United States Patent [19]

McKinnon, Jr.

[11] **3,737,975**

[45] **June 12, 1973**

[54] **ARRANGEMENT FOR EXPLOSIVELY FORMED CONNECTIONS AND METHOD OF MAKING SUCH CONNECTIONS**

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[21] Appl. No.: **55,154**

[52] **U.S. Cl.** **29/421**, 16/108, 29/517, 52/726, 287/109, 174/94

[51] **Int. Cl.** **B23p 17/00**, B23p 19/00

[58] **Field of Search** ..... 29/203 H, 421 E, 29/517; 174/94 RX; 16/108 X; 287/109 X; 339/275 E, 276 E; 52/726 X

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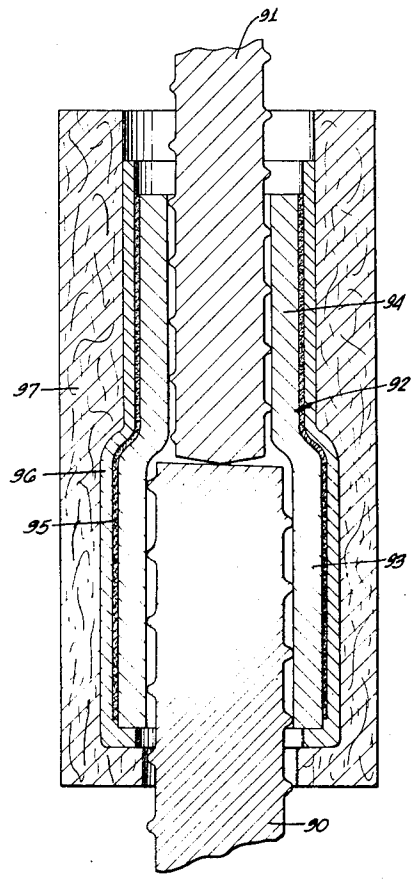
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[57] **ABSTRACT**

An arrangement (method and apparatus) for attaching together ribbed concrete reinforcing bars or the like in which the bar ends are inserted into a sleeve circumscribed by an explosive, such arrangement including means for confining the explosive and a damping material. The assembly is positioned in a protective shield or casing and, upon detonation, completes the joint by deforming the sleeve inwardly to grip the ribs on the bars. Provision can be made to join bars of unequal diameters or to provide for relative movement between the bars after joining.

34 Claims, 17 Drawing Figures



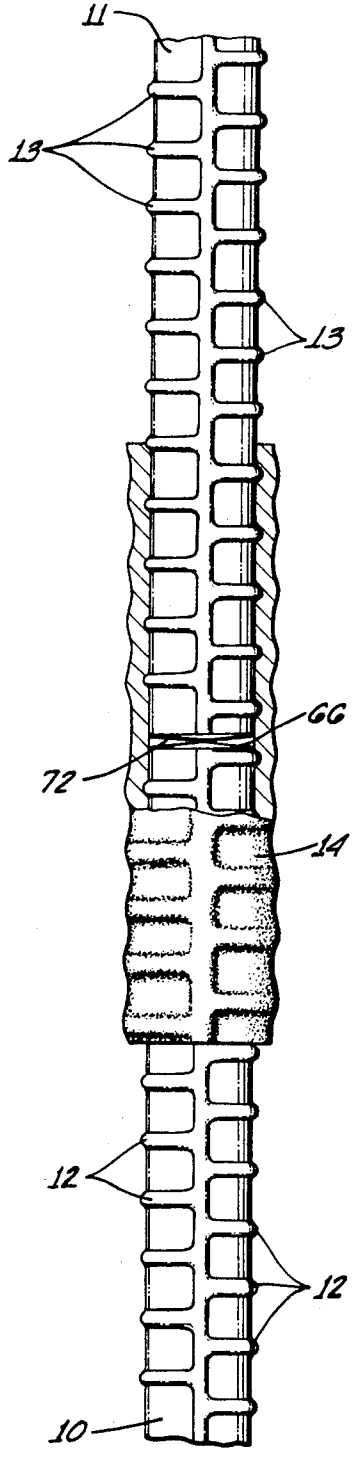


FIG. 1.

