

Oct. 27, 1970

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3,535,767

METHOD FOR JOINING METALLIC TUBES BY EXPLOSIVE BONDING

Filed Aug. 19, 1965

2 Sheets-Sheet 1

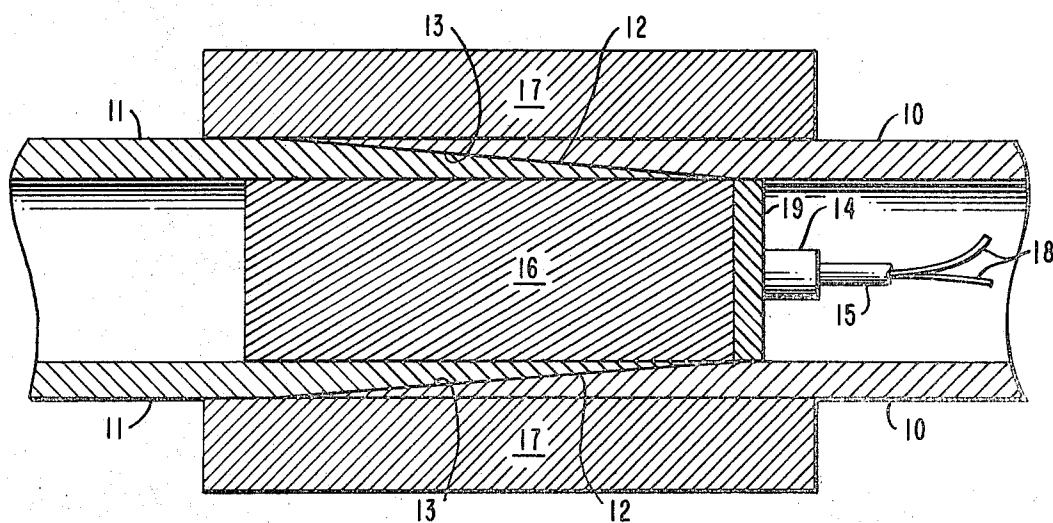


FIG. - 1

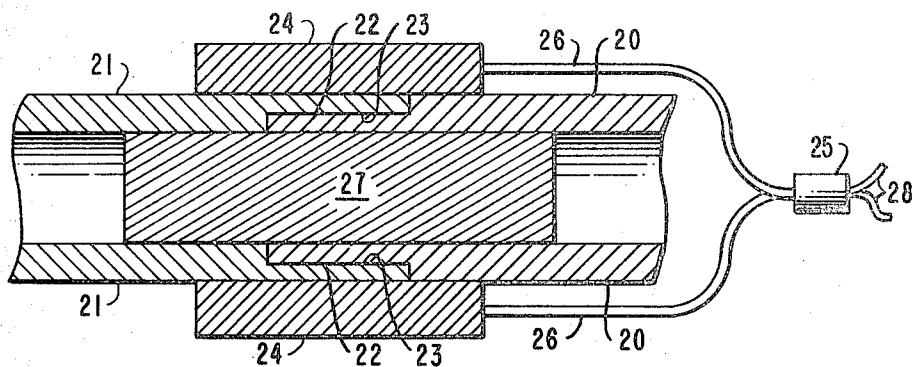


FIG. - 2

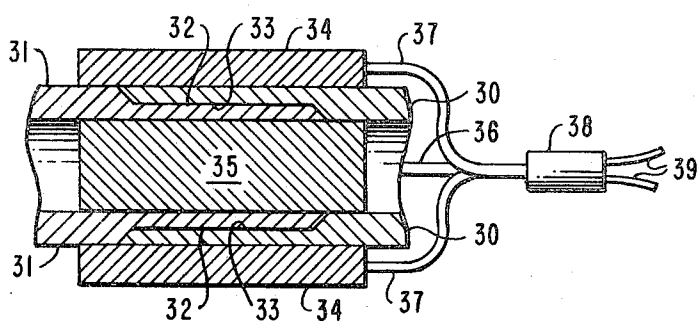


FIG. - 3

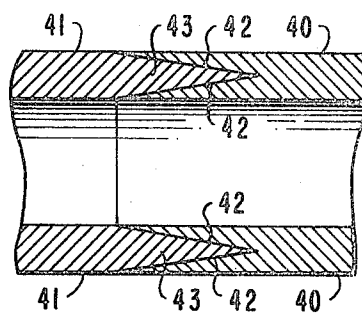


FIG. - 4

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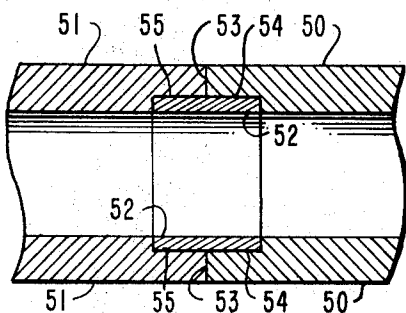


