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EXPLOSIVE FORMING WITH BALANCED CHARGES

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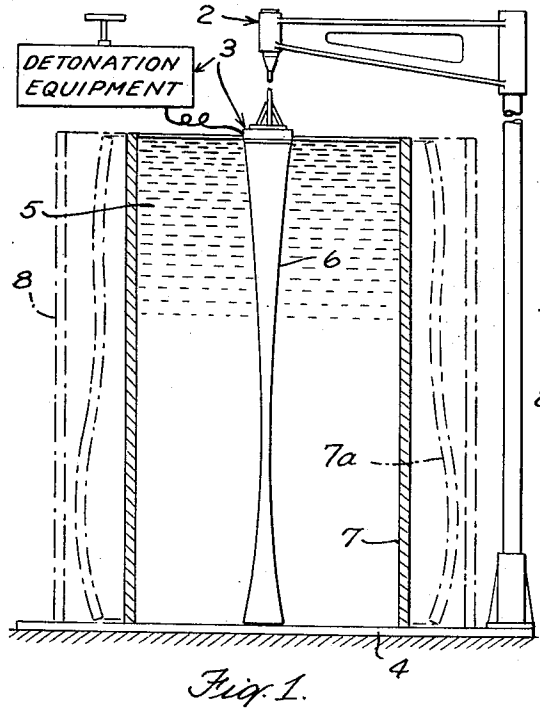


Fig. 1.

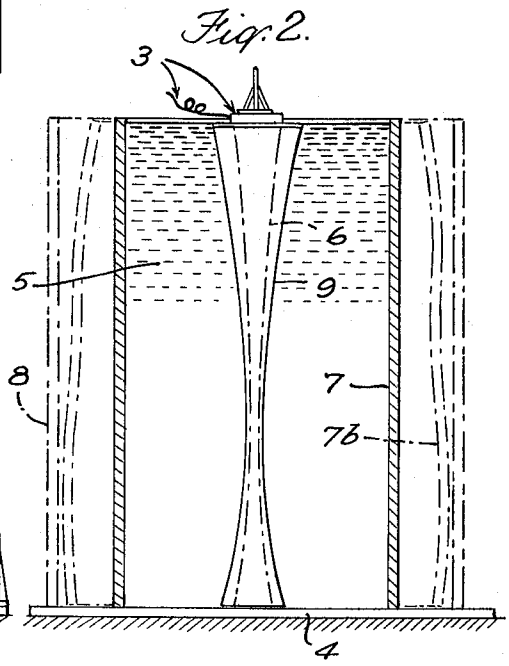


Fig. 2.

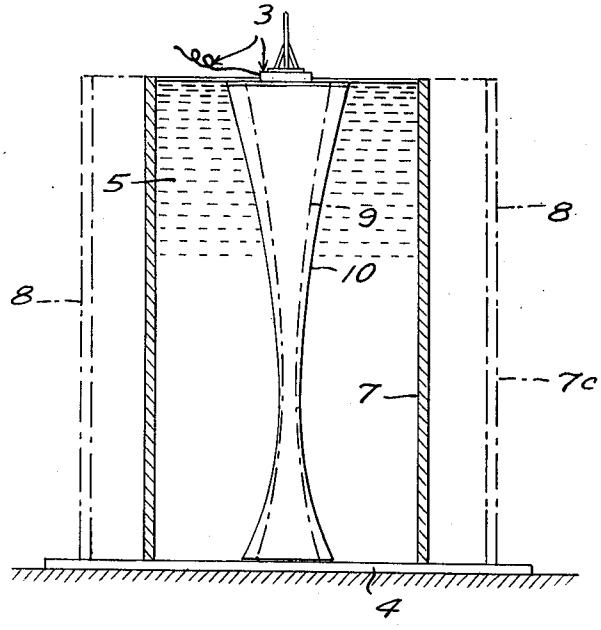


Fig. 3.

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EXPLOSIVE FORMING WITH BALANCED CHARGES

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This invention relates to the fabrication of open-ended annular vessels by explosive forming. In particular it relates to the forming of large diameter annular vessels by means of balanced charges that are created by a trial and error technique.

In the past open-ended vessels have been fabricated by rolling a plate and welding the meeting edges to form an elongated annulus or by exploding smaller vessels into larger dies. The present invention contemplates the use of a shock wave developed by an elongated balanced charge circular in cross section to expand an open-ended annular body, without the aid of a die, into a predetermined shape. The present invention teaches a method for forming the particular balanced charge required for the fabrication of the desired shaped vessels.

Employing this method large diameter vessels such as those used for rocket casings, otherwise cumbersome to fabricate, can be simply and inexpensively manufactured. Additionally, multi-layer vessels of any required wall thickness can readily be built by successively exploding thin layer vessels into each other. Furthermore, explosive forming produces vessels of improved metallurgical properties.