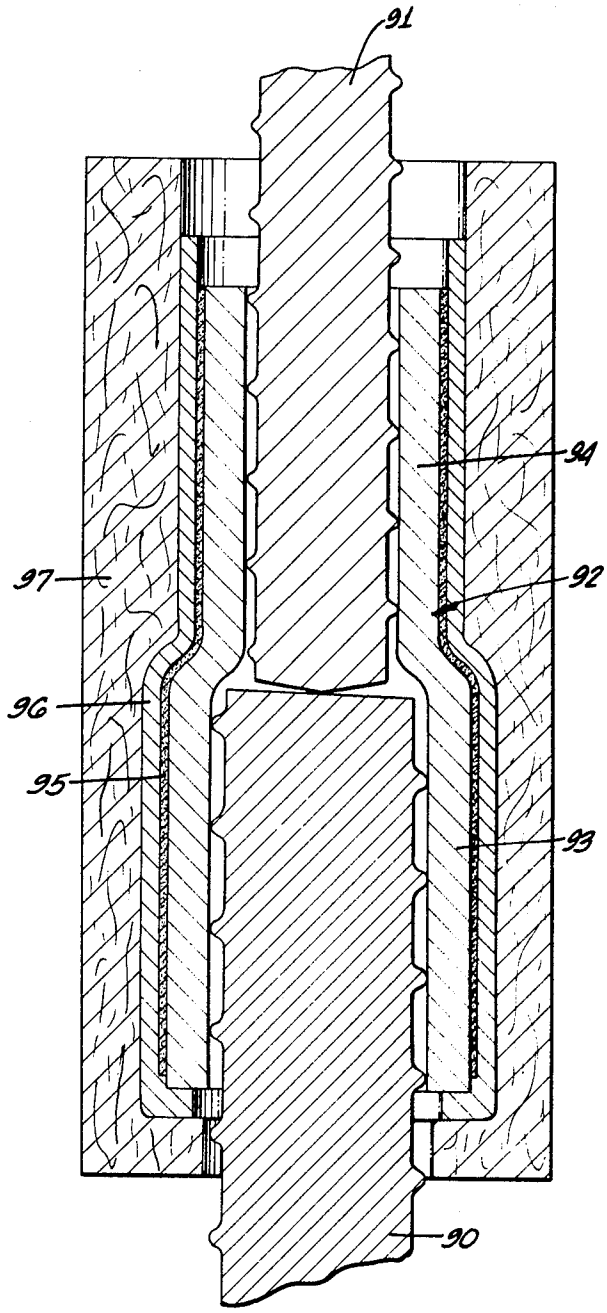


FIG. 10.

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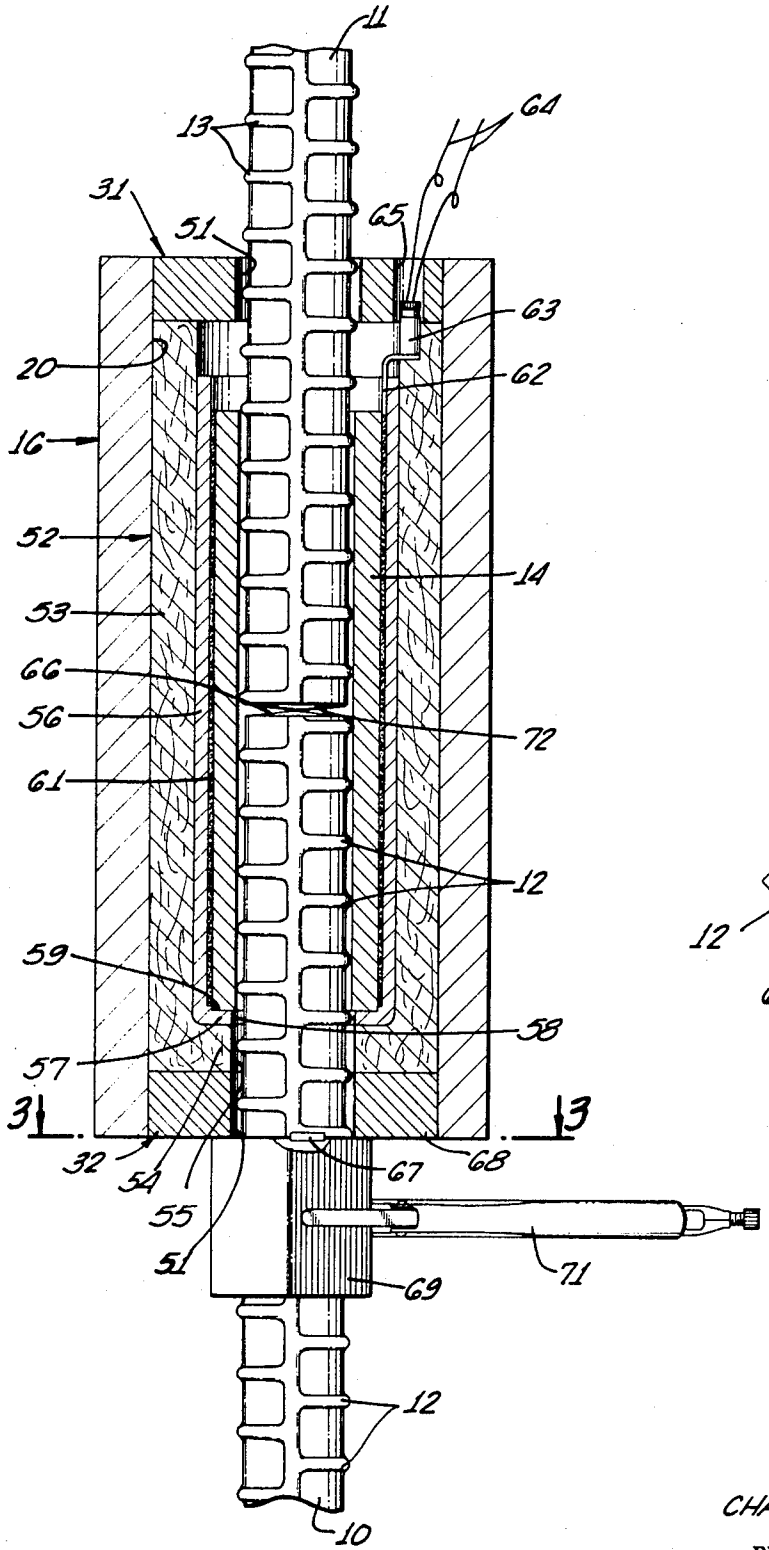


FIG. 2.