FIG. - 5

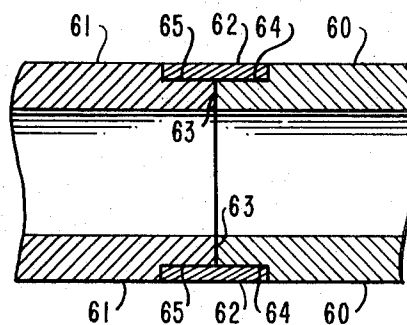


FIG. - 6

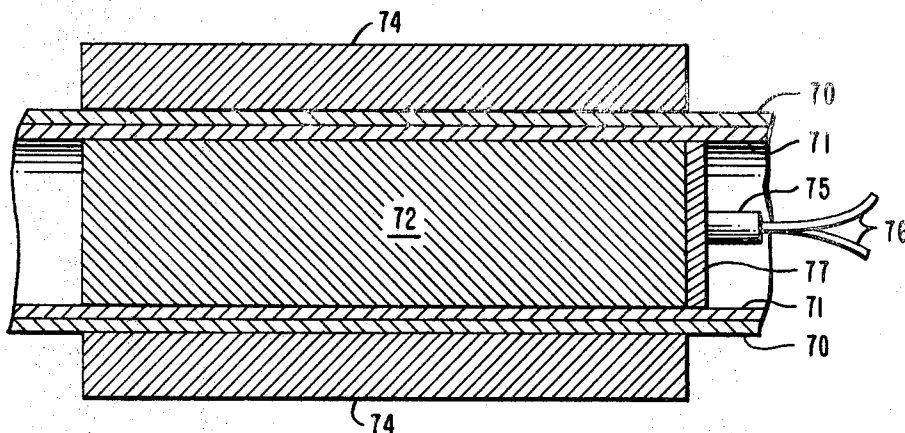


FIG. - 7

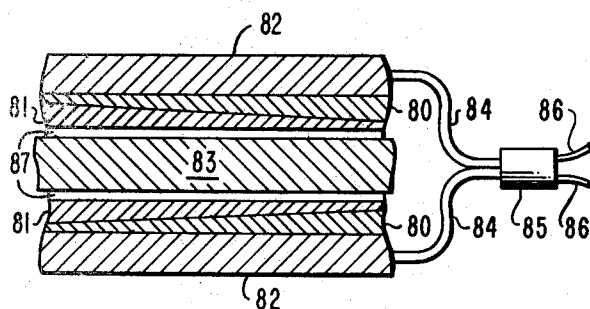


FIG. - 8

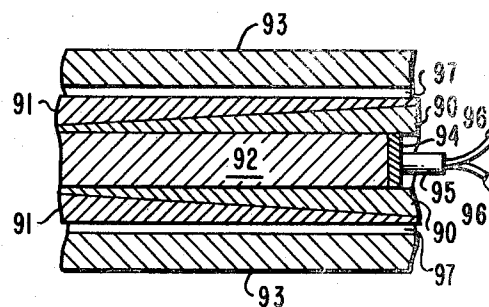


FIG. - 9

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METHOD FOR JOINING METALLIC TUBES BY EXPLOSIVE BONDING

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Filed Aug. 19, 1965, Ser. No. 481,023

