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AUTOFRETTAGE METHOD AND APPARATUS

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This invention relates to new and useful improvements in autofrettage methods and apparatus.

In the past, multi-layer vessels of the type disclosed in United States Reissue Patent No. Re. 22,251, and also solid wall vessels, have been subjected to the autofrettage process, an example of which is disclosed in United States Patent No. 2,337,247.

An object of this invention is to provide a new and improved autofrettage method and apparatus.

An important object of this invention is to provide a new and improved autofrettage process and apparatus wherein the extent of the autofrettage can be physically measured and/or observed.

Another object of this invention is to provide a new and improved method and apparatus wherein fluid pressure is applied internally of a cylindrical wall for only a portion of the length of such wall, whereby a pre-stressing of the cylinder wall may be accomplished in successive stages.

A further object of this invention is to provide a new and improved method and apparatus for pre-stressing a multi-layer or a solid wall cylinder, in successive portions until the cylinder wall is pre-stressed throughout its length, such pre-stress being preferably controlled so that when the cylinder is in use at a predetermined operating pressure, such pressure is substantially equally distributed to the layers or transverse portions of the cylinder wall.

A particular object of this invention is to provide a new and improved method and apparatus for applying a force internally of a wall of a cylinder, wherein an assembly having an expansible member is inserted into the bore of such cylinder and then such expansible member is radially expanded for subjecting the inner portion of the wall to a force in excess of its elastic limit, whereby the inner layers are placed under compression and the outer layers are placed under tension when the internal force is relieved.

The preferred embodiment of this invention will be described hereinafter, together with other features thereof, and additional objects will become evident from such description.

The invention will be more readily understood from a reading of the following specification and by reference to the accompanying drawings forming a part thereof, wherein an example of the invention is shown, and wherein:

FIG. 1 is a view in vertical section illustrating one type of apparatus of this invention adapted to be used in carrying out the method of this invention;

FIG. 2 is a fragmentary vertical sectional view illustrating the apparatus of FIG. 1 in an expanded position in a multi-layer cylinder; and

FIG. 3 is a partial vertical sectional view illustrating a modified form of the apparatus of this invention which is also adapted to be used in carrying out the method of this invention.

In the drawings, the letter A designates generally one form of the apparatus of this invention which is adapted to be used in carrying out the method of this invention. As illustrated in FIG. 1, the apparatus A is adapted to be inserted in the bore or interior of a cylinder C which may or may not have an end closure E connected at one end. Although the invention is illustrated in the drawings as applied to the cylinder wall of a multi-layer vessel having a plurality of layers 12, this invention may also be used in conjunction with a cylinder wall having only a single layer, sometimes referred to as a solid wall cylinder. Briefly,

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the invention involves the application of internal forces to the cylinder C at successive increments or portions of the cylinder. With the apparatus and method of this invention, the extent of the expansive force applied internally of the cylinder C may be readily measured and/or observed so that the extent of the radial expansion of the cylinder wall may be closely controlled to obtain the desired amount of autofrettage.

As illustrated in FIGS. 1 and 2, the apparatus A includes an annular external band 14 which is adapted to engage the internal surface of the cylinder C. The band 14 is connected at or near its outer ends by annular welds 16 or other suitable connections to a flexible support ring 20. Prior to the application of fluid pressure to the apparatus A, the internal surface 14a of the expansible band 14 is parallel, or substantially parallel, to the external surface 20a of the flexible support or ring 20. The welds 16 have a greater depth than the width of the band 14 so as to provide a chamber 22 between the band 14 and the flexible support ring 20.

Fluid pressure is introduced into such chamber 22 through one or more suitable openings 20b which establish communication with a hose or inlet tube 25 and the chamber 22. The hose or inlet tube 25 is connected to a source of fluid under pressure (not shown) so as to introduce such fluid under pressure into the chamber 22 when it is desired to expand the expansible band 14 radially for carrying out the autofrettage method of this invention.