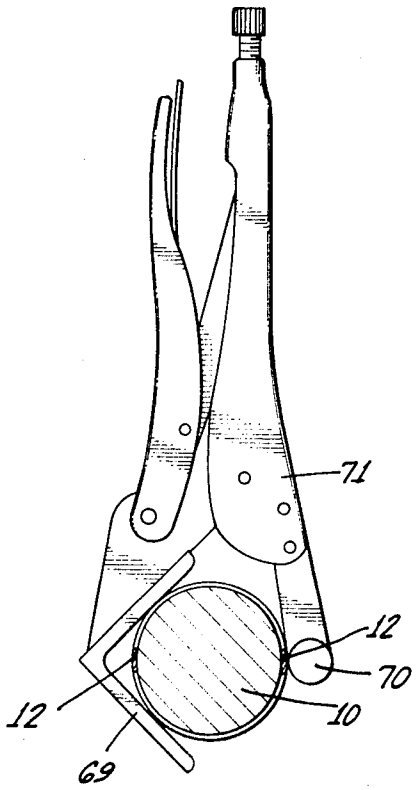


FIG. 3.

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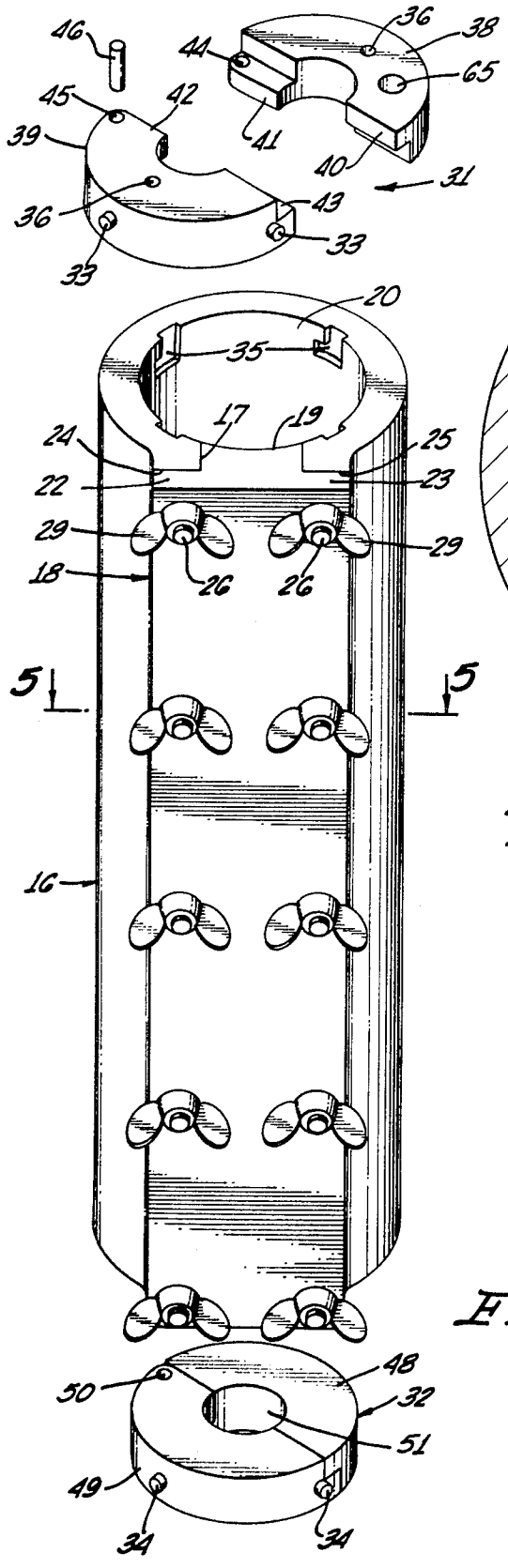