Int. Cl. B23k 21/00

U.S. Cl. 29—470.1

9 Claims

ABSTRACT OF THE DISCLOSURE

This disclosure concerns a method of bonding or welding metallic tubes together, wherein the end portions of the tubes are so shaped as to be initially disposed in mating intimately contacting relation to each other over a prescribed area, and an explosive charge in proximity to the area of intimately contacting engagement between the tubes is detonated. Detonation of the explosive charge releases explosive energy in the form of a shock wave which is directed to the area of intimately contacting engagement between the tubes and causes the tubes to be joined together by a bond or weld along this area.

This invention relates generally to bonding the ends of metal tubes to one another, and more particularly to such articles for use in cryogenic environments and a method and apparatus for the manufacture thereof.

In the prior art, when a section of tubing must be added to an existing section, the ends of the two tubing sections have been butted together and the abutted ends brazed or welded by heat using electrical resistance welding techniques. These prior art techniques are both time consuming and inefficient. Furthermore, if the section to be added is not of the same metal as that to which it is added, great complication develops because of the differences between the two different metals in melting points, plasticization and other characteristics.

Moreover, in the case where joined metal tubes are to carry cryogenic materials, or are disposed in exceptionally low temperature environments, the manner of joining the tubes is especially critical. Where the materials of the different tubes and the weldment are identical, there is still formed what is termed a heat-affected zone that is structurally weaker than the tubes themselves at very low temperatures, particularly when exposed to vibrations and shocks. This condition is further aggravated where tubes of different metals are joined in that not only are the specific heats usually different, producing a considerable heat-affected zone, but also there may be no satisfactory weld material for satisfactorily joining a specified set of metals.

According to the invention, a variety of end configurations of the pipe or tubing ends to be joined together may be employed. The ends of the pipes or tubes to be joined have male and female end configurations so as to mate together in intimate contact. The configuration of the ends may be angled to form cones, or flares, of a shallow or steep angle; they may be offset in appropriately matched steps; they may be joined by an external collar in an undercut portion of the outside diameter, or they may be joined upon an internal collar fitted into an undercut on the inside diameter. Furthermore, the joined ends may be of the same metal or of different metals as may be the case with cryogenic containers, tubings or vessels, or for other uses.

However the ends may be configured for the junction thereof according to this invention, the fusion or bonding of the ends being joined is accomplished generally by the utilization of the force provided by detonation of an explosive charge located either external to, or within the

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confines of the interior of the tubing members being joined.

The inner or outer surfaces of the pipe or tubing over the area to be joined is so constrained that the detonation force is confined to the area being joined. This is accomplished by providing the parts with an external force collar or internal mandrel to withstand the explosive force of the shock wave generated by the detonation of the explosive charge. If the explosion occurs outside the structure, an inner mandrel is used to take up the effects of the inwardly directed force. If the explosive force originates within the tubing, then an outer restraining collar or die is provided to take up the outwardly directed force and to provide a forming guide to the pipe ends being joined.

Accordingly, it is an object of this invention to provide a tubular metal article having a bonded joint between two sections thereof, wherein the tubular metal article is suitable for use at cryogenic temperatures.

Another object is the provision of a tubular, article formed by bonding at least a pair of tubes to one another, wherein bonding is accomplished without resort to intermediary welding materials.

Still another object is the provision of a tube-to-tube bonded article, wherein portions of the tubes are configured so as to be mutually fit together with the contacting surfaces thereof being directly joined by surface alloying effected through the medium of an explosive force.

It is another object of this invention to provide a method for the explosive joining together of the ends of tubing sections, wherein an explosive charge is placed within or outside of the area of the tubing section to be joined and an appropriate restraining means is provided in or about the tubing sections opposite the location of the explosive charge.

It is a further object of this invention to provide explosive welding means and a method for the joining of the ends of tubing sections of either similar or dissimilar metals.