These and other advantages will appear more fully from the accompanying drawings wherein:

FIGURES 1, 2, and 3, are sectional elevations depicting representative steps in the process of forming a balanced charge for the fabrication of an annular vessel. Taken together they show the trial and error method by which a balanced charge **10** is formed for the fabrication of predetermined cylinder **8** from cylinder **7**; although the present invention applies equally to various configurations other than cylinders.

The shape of charges **6**, **9** and **10** as shown in the drawings indicate schematically the amount of explosive at various portions of the length of the charge. The wider portions of the charge indicate larger amounts of explosive. The charge is drawn symmetrically about its longitudinal axis to further indicate explosive variation solely along the axis. That is, the amount of explosive is equally distributed in all radial directions from the axis at every portion along the length perpendicular to its axis. This is all that the drawings represent with regard to the charges. They show a charge distribution of explosive varying only as a function of the longitudinal axis. The explosive distribution in the perpendicular direction to the axis is radially symmetric. In this direction circular or annular charge distributions may be employed without departing from the scope of the invention. In practice the physical shape of the charge may be cylindrical containing a non-explosive supporting core. Nevertheless, the quantities of explosive can be varied along the longitudinal axis to be circularly distributed perpendicular to the axis. Sheet explosive may be wrapped about a solid supporting core for this purpose with perforations made uniformly in the sheet in all radial directions perpendicular to the axis at those portions along the length of the charge where it is desirable to have lesser quantities of explosive.

A balanced charge is that charge distribution which will cause a specified vessel to expand into a predetermined shaped vessel after explosion. A balanced charge may

consist of a series of individual, unconnected charges. The length of the balanced charge is the length along the axis from the uppermost portion of explosive to the lowermost portion of explosive. The balanced charge for exploding and expanding a specific vessel into a predetermined shape depends on various factors: materials, shapes, sizes, explosives, etc.

Referring now to the drawings for a step by step development of a balanced charge. In FIGURE 1, an annulus **7** identical to that from which a predetermined annular vessel **8** is to be fabricated is filled with an energy transmitting medium **5**. While air or any medium would serve this purpose, it is preferred that a liquid be employed; water performs nicely in this capacity. Rubber mat **4** provides a seal for water containment.

Means are provided to develop a shock wave of high kinetic energy within the annulus. A first explosive charge **6** having length substantially equal to the length of the annulus and having equal amounts of explosive in all radial directions perpendicular to its length is disposed axially within the annulus **7** in the energy transmitting medium **5**. A support means generally indicated by member **2** holds and positions the balanced charge **6** within the annulus **7**. The charge may be of any lengthwise explosive distribution, but a good first approximation for cylinders is that depicted schematically at **6**. That is, a larger quantity of explosive per length is provided at the top than at the center, and more at the top than the bottom with a gradual tapering therebetween; for the energy transmitting medium dissipates to some extent at the top and bottom, requiring larger amounts of explosive at these portions. Detonating equipment generally indicated at **3** is provided. Charge **6** is then detonated and a pressure wave is initiated through the liquid **5** impacting the annulus **7** and resulting in high strain rate forming. The annulus becomes expanded to some annular shape as indicated generally at *7a*.

The shape of expanded annulus *7a* depends upon the explosive charge distribution per length of annular charge **6**. For example, if charge **6** were uniformly distributed with equal quantities of explosive for every portion of its length (i.e., a cylindrical charge), then the shock wave transmitted on detonation would produce a larger expansion of annulus **7** at the center portions than at the top portions since annulus **7** is open-ended and the pressure transmitting medium **5** would be dissipated largely through the top by the explosion. This would result in a lesser impact and expansion against the uppermost portions of the annulus as against the lower portions resulting in a vessel with a center bulge. To compensate for this non-symmetry (when the vessel to be formed is a cylinder) the lengthwise charge distribution is varied. Placing a larger quantity of charge at the uppermost portions near the open end of the annulus as shown at **6** will somewhat compensate and cause additional expansive force at the top; similarly, on the bottom some of the pressure transmitting medium is dissipated via the open-ended bottom (although not as much as is dissipated at the top end) and additional charge may also be placed at the lower portions. For vessels other than cylinders the first charge **6** may have other shapes; although, any first charge distribution may be used without departing from the scope of the invention.