FIG. 4

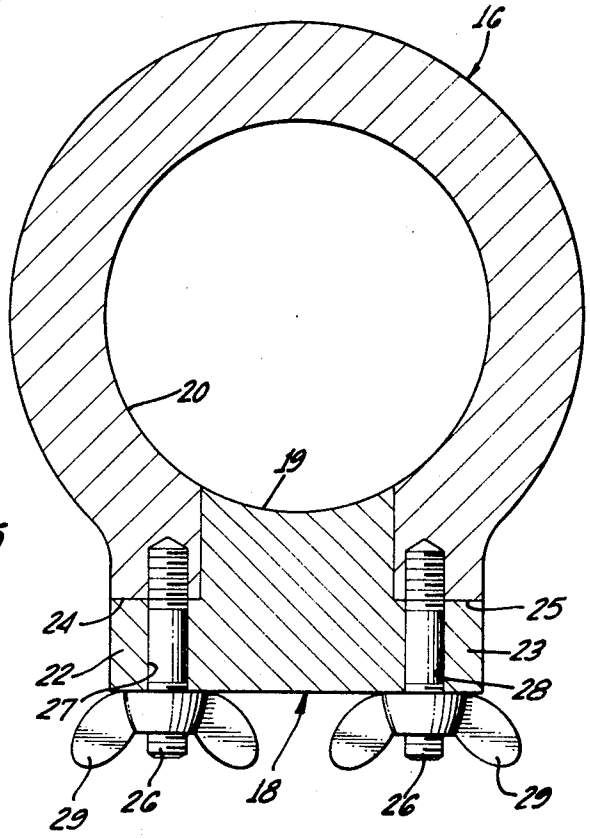


FIG. 5.

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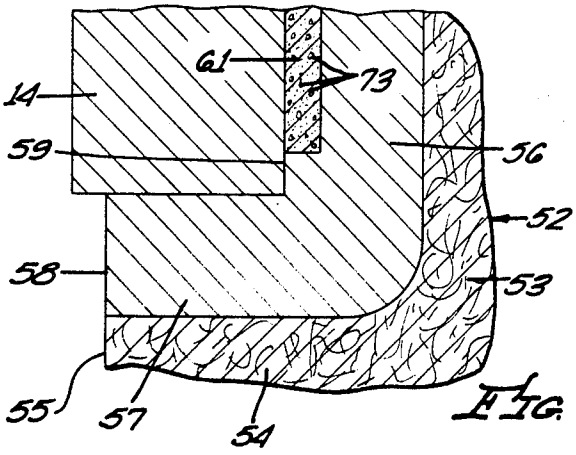


FIG. 6.

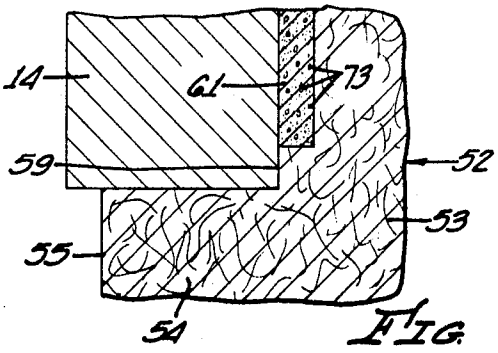
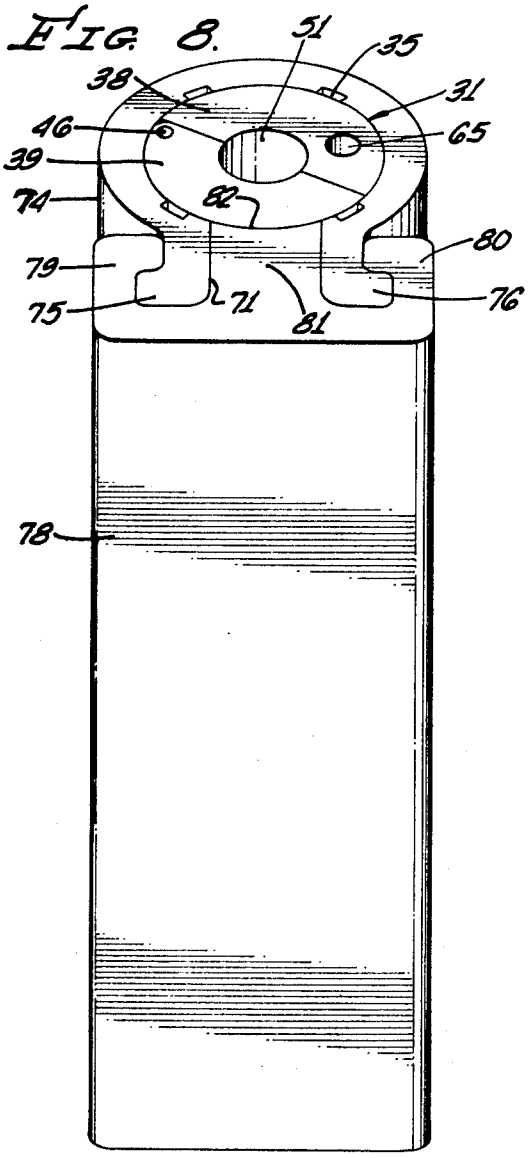


FIG. 7.

FIG. 8.