It is a still further object of this invention to provide means for explosively welding together the abutting ends of tubing members, the abutting ends being configured in complementary forms so as to interfit with one another.

These and further objects of the invention will be more clearly understood from the specification which follows, when taken together with the accompanying drawings and in the light of the appended claims. It should be clearly understood that the illustrative examples shown in the figures are representative of the manner in which the invention can be implemented and should not be construed as limiting the invention to the specific embodiments shown, since in accordance with the teachings herein, those skilled in the art to which the invention appertains will be able to devise other embodiments and applications thereof within the ambit of the appended claims.

In the drawings:

FIG. 1 is a longitudinal sectional view of two sections of tubing, or pipe, showing one form of interfitting pattern and with a constraining die therearound, and an explosive charge device in the center;

FIG. 2 is a longitudinal typical junction between two sections of pipe or tubing being joined by the technique of this invention showing another interfitting pattern therebetween, wherein the explosive charge means surrounds the pipe sections, and a central mandrel forms the die;

FIG. 3 is a longitudinal sectional view of a further embodiment, wherein another interfitting pattern is employed between two pipe or tubing ends being joined and

explosive charge devices are used both internally and externally;

FIG. 4 is a longitudinal sectional view of a pair of pipe or tubing ends prepared for joining by the techniques of this invention, wherein a predetermined male and female mating configuration is used on the ends of the respective pipes or tubes being joined;

FIG. 5 is a longitudinal sectional view of sections of pipe prepared for joining by the techniques of this invention, wherein an internal cylinder interfits with the interiorly undercut ends of the pipes to be joined;

FIG. 6 is a longitudinal sectional view of pipes similar to that of FIG. 5, wherein the cylinder is external to the pipes and the undercut is on the exterior peripheries of the pipe;

FIG. 7 is a longitudinal sectional view of an arrangement of inner and outer pipes being joined, employing means similar to that shown in FIG. 1;

FIG. 8 is a longitudinal sectional view of pipes being joined to show a further employment of the technique of the invention utilizing means shown in FIG. 2; and

FIG. 9 is a longitudinal sectional view of pipes similar to that in FIG. 8, wherein the technique shown in FIG. 1 is employed to join the pipes.

In the illustrations hereinabove listed, any combination of elements that is shown in any particular figure may be rearranged to incorporate similar elements from any other of the figures and still be within the spirit of the invention. That is, appropriate combinations of internal, external or both internal and external explosive charge elements, or combinations of explosive charge elements with an inner mandrel, or external die elements may be used in any combination as desired or required by selecting appropriate groups from the different figures.

With reference to FIG. 1, it may be seen that a typical pair of pipe ends 10, 11 have been machined so that the end of pipe 10 tapers outwardly from the inner diameter to the outer diameter thereof to form a female member as indicated at 12, and the end of pipe 11 tapers oppositely as shown at 13 to form a male member so that the ends 12 and 13 can be interfitted as illustrated. The angle of the tapered ends 12 and 13 may be small, as shown, or may be larger, thereby using a shorter length of the pipes being joined. The angles of the female end 12 and male end 13 are matched to insure a direct, flush and intimate contacting relationship between the metal tapering surfaces.

About the outer portions of the pipes 10, 11 in the region of the tapered junctions 12, 13, there is provided a supporting element 17, and concentrically therewith within the pipes, an explosive charge 16 is disposed. There is also provided a booster 19, a cord explosive 14, an initiator 15 and leads 18 for connection to external detonation means to detonate the charge 16.

Upon detonation of the charge 16, the mating surfaces 12, 13 are subjected to extremely high pressure which causes a true bond to be produced between the contacting surfaces. It can be shown that a bond so produced is relatively free of heat-affected zones and has increased qualities of strength at the extremely low temperatures encountered in conveying liquefied gases, for example.

