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EXPLOSIVE EXPANSION OF TUBES INTO TUBE SHEETS

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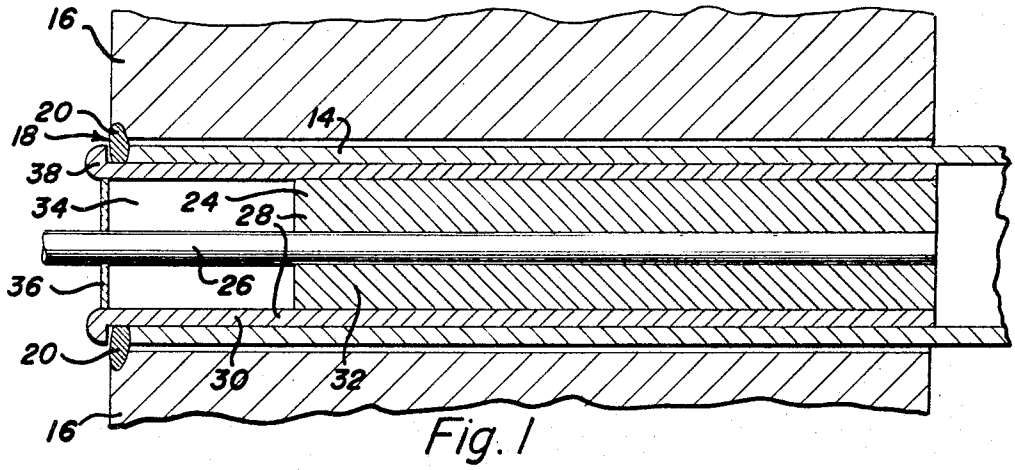


Fig. 1

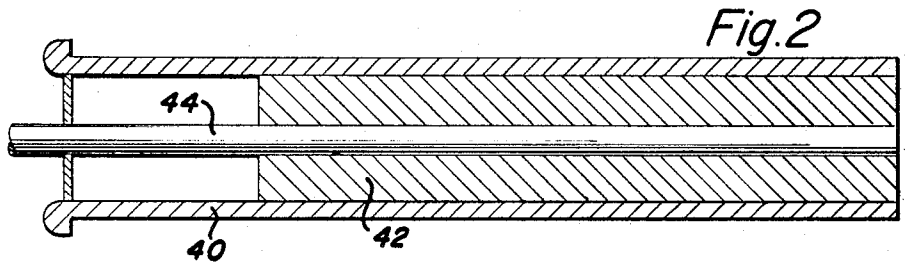


Fig. 2

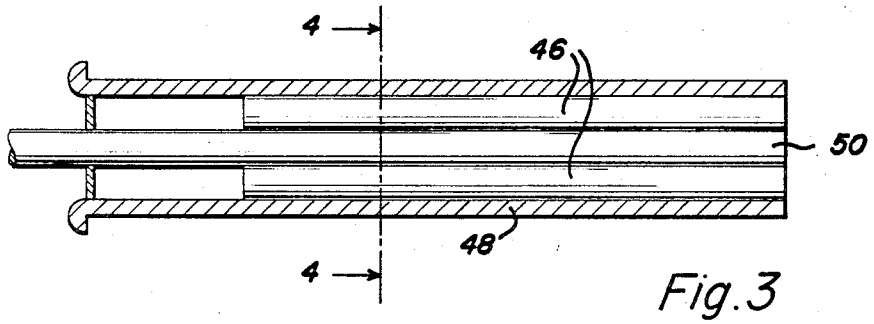


Fig. 3

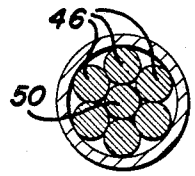


Fig. 4

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EXPLOSIVE EXPANSION OF TUBES INTO TUBE SHEETS

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ABSTRACT OF THE DISCLOSURE

Tubes expanded into tube sheets by cartridge in plastic insert spaced from tube sheet to form an air gap.

This invention relates to a novel method and apparatus for explosive expansion of tubes into a tube sheet.

The concept of expansion of tubes into a tube sheet is not new. For low pressure use, tubes have been mechanically expanded within tube sheet holes and frequently this is all that is needed to hold the tubes within the tube sheet. Frequently, circular or longitudinal grooves are made in the hole walls and the tubes are expanded into the grooves to obtain a more effective grip on them. In high pressure work, it is customary to weld the tube ends to the tube sheet, and then expand the tubes in the area of overlap, between the tubes and tube sheet, for the purpose of avoiding crevices in which corrosive materials can lodge.