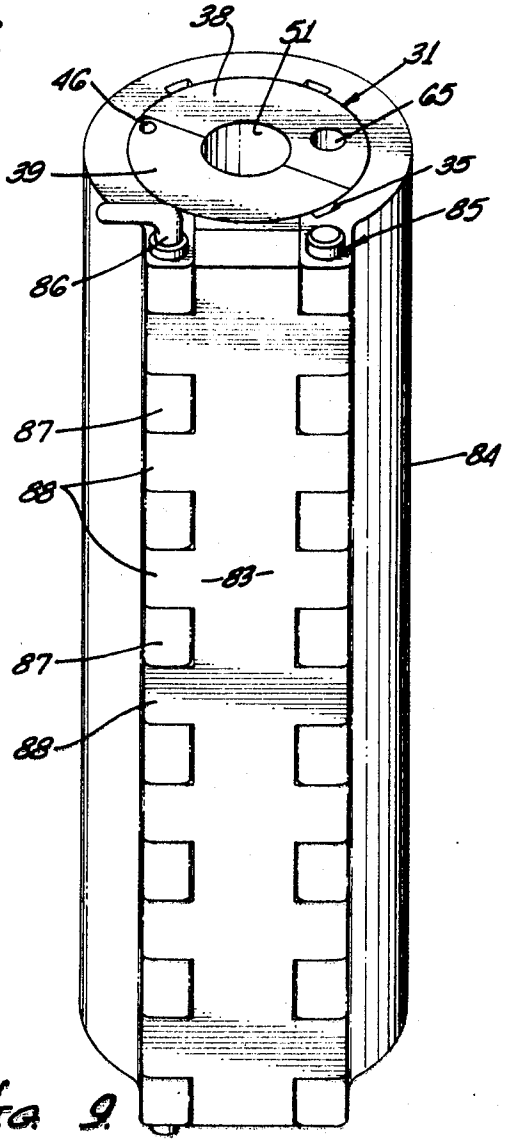


FIG. 9.

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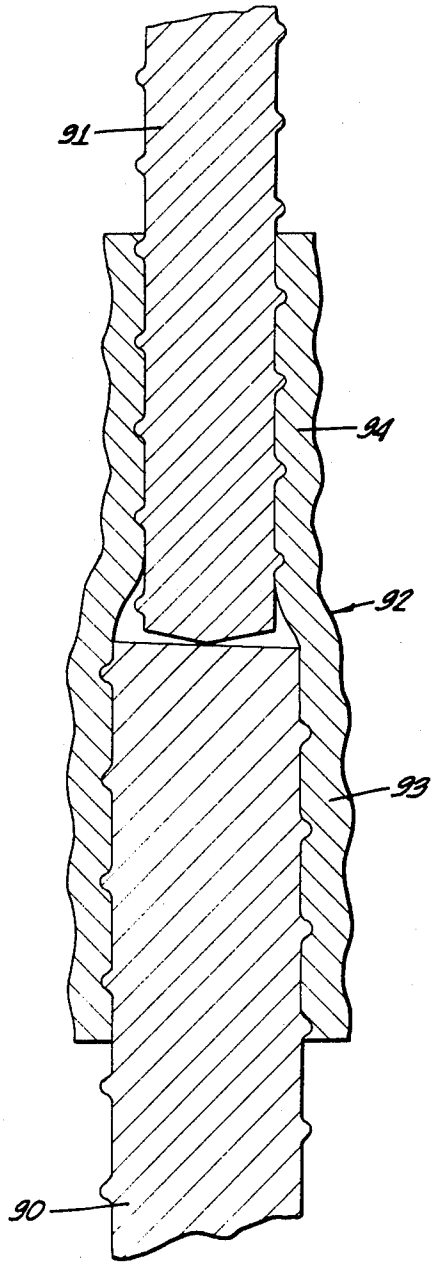


FIG. 11.

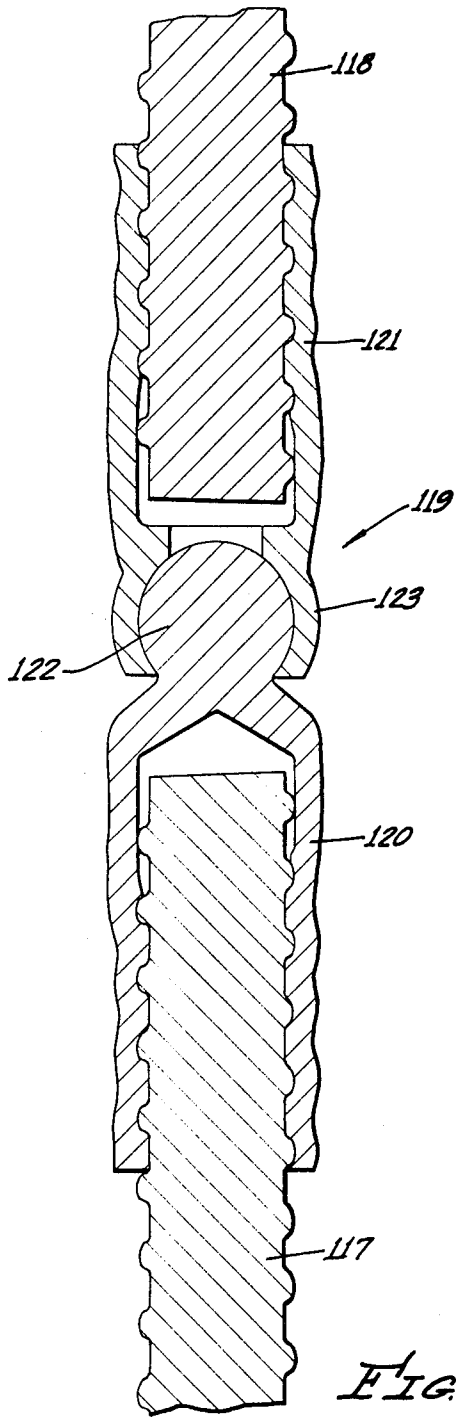


FIG. 15.