In FIG. 2, pipe ends 20, 21 are to be joined. Pipe end 20 has its outer diameter undercut as at 23 to form a male member and pipe end 21 has its inner diameter undercut as at 22 to form a female member. Undercuts 22, 23 are so dimensioned as to interfit for an intimate contacting relationship between the male and female members. A mandrel 27 is inserted as a supporting element in the inner diameter of joined pipes 20, 21, which mandrel is of such geometry as to be in even contacting relation to the inner surfaces of the pipes. An explosive charge 24 surrounds the outer diameter of the junction 22, 23 of pipes 20, 21. Plane wave generators 26, initiator 25 and leads 28 for connection to external detonating means serve as means for effecting detonation of the charge 24.

As shown in FIG. 3, the explosive charges may be in-

serted in the interior as at 35 and on the exterior as at 34 of the pipes 30, 31 to be joined. Another interfitting configuration 32, 33 is shown in FIG. 3 that differs from the arrangement of FIG. 1 in having a substantial extent of mating surfaces generally parallel to the peripheral surfaces of the pipes. Respective plane wave generators 36 and 37 are connected to the interior explosive charge 35 and the exterior explosive charge 34, the plane wave generators 36, 37 leading to a common initiator 38 which is connected by leads 39 to an external detonating means such that the exterior and interior explosive charges 34 and 35 may be simultaneously detonated to effect bonding of the mating surfaces 32, 33 of the pipes 30 and 31 together.

Further examples of the preparation of pipe sections for joining in the manner of the invention are shown in FIGS. 4-6. The pipe ends 40, 41 in FIG. 4 include V-groove 42 forming the female member which receives a suitably shaped male portion 43. Any of the explosive elements and mandrel or restraining collar devices shown in the preceding figures and discussed above, can be combined to bond the pipe ends 40, 41 together.

A collar 52, FIG. 5, is fitted into appropriately dimensioned undercuts 54, 55 in the inner surface of tubing sections 50, 51 to be joined. The opposed end surfaces of the tubing sections 50, 51 are in abutting engagement as at 53 along the portions thereof disposed radially outwardly of the collar 52 and the groove defined by the undercuts 54, 55 in which the collar 52 is matingly received. Similarly, in FIG. 6, a collar 62 may be disposed in outer surrounding relationship to pipe ends 60, 61 to be fitted together. The outer diameters of pipes 60, 61 are respectively provided with recesses 64, 65 which define a groove for receiving the collar 62. The opposed end surfaces of the pipes 60, 61 are in abutting engagement as at 63 along the portions thereof disposed radially inwardly of the collar 62 and the groove defined by the recesses 64, 65 in which the collar 62 is matingly received.

Where it is desired to join a pipe of larger diameter 70 to one of smaller diameter 71, as shown in FIG. 7, or where the inner pipe 71 is to be a cladding for the outer pipe 70, or similarly if the outer pipe 70 is to be a cladding for the inner pipe 71, the arrangement shown in FIG. 7 may be employed. While only an inner explosive charge 72 is shown in FIG. 7, an outer explosive charge, such as shown in FIG. 2, or combinations of inner and outer explosive devices, as in FIG. 3, may equally well be used here. As illustrated in FIG. 7, an outer die or collar 74 is provided in the exemplary structure shown. Booster 77, initiator 75, and leads 76 make up the explosive train for actuating the charge 72 and effecting bonding of the pipes.

FIG. 8 shows a pair of end contoured pipes 80, 81 arranged with an explosive charge 82 in surrounding relationship. An undersized mandrel 83 is situated within the tubes 80, 81 to provide a space 87 along at least one side thereof. Detonation actuation means 84, 85 and 86 are provided as in the previously described embodiments.

Similar, FIG. 9 illustrates pipes 90, 91 joined together with an explosive charge 92 contained within. A backstop die 93 is maintained about the outer pipe 91 is slightly spaced relation thereto as at 97. Conventional detonation means 94, 95 and 96 are also supplied.

With reference to all of the figures, the basic concept of the invention is seen to be the preparation of the ends of pipes to be joined into predetermined male and female mating configurations which are brought into full contacting relationship with one another by press fitting, for example. Although full reasons are not known, it is believed that the initial contacting relation has a salutary effect on the explosively formed bond.