At the present time, most of the expansion of tubes into a tube sheet is accomplished by rolling, with the rolls applying an outward radial force against the inside surface of the tubes. Rolling has a number of disadvantages, a primary one being the expense of the process and apparatus used for rolling. In addition, rolling tends to cause a local metal deformation with extrusion of the metal lengthwise of the tube, and general lengthening of the tube, perhaps .02 inch per inch. If the tubes are welded to the tube sheet, this has the disadvantatge of applying an axial stress on the tube weld. In addition, the large direct compressive forces experienced in tube rolling cause severe compressive strains in the tube wall.

Explosive forming of one metal against another has been done. As the expansion forces from explosive forming are applied uniformly throughout the expanded area of the metal, there is no localized compression of the metal and consequent lengthening. In these prior efforts of explosive forming, water has been one force transmitting medium, and wax another. Despite the substantial advantages of explosive forming, severe disadvantages were experienced with both these transmitting media, particularly in efforts at tube expansion, which prevented strong commercial acceptability of the process. Water is a difficult medium to handle, and the expansion must be carried out with the tubes in a vertically oriented position. Wax has many disadvantages, one being that it is not sufficiently deformable or bendable to use in close quarters. In addition, following explosive expansion, the wax adheres to the metal presenting a cleaning problem. Other disadvantages with these media have been experienced.

The present invention overcomes these disadvantages, and offers an improved procedure particularly for explosive expansion of tubes into a tube sheet which promises to make the process commercially desirable.

In accordance with the invention, the tubes to be expanded extend through the tube sheet and have one end adjacent a surface of the tube sheet, which end may or may not be welded or brazed to the tube sheet. The tube sheet also may be provided with circular grooves into which the tubes are expanded. A tube explosive insert is

used which has a length dimension less than but approximately equal to the thickness of the tube sheet. The insert comprises a center axial portion along its length dimension which contains a predetermined number of grains of explosive uniformly disposed therein, and an annular tubular force transmitting portion encompassing the center portion made of a thermoplastic hardenable resin of the class consisting of polyethylene, and resins having essentially the same flexibility, formability, resiliency, density and at least about as high a melting point as polyethylene. The annular portion makes a close fit with the inside of the tube, and the insert is positioned within the tube so that the length dimension is coextensive with a major part of the area of overlap between the tube and the tube sheet. The center portion is detonated, with the annular portion acting as a force transmitting medium, transmitting the explosixe force radially, and uniformly, to the tube.

The advantages of the invention over conventional mechanical and hydro-forming are numerous. For instance, with respect to hydro-forming, the force or pressure developed by the explosion is dissipated, the extent depending upon the particular medium, axially along the tube. In the kinetic expansion of the invention, all of the energy of the explosion is transmitted radially through the polyethylene transmitting medium, and the energy lost in the polyethylene medium is minimal. A particular disadvantage with mechanical forming is that the expansion does not necessarily conform to surface variations in the wall of the tube sheet with obvious adverse consequences. This disadvantage is fully overcome in the use of the kinetic expansion of the invention.

Following expansion of the tubes, the plastically expanded explosive inserts contract to their original shape and are easy to remove. In the case of expansion of U-tube bundles into a tube sheet, compressed air within the tubes force the inserts from the tube ends.

The advantages and the invention will become apparent upon the consideration of the following specification, and accompanying drawings, in which

FIGURE 1 is a partial section view illustrating the concepts of the invention;

FIGURE 2 illustrates an embodiment in accordance with the invention;

FIGURE 3 illustrates a further embodiment in accordance with the invention; and

FIGURE 4 is a section view taken on line **4—4** of FIG. 3.

Referring to the drawings, a tube **14** extends through a tube sheet **16**, and an end **18** of the tube is welded to one surface of the tube sheet, by weld **20**. The tube sheet can be carbon steel, or can be cladded with a nickel alloy or stainless steel and the tubes can be carbon steel, or an alloy such as copper-nickel or Monel. Generally the tube is inserted within the tube sheet with an annular clearance of .006 inch, plus or minus. For feedwater heater use, the tubes may be carbon steel, stainless steel, copper-nickel, Monel and others and may range from ¾ inch to ⅝ inch in diameter, although other dimensions or materials can be used. Typical tube thicknesses are 0.108 inch for carbon steel, and 0.067 inch for Monel. Grooves (not shown) in the tube sheet wall or may not be used.