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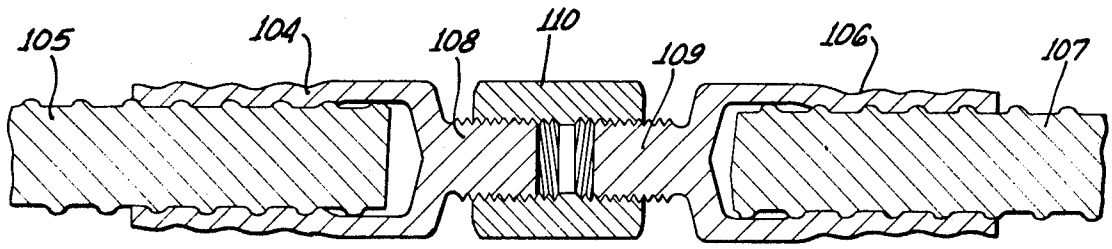


FIG. 13.

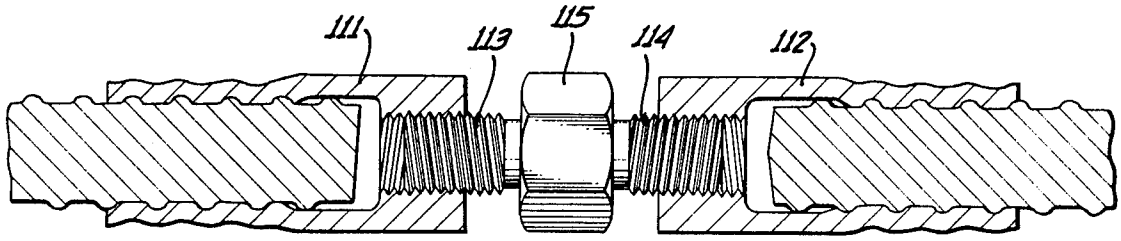


FIG. 14

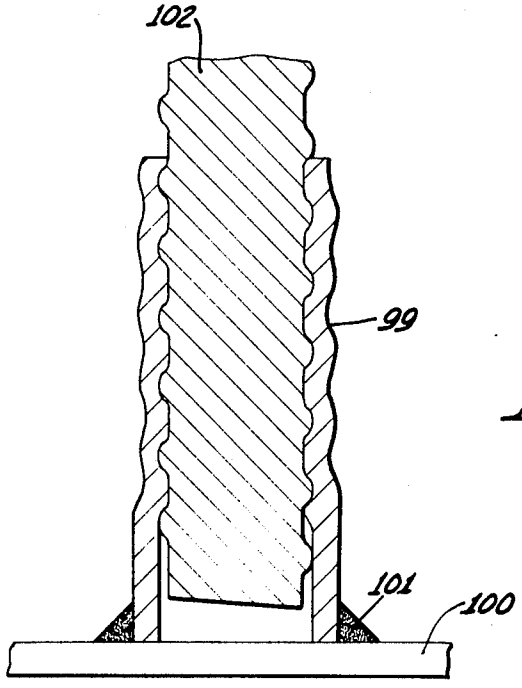


FIG. 12.

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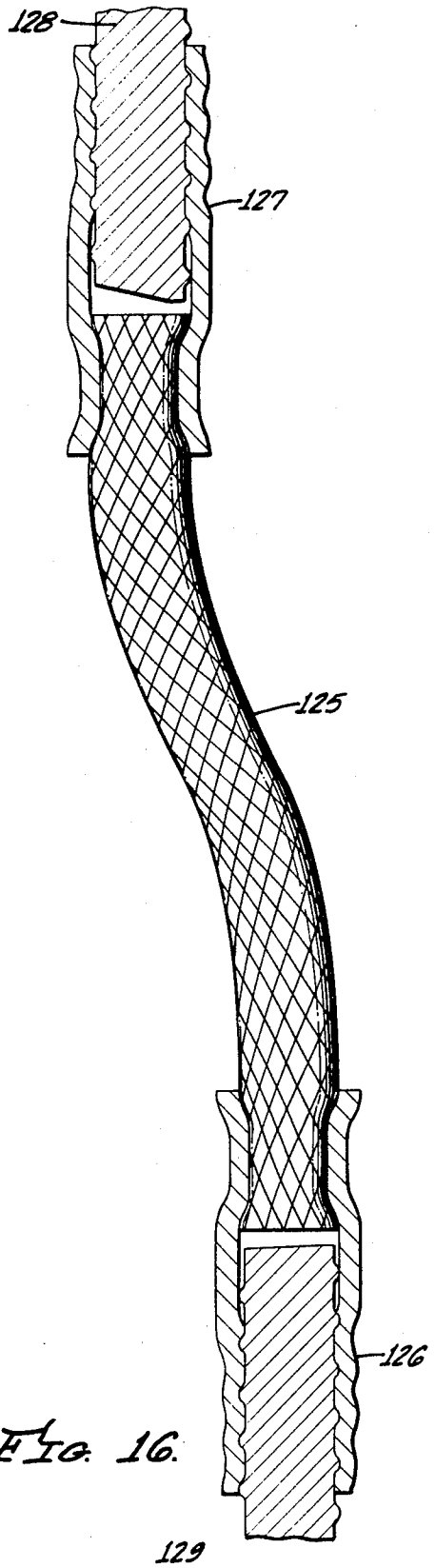


FIG. 16.