After detonation expanded annulus *7a* is compared with the predetermined annular vessel to be fabricated **8**. If the vessels are identical, then the balanced charge is that which caused the expansion. If expanded annulus *7a* deviates from predetermined vessel **8**, as shown in FIG. 1 by the lines *7a* and **8**, a new charge **9** of FIG. 2 is constructed from the distribution of charge **6** by adding explosive quantities uniformly in all radial directions perpendicular to its axis to those portions, if any, along

its length corresponding in height to those portions of exploded annulus 7*a* that are smaller in diameter than predetermined annulus 8, and by deleting explosive quantities uniformly in all radial directions perpendicular to its axis from those portions, if any, along its length corresponding in height to those portions of exploded annulus 7*a* that are larger in diameter than annulus 8. The amount of explosive to be added or deleted is estimated by keeping in mind that the greater the difference between corresponding portions of the exploded annulus and the predetermined annulus, the larger the amount of explosive to be added or subtracted to the corresponding portions of the charge, and that for equal expansion more explosive is required at the ends than toward the central portions with more required at the open top end than at the bottom. Charge 9 is then positioned axially within annulus 7 and annulus 7 is filled with liquid medium 5 as before. The charge is then detonated and newly formed expanded vessel 7*b* is compared with predetermined vessel 8. The expansion caused by the last formed charge 9 will produce an expansion more closely resembling predetermined vessel 8 than the prior explosive of FIG. 1.

Reference is now made to FIG. 3. The procedure described above is repeated: A new charge 10 is formed in accordance with the deviations of the last exploded annulus 7*b* from the predetermined vessel 8; the new charge is inserted into another identical annulus 7; the annulus is filled with medium 5; the charge is detonated. The new exploded annulus 7*c* is then compared with the desired end product, vessel 8, and if identical, as illustrated in FIGURE 3, charge 10 is the balanced charge. If the exploded annulus deviates from predetermined vessel 8, the procedures above are repeated until a final charge is developed which causes the exploded annulus to be identical to the desired vessel 8. The last charge causing the desired end product is the balanced charge, and it may be reproduced in quantity for the fabrication of annuli 8 from annuli 7.

It has been found in practice that this procedure produces very accurate expansions in a few trails. The inherent nature of this method may be likened to a mathematical series which converges strongly and rapidly. Three cycles have been shown in the description for illustrative purposes only, it being noted that the number of cycles may be greater or fewer by any number.

This method and apparatus may be used to explosively expand successive annular vessel layers into one another with a predetermined amonut of stress being developed in the outer layers thereby controlling distortion and expansion in the outer layers. Single layer vessels may be expanded into larger diameter vessels to produce multilayer vessels although the larger diameter vessels are not of sufficient thickness or strength to act as dies with respect to the vessel to be exploded. Other advantages along these lines, are apparent.

Furthermore, it will be understood that various changes in details, steps, arrangements of structure, for different materials and shapes from that described above may be made by those skilled in the art to which this invention pertains within the principle and scope of the invention as expressed in the appended claims.

What is claimed is:

1. A method for fabricating a predetermined cylindrical vessel from a first open-ended cylindrical vessel of length greater than its diameter comprising the steps of:

supporting the first cylindrical vessel upright on a surface;

filling the first cylindrical vessel with an energy transmitting medium;

fabricating a cylindrical charge of length substantially equal to the length of the first cylindrical vessel by disposing progressively increasing quantities of explosive therein in the lengthwise direction from the center of the charge approaching the ends;

disposing the charge axially and entirely within the first cylindrical vessel; and

detonating the charge from one end to develop a shock wave of high kinetic energy in the energy transmitting medium so that a rapid strain is imparted to the first cylindrical vessel, the progressively increasing quantities of explosive sufficient to cause the first cylindrical vessel to expand uniformly so as to become the expanded predetermined cylindrical vessel.

2. The method of claim 1 wherein the charge comprises a solid cylindrical core and a layer of explosive material covering the periphery of the core, said layer comprising the progressively increasing quantities of explosive.

3. The method of claim 2 wherein the layer of explosive material is sheet explosive wrapped about the core having perforations therein.

4. A process for fabricating an open-ended multi-layer cylindrical vessel comprising the steps of:

(1) supporting a first open-ended cylindrical vessel having a length greater than its diameter upright on a surface;

(2) filling the first cylindrical vessel with an energy transmitting medium;

(3) fabricating a cylindrical charge of length substantially equal to the length of the first cylindrical vessel by disposing progressively increasing quantities of explosive therein in the lengthwise direction from the center of the charge approaching the ends;

(4) disposing the charge axially and entirely within the first cylindrical vessel; and

(5) detonating the charge from one end to develop a shock wave of high kinetic energy in the energy transmitting medium so that a rapid strain is imparted to the first cylindrical vessel, the progressively increasing quantities of explosive sufficient to cause the first cylindrical vessel to expand uniformly so as to become a predetermined expanded cylindrical vessel;

(6) positioning a second open-ended cylindrical vessel substantially identical to said first cylindrical vessel concentrically within the expanded cylindrical vessel;

(7) expanding the second cylindrical vessel into engagement with the expanded first cylindrical vessel by the process of steps 2 through 5; and

(8) repeatedly fabricating expanded open-ended cylindrical layers from additional vessels substantially identical to said first cylindrical vessel by the steps of 6 and 7 until a multi-layer vessel of desired thickness is formed.

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