An insert **24** has an external diameter by which it can be inserted within the tube, and a length so that when it is positioned within the tube, the insert is substantially coextensive with the area of overlap between the tube and tube sheet. In essence, the insert comprises a central axial portion **26** which contains a predetermined number of grains of explosive, generally from 25 grains per foot to 40 grains per foot, uniformly disposed along the insert axis. "Primacord" is a known material which can be used, consisting of grains of explosive embedded

in a fiber or plastic body. The Primacord can be manufactured in any desired diameter, within limits, simply by varying the ratio of carrier material to grains of explosive. Charge concentrations as low as 4 grains per foot can be obtained.

Encompassing the axial portion, an annular tubular force transmitting portion **28** occupies the space between the center portion and the tube inside surface. In practice, the annular force transmitting portion is extruded with the center portion and the portions are then cut to desired insert lengths. In this instance, the force transmitting portion includes an outer layer **30**, and an inner layer **32** of lesser length.

The purpose of this is to provide an air gap **34**, usually less than an inch in axial length, around the explosive in the area of the tube to tube sheet weld **20** (in the case of welded connections) or within about an inch of the tube sheet surface adjacent the tube free end (in the case of non-welded tubes). In addition, a lesser charge concentration, for instance four grains per foot may be used in the area of the air gap connected to the higher charge concentration further from the tube sheet surface, although wtih the air gap shown, the concentration of 25 grains per foot can be extended the full length of the insert. Essentially, the air gap reduces expansion of the weld connection, or application of an excessive force to the tube free end. Air is a poor transmitting medium, and the force is dissipated outwardly against a thin cap **36** of the insert, the cap holding the explosive axially relative the tube.

For accurately locating or gauging the extent of the insert within the tube, a shoulder **38** is provided on the insert engaging the tube end, or tube sheet surface. The location of the insert should be such that the explosive extends to within about ⅛ inch to 1/16 inch from the opposite tube sheet surface to avoid rupture of the tube.

A preferred transmitting medium is polyethylene, or another thermoplastic hardenable resin having essentially the same properties as polyethylene. Suitable mediums other than polyethylene are polyvinyl acetals, polyvinyl butyrals, polystyrene, nylon, Teflon, polyester resins, Delrin, Lexan, polypropylene and Tygon. The critical properties of these materials for purposes of the invention are defined as follows:

Flexibility.—The material must be sufficiently flexible so that it holds its shape, i.e., outside and longitudinal dimension, when bent to between approximately 30° and approximately 90°. In the case of feedwater heaters, utilizing a hemispherical head chamber, the outer ring of tube sheet holes are relatively inaccessible, and the inserts must be bent at least 30° for insertion into the tubes. Flexibility or bendability also is important in the case of tube sheet holes adjacent to or contiguous with a partition wtihin the tube sheet channel.

Melting point.—A problem with wax is that it melts following explosion and adheres to the inside surfaces of the tubes. With polyethylene, only a small residue of material is left on the inside surfaces of the tubes, and this residue is easily wire-brushed from the tubes. The plastic should leave no substantial residue, as a large number of tubes usually are involved making cleaning important.

Formability.—The force transmitting medium must be hardenable and capable of being machined or extruded to close tolerances, less than about 1/16 (.060) inch. In this respect, easy insertion within the tubes is a criterion, but the fit with the tubes cannot be too loose. In the case of carbon steel tubes, the insert can make a relatively loose fit with the inside of the tube, up to 1/16 of an inch. However, with harder tube materials, such as copper and nickel, the expansion must be more closely controlled (because of the higher yield point in the tubes and in the tube sheet) requiring tolerances of approximately .010 inch between the insert and the tube inside surface.

Mold shrinkage preferably is small (0.02–0.05 inch per inch) to obtain desired tolerances.

Resiliency.—The insert force transmitting portion expands outwardly against the tube, and somewhat further as the tube expands. It must be capable of withstanding approximately a 20% strain (change in radius per unit radius) without substantial fracture or rupture, and further capable of return to approximately the original dimensions.

Density.—The material requires approximately the density of polyethylene to effectively transmit the explosive force.

Miscellaneous.—The material must be inert with respect to the tube and tube sheet metals, must be generally water and solvent resistant, inflammable, and have other such obvious characteristics. Other requirements for the insert can be made. For instance, with certain materials, the tube sheet is maintained at what is called a "nulductility" temperature, up to perhaps 130° F., the temperature at which transition from ductile to brittle for the metal occurs. In such instances, the insert must maintain its integrity.

As an aspect of the invention polyethylene is a relatively inexpensive material to use.

