub 133, there is a fluid impermeable block formed; although fluid may flow through the bores of the respective apertures within the element so emplaced. The bores 163-165 may have conduits sealingly emplaced within them so that the conduits define the flow passageways, whereas the single aperture 161 of the seal nipple 147 may define the flow passageway therethrough.

While the straddle packer illustrated in FIGS. 10-12 employed a unitary elongate sleeve portion 93, the sleeve portion may comprise a plurality of joined sections such as illustrated in FIGS. 17 and 18. The unitary sleeve portion 93 was ordinarily short enough that the two liners could be set by two swage means 15 and 101 that were drawn upwardly through the respective liners by a single setting tool. Sometimes there are undesirable strata of such a long interval that a plurality of sections must be employed and the use of a single setting tool is impractical. In such an event, it may be desirable first to set a liner 13, such as that shown by FIG. 13. Such setting is carried out as described hereinbefore with respect to FIGS. 2-9. Thereafter, an assembly including a top liner 13 is connected to a plurality of threadedly connected liner sections such as 173, 175 making up the desired length and having a seal nipple disposed at its lower end is introduced into the borehole and is sealingly stabbing into the set liner 13. The lower seal nipple is similar to that illustrated in FIG. 14. Finally, the top liner 13 with its expansible portion 179 and the remainder 67a of the connector means 67, is expanded outwardly to engage the casing 21. Instead of the use of such a multi-step process; made necessary by a long interval of the conduit in which a straddle patch is desired; ordinarily, relatively shorter sections threadedly joined together may be employed in the elongate sleeve portion 93 and the straddle patch still be set as described with respect to FIGS. 10-12. That is, the liners and the connector means with the jointed elongate sleeve portion and the expansible portions may be pre-assembled into a straddle patch; and, thereafter, be set by employing the dual swage means with the second adapter rod 107 connecting the two swage means and pulling the swage means upwardly through their respective associated liners with a single setting tool.

Except for the liner 13, the materials of construction of the respective elements employed in the invention are well known to those skilled in wire line operations and need not be described in detail herein.

The setting sleeve means has been illustrated and described herein as being primarily cylindrical in shape, having expansible fingers for allowing passage of the swage means therethrough, and being connected with the setting tool so that it is removed with the setting tool, since that form of setting sleeve means is the preferred embodiment. The setting sleeve means may, however, take any other structure, or form, of setting means as long as it provides the two functions described hereinbefore; namely, (1) transmitting the
downwardly acting force from the force generating means to the liner, and (2) allowing passage of the swage means completely out of the upper end of the liner; thereby obviating the need for an anchor means in setting the liner in the conduit.

Also, the liner has been described as having interior and exterior surfaces that define cylinders. The cylinders so defined need not be perfect cylinders in the mathematical sense. It is deemed within the scope of this invention if the interior and exterior surfaces define cylinders having small irregularities, or grooves, whether accidentally or deliberately induced, as long as the irregularities are not as severe as the corrugations of the prior art; and are not sufficient to produce the nonuniform crystallographic structure; or result in a tight frictional engagement with the conduit that is unsatisfactory for the application for which the liner is emplaced.

It is apparent from the foregoing drawings and description that the invention accomplishes its objects of providing an improved method of setting a liner in a conduit in a wellbore penetrating subterranean formations, and providing combinations of apparatus that:

1. employ a cylindrical liner,
2. do not depend upon a separate supplemental support, or anchor, to hold the liner in place for setting in the conduit,
3. do not depend on an outside coating of resilient material for sealing,
4. do not require additional pieces to be retained in the well to retain the liner in place in the conduit,
5. are not limited to thin walled sections,
6. effect a more nearly uniform crystallographic structure at the metallurgical crystalline structure level without regions of low yield strength caused by large flexure such as corrugations,
7. have a large smooth internal bore that forms a uniform internal diameter for sealing additional elements thereon,
8. may be emplaced at any point without being restricted to joints,
9. are operable by means of a wire line without requiring an additional string of pipe,
10. do not require a plurality of trips into the well to effect passage of the swage means completely through the liner,
11. do not destroy equipment by an uncontained explosion in the well; and
12. in a particular embodiment, leave a liner that is physically, chemically, and electrochemically compatible with the conduit in the well and the job the liner is required to do. Specifically, with the particularly preferred commercially pure iron liners, no galvanic cell action will create localized corrosion problems for damaging the casing by electrochemical action. Moreover, the pure iron liners have low yield strengths and high elongations to make them more easily cold formed; yet, they work harden during the cold forming operation such as results in expanding the liner into tight frictional engagement with the casing, and effect additional strength after emplacement. Further, the pure iron is resistant to action by chemicals such as the caustics which are common in oil wells, yet resists fluids that may be produced from the formation longer than the softer metals such as aluminum and the like.

Although the invention has been described with a certain degree of particularity, it is understood that the present disclosure has been made not only by way of example and that numerous changes in the details of construction and the combination and arrangement of parts may be resorted to without departing from the spirit and the scope of the invention.

What is claimed is:
1. A liner for a conduit in a well penetrating subterranean formations and having a given diameter comprising an annular body portion having substantially cylindrical interior and exterior surfaces that are at least partially coextensive, having an outside diameter less than the internal diameter of said conduit; said body portion being formed of a highly refined commercially pure iron having a yield strength in the range of 15,000–30,000 pounds per square inch and an elongation in the range of 37–41 percent in 2 inches in order to have sufficient malleability for being expanded to conformingly engage said conduit; said body portion having a modulus of elasticity in compression sufficient to retain tight frictional engagement with said conduit after expansion thereagainst.
2. The liner of claim 1 wherein said commercially pure iron has no more than one percent by weight of alloy constituents and has a tensile strength in the range of 39,000–43,000 pounds per square inch; and said body portion has a thickness sufficient to effect a wall after expansion capable of withstanding the pressure normally within or outside said conduit.
3. The liner of claim 1 wherein said commercially pure iron has a ladle analysis of alloy constituents as follows: a total concentration of no more than 0.1 percent by weight of carbon, manganese, phosphorus, sulfur and silicon with no more than 0.01 percent by weight of phosphorus and no more than 0.03 percent by weight of sulfur; and no more than 0.15 percent by weight of copper.
4. The liner of claim 3 wherein said commercially pure iron has a typical analysis in sheet form about as follows; the concentrations of the elements as the alloy constituents being given in percent by weight: carbon 0.015%, manganese 0.028%, phosphorus 0.005%, sulfur 0.025%, and silicon 0.003.
5. A combination liner and element for a conduit in a well penetrating subterranean formations and having a given diameter comprising:
   a. an annular body portion having substantially cylindrical interior and exterior surfaces that are at least partially coextensive, having an outside diameter less than said given diameter, having sufficient malleability for and adapted for being expanded to conformingly engage said conduit, having a thickness sufficient to effect a wall after expansion capable of withstanding the pressures normally encountered within or outside said conduit and having a modulus of elasticity in compression sufficient to retain tight frictional engagement with said conduit after expansion thereagainst; and
   b. a connector means connected at its one end with said body portion and at its other end with a terminal element; said connector means having an expandable portion for retaining a sealing interconnection after expansion of said body portion.
6. The combination of claim 5 wherein said terminal element is at least a section of a production liner whereby said section of said production liner can be
emplaced at a given location in said conduit by expansion of said body portion into frictional and sealing engagement with said conduit, and said production liner will resist being displaced upwardly by pressure or downwardly by its weight.

7. The combination of claim 5 wherein said terminal element is a bull plug seal means and wherein said bull plug seal means can be emplaced at a given location in said conduit by expansion of said annular body portion into frictional and sealing engagement with said conduit and said bull plug seal means will resist being displaced upwardly or downwardly by force of a pressure acting thereon.