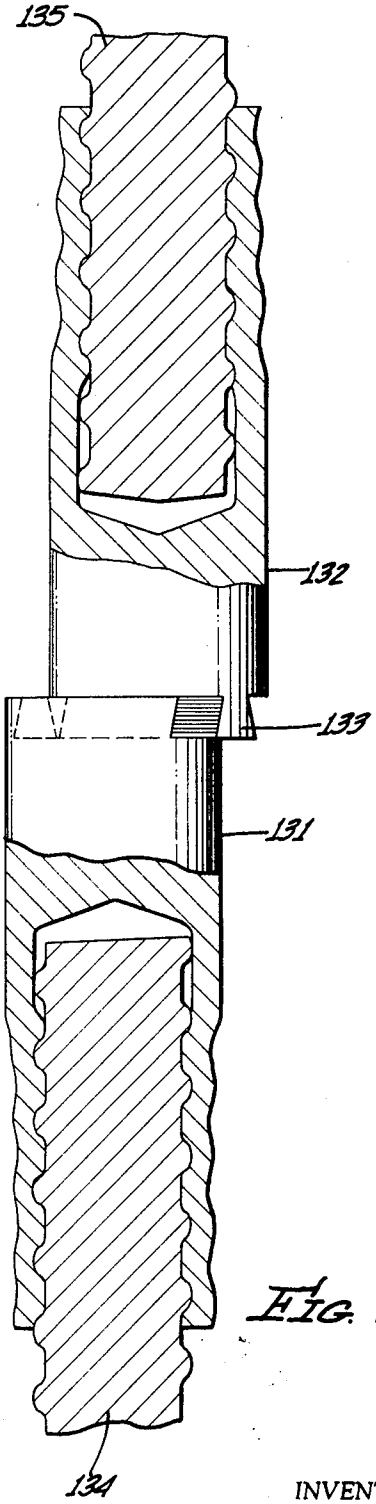


FIG. 17.

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ARRANGEMENT FOR EXPLOSIVELY FORMED CONNECTIONS AND METHOD OF MAKING SUCH CONNECTIONS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention pertains to the explosive forming of joints for reinforcing bars or the like.

2. Description of Prior Art

In reinforced concrete structures, frequently it is necessary to make load-transmitting connections or joints between the steel reinforcing bars. Such joints have been provided by overlapping the ends of adjoining bars and binding them together with soft iron wire. The load then is transferred from one bar to the other through the shear resistance of the concrete. While suitable for some purposes, this type of joint is both unsatisfactory and uneconomical for bars of large diameter, one reason being that the weight of material required for an overlapping joint increases as the cube of the bar diameter.

This has led to the development of other techniques for joining large diameter bars. One of these is by arc welding, which is a relatively slow and expensive process. The metallurgy of the welding rod must be matched to that of the reinforcing bar, and this requires that the composition of the bar be known. The hydrogen content of the flux of the welding rod must be kept low. Thermit welding also is used in forming reinforcing bar joints as iron oxide and a light metal, such as aluminum, are reacted to form molten metal that is cast around the abutting ends of the bars to be joined. The molten metal engaging the ends of the bars fuses the bar ends into the joint. Like arc welding, this is a relatively expensive procedure. It requires that the reinforcing bars be held in precise alignment as the joint is formed. Another arrangement for attaching reinforcing bars has been by what is known as the Cadweld process. In this, a steel collar surrounding the joint is filled with a molten metal generated by a Thermit type of reaction. There are ribs on the inside of the collar which cooperate with the metal cast in the joint to transmit stresses to the ribs of the connected bars. In this process, not all of the joint is in a molten state at the same time, so that in some instances there are voids in the metal cast under the collar, with resultant loss of joint strength. Again, forming the joint is relatively expensive and time consuming. Mechanical connectors also have been used for tension joints between reinforcing bars. In one such connector, the two reinforcing bars are threaded and screwed onto a connecting member. The high cost of threading the bars has prevented any extensive use of this type of connection.

Other procedures have been followed in forming joints for purposes other than reinforced concrete structures. For example, in U.S. Pat. No. 3,432,192, the ends of adjacent pipes are explosively formed to grip grooved members inserted into the pipe ends. The unconfined explosive rapidly dissipates so that its reaction time is short. This means that a relatively large amount of explosive is required to effect adequate deformation of the pipes, and also that the procedure is hazardous. Also, the noise is not attenuated.

An electrical connection is formed in the invention of U.S. Pat. No. 3,341,650, where an explosive within an outer sleeve drives pistons that serve to compress a tubular member onto the ends of adjacent cables. Here, the explosive, not acting directly on the material forming the joint but merely moving the pistons, is inefficiently used due to the friction created, so that considerable quantities of explosives are needed. Another piston-type explosive arrangement is found in U.S. Pat. No. 3,333,046. Coils of explosives for imparting an undulating contour to adjoining pipes to attach them together are used in U.S. Pat. No. 3,160,949.