The technique of the invention also enables cladding the interior or exterior of pipes with a complementary

metal layer, or of joining pipes of different diameters where the inner diameter of one matches the outer diameter of the other. That is, the form of the invention of FIG. 7 can be utilized for end connection or for the bonding of entire lengths of tubing to each other.

Because the bonding of the invention is accomplished by explosive shock waves and the attendant very high pressures so generated, pipes of the same or dissimilar metals can be joined into an integral unit of great strength. This is believed to be a direct function and result of the application of very high pressures in an extremely short time, as compared to the relatively low melting and fusion achieved by conventional welding methods. It is this feature which is also believed to make metal bonds formed in accordance with the practice of the invention ideal for use in a cryogenic environment. Thus, these bonds do not exhibit the characteristics of a heat-affected area associated with conventional welds.

Implementation of the invention can be accomplished without heavy or complex machinery. No specialized tooling or materials are necessary to support the members being explosively bonded. For example, central mandrels can be made of steel, wood, plastics, rubber, ice, or fluids. Similar materials may also be used for the outer constraining and backstop means. Moreover, explosives may be of the castable types formed into appropriate cylindrical or other shapes as required.

While particular embodiments of the invention have been illustrated and described, it will be understood that the invention should not be construed as being limited thereto, but only to the scope of the claims.

We claim:

1. A method of bonding together a pair of metallic tubing sections comprising the steps of:

securing the metallic tubing sections so that at least portions thereof are disposed in intimately contacting engagement with each other over a prescribed area,

placing an explosive charge with respect to the pair of tubing sections such that the explosive charge is disposed along one side of the prescribed area of intimately contacting engagement between the pair of tubing sections,

placing a supporting die so as to lie along the opposite side of the prescribed area of intimately contacting engagement between the pair of tubing sections in opposed relation to the explosive charge, and

detonating the explosive charge to securely bond the pair of tubing sections together at the prescribed area of intimately contacting engagement therebetween by a shock wave generated by the detonation of the explosive charge and travelling in a direct path across said prescribed area.

2. A method of joining tubular metallic parts together comprising the steps of:

forming portions of the tubular metallic parts for mutually being fitted together in intimately contacting engagement over a prescribed area,

securing the tubular metallic parts so that the formed portions thereof are disposed in intimately contacting engagement with each other over the prescribed area,

mounting an explosive charge in proximity to the prescribed area of intimately contacting engagement between the formed portions of the tubular metallic parts such that a shock wave generated by the explosive energy released by the detonation of the explosive charge will travel across the prescribed area of intimately contacting engagement between the formed portions of the tubular metallic parts in a direct path, and

detonating the explosive charge to effect an intimate bonding relation at the prescribed area of intimately contacting engagement between the formed portions of the tubular metallic parts caused by the passage

of the shock wave generated by the detonation of the explosive charge across said prescribed area.

3. A method of bonding together a pair of metallic tubing sections comprising the steps of:

machining one end of a first of said metallic tubing sections into a predetermined configuration,

machining an end of the other of said metallic tubing sections into a complementary configuration to that of said one end of the first tubing section and of such dimensions as to enable mutual fitting of the pair of tubing sections together with the respective machined ends thereof in an intimately contacting surface engagement,

press-fitting the respective machined ends of the pair of tubing sections together with the respective machined ends being disposed in an intimately contacting surface engagement over a prescribed area,

placing an explosive charge with respect to the pair of tubing sections such that the explosive charge is disposed along one side of the prescribed area of intimately contacting engagement between the press-fit machined ends of the pair of tubing sections,

placing a supporting die so as to lie along the opposite side of the prescribed area of intimately contacting engagement between the press-fit machined ends of the pair of tubing sections in opposed relation to the explosive charge, and

detonating the explosive charge to securely bond the pair of tubing sections together at the prescribed area of intimately contacting engagement between the press-fit machined ends of the pair of tubing sections by a shock wave generated by the detonation of the explosive charge and travelling in a direct path across said prescribed area.