8. The combination of claim 5 wherein said terminal element comprises a seal sub having a longitudinally extending internal sealing surface defining a bore for receiving in sealing relationship a large bore packer including single bore packers such as seal nipples; whereby said seal sub can be emplaced at a given location in said conduit by expansion of said annular body portion into frictional and sealing engagement with said conduit and said seal sub will resist being displaced upwardly or downwardly by a weight and the force of a pressure acting thereon.

9. The combination of claim 5 wherein said body portion serves as a first liner and said terminal element is a second liner sealingly connected at one end to said connector means via an expansible portion and said connector means includes an elongate sleeve portion, to form a straddle pack for emplacing in said conduit for blocking a communicating passageway between the interior of said conduit and the exterior of said conduit.

10. The combination of claim 9 wherein there are two expansible portions, one said expansible portion being sealingly connected with one end of said first liner and the other said expansible portion being sealingly connected with one end of said second liner, and said elongate sleeve portion is connected with said two expansible portions; said elongate sleeve portion comprising a plurality of sections that are joined together.

11. The combination of claim 5 wherein said body portion is formed of a highly refined commercially pure iron having yield strength in the range of 15,000–30,000 pounds per square inch and an elongation in the range of 37–41 percent in 2 inches.

12. The combination of claim 11 wherein said commercially pure iron has no more than 1 percent by weight of alloy constituents and has a tensile strength in the range of 39,000–43,000 pounds per square inch.

13. The combination of claim 11 wherein said commercially pure iron has a ladle analysis of alloy constituents as follows: a total concentration of no more than 0.1 percent by weight of carbon, manganese, phosphorus, sulfur and silicon, with no more than 0.01 percent by weight of phosphorus and no more than 0.03 percent by weight of sulfur, and no more than 0.15 percent by weight of copper.

14. The combination of claim 13 wherein said commercially pure iron has a typical analysis in sheet form about as follows; the concentrations of the elements as the alloy constituents being given in percent by weight; carbon 0.015, manganese 0.028, phosphorus 0.005, sulfur 0.025, and silicon 0.003.

15. In a well penetrating subterranean formations, the combination comprising:

a. a conduit traversing a portion of the length of said well;

b. an expanded annular liner frictionally and sealingly engaging a small portion of said conduit with sufficient frictional engagement to resist being displaced upwardly or downwardly in said well; said annular liner having a body portion that is formed of a highly refined commercially pure iron having a yield strength in the range of 15,000–30,000 pounds per square inch and an elongation in the range of 37–41 percent in 2 inches; and

c. a connector means having an expanded expansible portion and sealingly connected at one end with said liner and connected at the other end with a terminal element.

16. The combination of claim 15 wherein said commercially pure iron has no more than 1 percent by weight of alloy constituents and has a tensile strength in the range of 39,000–43,000 pounds per square inch.

17. The combination of claim 15 wherein said commercially pure iron has a ladle analysis of alloy constituents as follows: a total concentration of no more than 0.1 percent by weight of carbon, manganese, phosphorus, sulfur and silicon with no more than 0.01 percent by weight of phosphorus and no more than 0.03 percent by weight of sulfur; and no more than 0.15 percent by weight of copper.

18. The combination of claim 17 wherein said commercially pure iron has a typical analysis in sheet form about as follows; the concentrations of the elements as the alloy constituents being given in percent by weight; carbon 0.015, manganese 0.028, phosphorus 0.005, sulfur 0.025, and silicon 0.003.

19. The combination of claim 15 wherein said terminal element comprises a seal sub having a longitudinally extending internal sealing surface defining a bore and receiving in sealing relationship a large bore packer; and said liner sealingly and frictionally engages said conduit with sufficient force to support the weight of said packer in said well and to resist being displaced by pressure acting on said liner.

20. The combination of claim 19 wherein said large bore packer comprises a body having a longitudinally extending aperture penetrating therethrough.

21. The combination of claim 20 wherein said large bore packer body has a plurality of apertures extending longitudinally therethrough.