A frame is provided internally of the flexible support ring 20 by one or more plates or disks 30, each of which has a circular external surface 30a in the preferred form of the invention. The disks 30 may have central openings 30b therein as shown in FIG. 1 or they may be made of solid plate. Preferably, the disks 30 are welded or are otherwise connected together by a connecting ring 35 so as to form a unitary frame within the support 20. The external surfaces 30 of the frame disks 30 are preferably formed parallel to and radially spaced from the internal cylindrical surface 20b of the ring 20 prior to the application of fluid under pressure within the chamber 22. The spacing of such surfaces 30a and 20b from each other is fixed at the outer extremities of the disks 30 by fulcrum elements 36. Such fulcrum elements 36 may be formed as welds extending circumferentially for the entire circumference of the external surface of the cylinder 30, but spaced at the outer extremities as shown in FIGS. 1 and 2. On the other hand, the fulcrum elements 36 may be metal rings which are secured to the disks 30 and in the usual case also to the ring 20 by welds or other connecting means.

The purpose of the fulcrum elements 36 is to provide spaced longitudinal fulcrum points for the flexing of the support 20 upon the application of fluid pressure within the chamber 22. If such fulcrum points were not provided, upon the application of fluid pressure within the chamber 22, there would be a tendency for the flexible band 14 to expand with a bulge at the central portion thereof throughout its circumference. With the present invention, upon the application of the fluid pressure, the band 14 moves radially outwardly throughout its full longitudinal extent and its full circumferential extent because the ends of the band 14 at the welds 16 and slightly inwardly thereof are forced upwardly by the flexing of the support ring 20. Thus, the fluid pressure acts to force the band 14 outwardly at its central portion, but at the same time, the fluid pressure acts to force the flexible support 20 inwardly at its central portion causing a flexing or bending on the fulcrum elements 36 as shown in FIG. 2 (solid lines). The flexing downwardly or inwardly of the support 20 by the fluid pressure causes the outer ends of the support ring 20 to move radially outwardly as shown

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in FIGS. 2 to apply an outward radial force to the outer portions or ends of the flexible cylindrical band 14. Thus, any tendency of the flexible cylindrical band 14 to bulge at the center and thus apply more force to the cylinder wall C at the center is offset and balanced by the counter-acting effect of the flexing of the support 20. In that way, the force applied to the bore or interior surface of the cylinder wall C is uniform throughout the full annular circumference of the flexible band 14.

In carrying out the method of this invention using the apparatus A of this invention, such apparatus A is positioned in the cylinder C at any desired longitudinal portion of the cylinder C. In the usual case, the longitudinal extent or width of the flexible band 14 is only a portion of the longitudinal length of the cylinder C so that the fluid pressure applied with the apparatus A to the bore or interior surface of the cylinder C is applied to only a portion thereof. The apparatus A may be inserted at the extreme outer portion of the cylinder C as shown in FIG. 1 during the initial application of the fluid pressure, or it may be positioned at any other selected portion of the interior of the cylinder C for the initial application of pressure. The external diameter of the flexible expansible band 14 is slightly smaller than the internal diameter of the cylinder C, although a relatively snug fit which still permits longitudinal movement of the apparatus A within the bore of the cylinder C in the absence of fluid pressure within the chamber 22 is preferred.

After the apparatus A has been positioned at the portion of the cylinder C where the autofrettage pressure is to be applied, the fluid under pressure from any suitable source (not shown) is introduced through the hose or tube 25 into the annular chamber 22. The extent of the pressure introduced is variable depending upon the steel or other metal of the cylinder C, and the degree of expansion desired in such metal. Preferably, in carrying out the method of this invention, the forces applied radially by the expansion of the expansible member 14 are sufficient to stretch or expand the inner part or layers of the cylinder C beyond their elastic limit. In fact, all of the layers 12 of the cylinder C, or the entire solid wall thickness of a single layer vessel may be stretched beyond the elastic limit thereof with the apparatus A of this invention. However, in order to provide a vessel wherein the cylinder is capable of uniformly distributing the stress imparted thereto by a fluid under pressure within such vessel in use, it is preferable to stretch only the inner half or other pre-calculated portion of the wall of the cylinder C beyond its elastic limit and without stretching the layers therebeyond past their elastic limit. Therefore, when the pressure within the chamber 22 is released and the expansible member 14 returns to its normal position as shown in FIG. 1, the inner layers will have received a permanent set or deformation while the outer layers will not have been so deformed. Thus, due to such deformation of the inner layers, the outer layers exert a compressive squeezing force on the inner layers when the vessel is in a relaxed position without any pressure interiorly of the cylinder C. Then, when the vessel is subjected to the internal fluid pressure in use at the predetermined operating pressure, the inner layers will first assume their portion of the load and in doing so will overcome the compressive force created by the autofrettage and then the outer layers will successively assume their proportion of the load. This stress distribution to the various layers 12 of the multi-layer cylinder C takes place in the same manner throughout the cylinder wall of a solid wall vessel.