4. A method of bonding together a pair of metallic tubing sections as set forth in claim 3, wherein

the explosive charge is placed on the outer surface of the pair of tubing sections overlying the prescribed area of intimately contacting engagement between the press-fit machined ends of the pair of tubing sections, and

the supporting die is placed within the interior of the pair of tubing sections underlying the prescribed area of intimately contacting engagement between the press-fit machined ends of the pair of tubing sections.

5. A method of bonding together a pair of metallic tubing sections as set forth in claim 3, wherein

the explosive charge is placed within the interior of the pair of tubing sections underlying the prescribed area of intimately contacting engagement between the press-fit machined ends of the pair of tubing sections, and

the supporting die is placed on the outer surface of the pair of tubing sections overlying the prescribed area of intimately contacting engagement between the press-fit machined ends of the pair of tubing sections.

6. A method of bonding together a pair of metallic tubing sections comprising the steps of:

assembling the pair of metallic tubing sections so that at least portions thereof are disposed in intimately contacting engagement with each other over a prescribed area,

placing a first explosive charge on the outer surface of the pair of tubing sections so as to circumferentially overlie the prescribed area of intimately contacting engagement between the portions of the pair of tubing sections,

placing a second explosive charge within the interior of the pair of tubing sections so as to underlie the prescribed area of intimately contacting engagement between the portions of the pair of tubing sections, and

detonating the first and second explosive charges simultaneously to securely bond the pair of tubing sections

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together at the prescribed area of intimately contacting engagement between the portions of the pair of tubing sections by opposing shock waves produced by the simultaneous detonation of the first and second explosive charges which respectively travel in a direct path in opposite directions across said prescribed area.

7. A method of bonding together a pair of metallic tubing sections having respective ends provided with adjoining recesses defining an endless groove extending across the ends of the pair of tubing sections, said method comprising the steps of:

fitting a metallic sleeve within the groove so that a first major surface of the sleeve is disposed in intimately contacting engagement with the surfaces of each of the metallic tubing sections bounding the groove over a prescribed area,

placing an explosive charge with respect to the pair of tubing sections such that the explosive charge is disposed along the first major surface of said sleeve on one side of the prescribed area of intimately contacting engagement between the first major surface of the sleeve and the surfaces of the pair of tubing sections bounding the groove,

supporting the sleeve along its other major surface on the opposite side of the prescribed area of intimately contacting engagement between the first major surface of the sleeve and the surfaces of the pair of tubing sections bounding the groove in opposed relation to the explosive charge, and

detonating the explosive charge to securely bond the sleeve and the pair of tubing sections together at the prescribed area of intimately contacting engagement between the first major surface of the sleeve and the surfaces of the pair of tubing sections bounding the groove by a shock wave generated by the detonation of the explosive charge and traveling in a direct path across said prescribed area.

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8. A method of bonding together a pair of metallic tubing sections as set forth in claim 7, wherein

the sleeve is fitted within the groove so as to extend circumferentially about the pair of tubing sections with its first major surface overlying the surfaces of each of the tubing sections bounding the groove in intimately contacting engagement therewith over the prescribed area, and

the explosive charge is placed within the interior of the pair of tubing sections underlying the prescribed area of intimately contacting engagement between the first major surface of the sleeve and the surfaces of the pair of tubing sections bounding the groove.

9. A method of bonding together a pair of metallic tubing sections as set forth in claim 7, wherein

the sleeve is fitted within the groove so as to extend circumferentially within the pair of tubing sections with its first major surface underlying the surfaces of each of the tubing sections bounding the groove in intimately contacting engagement therewith over the prescribed area, and

the explosive charge is placed on the outer surface of the pair of tubing sections overlying the prescribed area of intimately contacting engagement between the first major surface of the sleeve and the surfaces of the pair of tubing sections bounding the groove.

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U.S. Cl. X.R.

29—421, 497.5