Example I

In an example in accordance with the invention, ¾ inch carbon steel tubes were explosively expanded into a carbon steel tube sheet. The tube wall thickness was 0.108 inch, and the annular clearance between the tube and tube sheet was about .006 inch. The insert comprised a central axial portion which extended the full length of the insert and on outwardly to a suitable detonating cap, having 25 grains per foot and an outside diameter of .130 inch. The annular tubular force transmitting medium was polyethylene, having an outside diameter of .405 inch. The length of the insert was 11⅝ inches, corresponding to the thickness of the tube sheet, with the polyethylene annular tubular transmitting portion extending to within 1/16 of an inch of the surface of the tube sheet. The tubes were welded to the tube sheet.

No difficulty was experienced with positioning the inserts in the tubes, as the close tolerance inserts fitted easily within the tubes, and were sufficiently flexible for all conditions.

Following expansion, a very thin non-continuous film of polyethylene was observed by microscopic and infra-red examination. This is not serious, but a paper covering could be disposed over the polyethylene without losing flexibility of the insert to avoid even this small film.

No surface distortion of the tube wall was evident, and the tube expanded without overstraining the tube metal. In addition, no distortion of the tube sheet wall was detected. The circumferential strain developed was within the 1.75 to 2% range. No noticeable change in the length of the tube was found.

In the first one inch to 1¼ inches from the welded tube end, the explosive energy transmitted through air created some expansion, but this was greatly reduced in magnitude. The deformation in the tube gradually increased in this area in the direction away from the tube sheet surface and then remained constant in the remaining area of overlap between the tube and tube sheet. This is of importance as it presented no critically work hardened highly stressed portion near the welded tube end, and the tube is correspondingly less susceptible to stress corrosion when subjected to thermal shocks.

In this example, U-tubes were used, oriented horizontally, and it was found that following expansion the inserts shrank to original dimensions and the pressure within the tubes easily forced them from the tubes.

Example II

Two ⅝ inch diameter carbon steel tubes 0.108 inch in thickness were expanded into a four inch thick tube sheet using 25 grains per foot to evaluate the effect of the pressure generated within the tube on the tube. One

tube was plugged and the other tube was fitted with an 80 p.s.i.g. rupture disc. The tubes were adequately expanded. The plugged tube was found self-cleaned by means of the pressure generated in the tube. The rupture disc at the end of the other tube failed, thus indicating a pressure greater than 80 p.s.i.g. Generally 450 lbs./sq. inch is a prescribed limit for ⅝ inch diameter carbon steel tubes, and a similar experiment with 450 lbs./sq. inch rupture disc showed no failure. For a reasonably long tube, the pressure generated in the tube is not excessive.

Example III

A low-ductility A–213–T22 ASTM steel tube sheet was drilled to contact expand two ¾ inch 0.108 inch thick carbon steel tubes by mechanical rolling. One hole of the tube sheet was slotted longitudinally and the other one circumferentially and the tubes were expanded mechanically. There was no damage to the tube sheet. The slots opened up approximately 0.002 inch. No cracks were observed.

In a similar tube sheet with similar slots, tubes were explosively expanded with 25 grains per foot polyethylene inserts and the same results were found.

Example IV

A monel tube ⅝ inch diameter and having a wall thickness of 0.067 inch was explosively expanded into a cast iron sleeve using 25 grains per foot and sufficient tightness of the tube in the sleeve was achieved. No cracks were observed.

Example V

Eight carbon steel tubes were explosively expanded in a tube sheet, some of the holes having circular grooves. The tubes were ⅝ inch in diameter and ten inches long, with a wall thickness of 0.11 inch. A 25 grain per foot polyethylene insert was used. All the tubes were tight. A hydropressure test and pull-out test indicated an effective bond.

The pull-out tests for grooved and ungrooved holes showed 10,000 lbs. and 9,000 lbs. respectively.

Example VI

Four ⅝ inch diameter Monel tubes 0.06 inch in diameter were explosively expanded into a ten inch thick grooved tube sheet.

Pull-out tests on the tubes showed the following readings:

	Lbs.
Tube #1	6,150
Tube #2	5,400
Tube #3	8,150
Tube #4	7,400

These tubes were simultaneously expanded by means of a 25 grain per foot polyethylene insert.

In the embodiment of FIG. 2, the insert comprises a single outer force transmitting layer **40**, encompassing a primary tubular charge layer **42** having 25 grains per foot. The latter is provided with an axial connection **44** having a relative low charge of four grains per foot extending from the insert.