With the present invention, when the fluid pressure is inserted within the chamber 22, the external cylindrical band 14 tends to expand or move radially outwardly and actually exerts an expansive force as indicated in FIG. 2 on the cylinder C. The relative movement of the parts in FIG. 2 are illustrated by showing the original unexpanded position of the parts in dotted lines and the

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expanded position of the parts of the apparatus A in solid lines. With the present invention, the extent of the circumferential expansion obtained by the apparatus A can be readily measured with the customary gauges, and can actually be visually observed so that the exact amount of radial expansion in the cylinder C can be determined. Such determination can be made at the time the pressure is being applied for the autofrettage and therefore the process of this invention eliminates the guesswork normally involved in the autofrettage process.

The apparatus A is returned to its normal or unexpanded position shown in FIG. 1 after it has been used for expanding a particular portion of the cylinder C. Thereafter, the apparatus A is moved to successive increments or portions of the cylinder C to ultimately expand the entire inner bore of the cylinder C uniformly throughout the length of the cylinder C. Since the extent of the expansion can be readily measured and observed during each of such successive expansion steps, the cylinder wall is subjected to a uniform autofrettage process, the results of which are visually and physically measured and determined at the time of the expansion. As previously noted, the end closure E is any type of closure conventionally used for closing the ends of solid wall or multi-layer vessels. One of such enclosures E is welded as illustrated in FIG. 1 to one of the ends of the cylinder C in the usual state of the cylinder and vessel at the time of the autofrettage with the method of this invention. However, it will be understood that the closure E may be left off of the cylinder C until after the autofrettage process has been completed.

In FIG. 3 another form of the apparatus of this invention is illustrated and is indicated generally by the designation A-1. The apparatus A-1 is shown only partially in FIG. 3 because it is basically of the same construction as that shown in FIGS. 1 and 2 with the exception of the parts clearly illustrated in FIG. 3. Thus, the apparatus A-1 includes an annular cylindrical expansible band 114 which corresponds with the cylindrical expansible band 14. A support ring 120 is positioned internally of the annular band 114, with the internal surface 114a with the band 114 substantially parallel to and spaced from the external surface 120a of the support ring 120 to provide an annular fluid chamber 122 therebetween. The annular band 114 is not physically connected to the support ring 120, but seal rings 116a and 116b are provided on each end of the band 114 for sealing purposes to prevent the escape of fluid pressure from the chamber 122, as will be more evident hereinafter.

In the apparatus A-1, the support ring 120 preferably has a flange 120b at one end thereof which forms an annular laterally extending surface 120c for engagement by the seal ring 116b. At the other end of the support ring 120, a keeper ring 50 is provided, with an annular laterally extending surface 50a engageable by the seal ring 116a. The keeper ring 50 is complementary to the flange 120b so as to securely position the expansible band 114 therebetween as best seen in FIG. 3. The keeper ring 50 is removable from the support ring 120, but is held in place under normal operating conditions by a plurality of machine bolts 51 or similar securing means.

The support ring 120 has one or more fluid passages 120d establishing communication from an inlet tube or hose 125 to the chamber 122. Such hose or tube 125 corresponds with the hose or tube 25 of the apparatus A, both of which are suitably connected to a source of fluid under pressure (not shown).