In FIGS. 3 and 4, a plurality or array of charge lengths **46**, each having about four grains per foot, is encompassed by force transmitting layer **48**, the connection **50** making up the axial charge length. In the embodiments of FIGS. 2–4, the inserts are conveniently manufactured and cut into suitable lengths. In both embodiments, advantages reside in the reduced noise level of the explosive, and reduced explosive effect on the tube free end.

Although the invention has been described with reference to particular embodiments, variations within the spirit and scope of the invention will be apparent to those skilled in the art.

What is claimed is:

1. Apparatus for expanding a tube within a tube sheet wherein the tube extends through the tube sheet and one end thereof is adjacent to one surface of the tube sheet, comprising

an insert which includes a length dimension approximately equal to the thickness of the tube sheet;

the insert comprising a center axial portion along said length dimension including a predetermined number of grains of explosive uniformly disposed therealong;

an annular tubular force transmitting portion encompassing the center portion;

the annular portion being a thermoplastic hardenable resin of the class consisting of polyethylene, and resins having essentially the same flexibility, formability, resiliency, density, and at least about as high a melting point as polyethylene;

the annular portion further being formed to make a close fit with the inside of the tube;

means to position the insert within the tube whereby the length dimension thereof is coextensive with a major portion of the area of overlap between the tube and tube sheet.

2. Apparatus for expanding tubes into a tube sheet comprising

an insert; the insert comprising a center axial portion including a predetermined number of grains of explosive uniformly disposed along the axis of the insert;

an annular tubular force transmitting portion encompassing the center portion;

the annular portion being a thermoplastic hardenable resin of the class consisting of polyethylene, and resins having essentially the same flexibility, formability, resiliency, density, and at least about as high a melting point as polyethylene;

the annular portion being formed to make a close fit with the inside of the tube;

means to position the insert within the tube whereby the length thereof is coextensive with a major portion of the area of overlap betwen the tube and tube sheet.

3. A method for expanding tubes into a tube sheet comprising the steps of

positioning the tube within a tube sheet hole to define an area of overlap between the tube sheet and tube;

positioning a cylindrical explosive insert within the tube and gauging the insertion wherein the insert is coextensive with a major portion of the area of overlap;

the explosive insert including a center axial portion comprising a predetermined number of grains of explosive uniformly disposed along the axis of the insert, and an annular tubular force transmitting portion between the center portion and tube inside surface;

the insert outside surface defining a close fit with the inside surface of the tube;

the annular portion being a thermoplastic hardenable resin of the class consisting of polyethylene, and resins having essentially the same flexibility, formability, resiliency, density, and at least about as high a melting point as polyethylene.

4. The method of claim **3**, including the step of maintaining an air gap between the center axial portion and the annular force transmitting portion, to reduce the effect of the explosive in the area adjacent the free end of the tube and contiguous tube sheet surface; and wherein the flexibility of the insert force transmitting portion is sufficient to permit bending the insert 30–90° along its length, wherein the formability thereof is such that the insert can be formed to outside dimension tolerances of equal to or less than about .060 inch, wherein the force transmitting portion is capable of withstanding about a 29% strain, and wherein the density and melting point of the force transmitting are at least about those of polyethylene.

5. An insert for expanding tubes into a tube sheet comprising

a center axial portion including a predetermined number of grains of explosive disposed along the axis of the insert;

an annular tubular force transmitting portion encompassing the center portion;

the annular portion being a thermoplastic hardenable resin of the class consisting of polyethylene, and resins having essentially the same flexibility, formability, resiliency, density, and at least about as high a melting point as polyethylene;

the annular portion being formed to make a close fit with the inside of the tube;

means to position the insert within the tube whereby the length thereof is coextensive with a major portion of the area of overlap between the tube and tube sheet; and

means to reduce the effect of the explosive in the area adjacent the free end of the tube and contiguous tube sheet surface.

6. The insert of claim 5 including an air gap between the center axial portion and annular force transmitting portion in said area adjacent the tube free end; and

a washer-like cap covering said air gap including a central operative axially holding the center axial portion as it protrudes beyond the tubular force transmitting portion, the center axial portion being suitably connected to effect the explosion thereof.

7. The insert of claim 6 wherein said center axial portion further includes a reduced number of grains of explosive in said area adjacent the tube free end.

8. The insert of claim 5 wherein the center axial portion comprises a connecting length of explosive having approximately 4 grains of explosive per foot, and encompassing said length, an amount of explosive having approximately 25 grains per foot substantially uniformly disposed around said connecting length.

9. The insert of claim 8 wherein said amount of explosive is in layer form.

10. The insert of claim 8 wherein said amount of explosive is in the form of an array of lengths, uniformly disposed around the connecting length.

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