The support ring 120 is preferably also supported internally by frame rings or disks 130, each of which may be welded or otherwise secured to the support ring 120 as shown in FIG. 3. Such frame members or disks 130 are provided to withstand the extreme pressures employed in the expansion of the band 114 during the autofrettage process of this invention.

In the use of the apparatus A-1 of this invention, the

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same steps as described heretofore in connection with the apparatus A are employed, the only difference being in the physical construction of the apparatus A-1 as compared to the apparatus A. The support 120 of the apparatus A-1 remains in the same position during the expansion of the expansible member 114. Thus, when the fluid under pressure is introduced into the chamber 122, the band 114 is urged radially outwardly and thereby imparts such expansion force circumferentially to the internal surface of the cylinder C for expanding same beyond the elastic limit of at least the inner portion of the cylinder wall. Upon a release of the fluid pressure within the chamber 122, the flexible band 114 returns to the position shown in FIG. 3 for the movement to the next successive increment or portion of the cylinder C and the subsequent subjection of the cylinder C to the autofrettage pressure.

The foregoing disclosure and description of the invention is illustrative and explanatory thereof and various changes in the size, shape and materials, as well as in the details of the illustrated construction, may be made within the scope of appended claims without departing from the spirit of the invention.

What is claimed is:

1. A method of applying pressure internally of a cylinder wall for the auto-frettage thereof, comprising the steps of,

- (a) applying internal pressure only radially outwardly of a cylinder wall for only a portion of the length thereof to expand the inner part of said portion,
- (b) releasing the pressure on said portion,
- (c) thereafter repeating the foregoing steps of applying the internal pressure and releasing same on successive lengthwise internal portions of said cylinder wall,
- (d) each of said portions extending completely around the internal circumference of the cylinder, and
- (e) said pressure being applied by means of an expansible annular band having means for fluid pressure to expand the annular band to flex same radially outwardly.

2. An apparatus adapted to be used for the autofrettage of a cylinder wall, comprising:

- (a) an annular band having an external annular surface engageable with only a lengthwise circumferential portion of the internal surface of a cylinder wall,
- (b) means forming a fluid chamber inwardly of said annular band for receiving fluid pressure, and
- (c) means for introducing fluid pressure into said chamber for radially expanding said annular band for thereby expanding the cylinder wall,
- (d) said band being adapted to extend completely around the internal surface of the cylinder wall, and

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(e) means for flexing said annular band radially only as the fluid pressure is introduced into said chamber for effecting the substantially radial expansion of the cylinder wall.

3. An apparatus adapted to be used for the autofrettage of a cylinder wall, comprising:

- (a) an annular band having an external annular surface engageable with the internal surface of a cylinder wall,
- (b) a flexible support connected at spaced longitudinal points on the inner surface of said annular band and forming a fluid chamber inwardly of said band,
- (c) a frame having longitudinally spaced fulcrum elements therewith engageable with said flexible support for enabling said flexible support to flex inwardly at its central portion upon the application of fluid pressure in said fluid chamber for applying an outward force to the outer ends of said band corresponding to the outward force exerted on the central portion of said band so that said band exerts a substantially equal force to the cylinder wall throughout said external annular surface, and
- (d) means for introducing fluid pressure into said chamber for radially expanding said annular band for thereby expanding the cylinder wall.

4. A method of applying pressure internally of a cylinder wall for the auto-frettage thereof, comprising the steps of,

- (a) applying internal pressure only radially outwardly of a cylinder wall for only a portion of the length thereof to expand the inner part of said portion,
- (b) measuring the amount of radial expansion to determine the extent of the auto-frettage,
- (c) releasing the pressure on said portion,
- (d) thereafter repeating the foregoing steps of applying the internal pressure and releasing same on successive lengthwise internal portions of said cylinder wall,
- (e) each of said portions extending completely around the internal circumference of the cylinder, and
- (f) said pressure being applied by means of an expansible annular band having means for fluid pressure to expand the annular band to flex same radially outwardly.

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