SUMMARY OF THE INVENTION

The present invention involves both a particular method and a particular apparatus and provides an improved joint-forming arrangement particularly adapted for interconnecting ribbed concrete reinforcing bars. It includes an explosive package which at its center has a load transmitting sleeve that is adapted to receive the ends of the reinforcing bars to be connected. Around the sleeve is a tube or layer of secondary high explosive material, which is received within a metal sleeve or layer-forming jacket. An outer layer-forming tube of damping material circumscribes the metal jacket. As described more specifically hereinafter, the jacket and the damping material are frangible materials which are fractured by the explosion. The aforesaid explosive package or assembly is received within a protective casing or shield, the ends of the reinforcing bars to be connected are inserted into opposite ends of the deformable load-transmitting sleeve, and the explosive is detonated. This produces a reaction that contracts the sleeve inwardly to tightly grip the ends of the reinforcing bars. The sleeve is caused to flow plastically to bear against the peripheries or outer surfaces of the bars between the adjacent spaced ribs. The result is a strong mechanical connection or joint, easily, rapidly and economically produced. The resulting joint meets or exceeds existing performance specifications. The explosive is efficiently used in directly reacting against the sleeve of the joint. The frangible metal jacket around the explosive layer confines the explosion, delaying the expansion of the gases to atmospheric pressure so that the time of the reaction is increased. This reduces the quantity of explosive needed and minimizes hazard.

Confinement of the explosion also may be accomplished by adding an inert powder to the explosive, such as 60 percent by weight stainless steel or sponge iron powder of −80 mesh. This also slows the progress of the detonation wave, avoiding extension of the high-pressure zone and possible overcompression of the downstream end of the deformable joint forming sleeve. The metal powder and explosive mixture may be used alternatively to the metal jacket, or in combination with it.

The damping material around the exterior of the metal jacket helps attenuate the explosion and prevents fragmented particles from striking the outer casing or shield, which could lead to fatigue failures. It also reduces the noise of the explosion. The outer casing or shield protects personnel, so that it is possible to remain near where the joint is being formed without danger.

The ends of the ribbed concrete reinforcing bars are positioned at the middle of the deformable load-transmitting sleeve in order to obtain a joint of maximum strength. This is accomplished by inserting one of the bars into the casing a predetermined distance such that its end is at the middle of the sleeve when the explosive package is received in the casing. The other bar

then is inserted into the casing from the opposite direction until its end engages that of the first bar. The first bar is positioned the correct distance in the casing by first placing a mark on it at a known distance from its end. When this mark is aligned with a second indicator on the exterior of the casing, such as the outer surface of one of the removable end closures for the casing, the bar end will be at the proper location.

Many variations are possible using the same basic techniques in attaching the sleeve to the bars. For example, bars of unequal diameters may be connected through the use of a sleeve having sections of different internal diameters. Again, the explosion causes the sleeve to be swaged over the ends of the bars to effect the connection or joint. Where there may be lateral or angular movement between the reinforcing bars, two sleeves may be utilized, each separately being explosively formed on its reinforcing bar. A ball-and-socket joint, dovetail joint or cable may connect the two sleeves to allow for relative movement. In other instances, turnbuckle threads may be provided on the two sleeves to permit the reinforcing bars to be prestressed, or, if the bars are embedded in precast concrete, the turnbuckle provides a means of alignment of of adjacent sections. An attachment to a support plate or other structure may be accomplished by welding or otherwise securing a sleeve to the plate and then explosively attaching the sleeve to the reinforcing bar.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an elevational view, partially broken away, of a joint formed in accordance with this invention;

FIG. 2 is a longitudinal sectional view of the arrangement for forming the joint;

FIG. 3 is a transverse sectional view taken along line 3—3 of FIG. 2, showing how the lower bar is gripped for positioning in the casing or shield;

FIG. 4 is an exploded perspective view of the casing within which the explosive forming takes place;

FIG. 5 is a transverse sectional view taken along line 5—5 of FIG. 4;

FIG. 6 is an enlarged fragmentary sectional view of a portion of the explosive package, showing metal powder mixed in the explosive;

FIG. 7 is a view similar to FIG. 6 but of a modification in which there is metal powder in the explosive and the exterior metal jacket is omitted;

FIG. 8 is a perspective view of a modified casing construction;

FIG. 9 is a perspective view of a different modified casing;

FIG. 10 is a sectional view showing how the invention can be used in attaching together bars of unequal diameters;

FIG. 11 is a sectional view of the complete joint between bars of unequal diameters;

FIG. 12 is a sectional view of a bar connected to a plate in accordance with the present invention;

FIG. 13 is a sectional view of the bars interconnected in accordance with this invention by a turnbuckle arrangement permitting prestressing of the bars;

FIG. 14 is a view similar to FIG. 13 of a modified turnbuckle connection;

FIG. 15 is a sectional view showing bars connected so as to permit universal pivotal movement between them;

FIG. 16 is a sectional view showing bars connected through an intermediate cable, allowing relative movement between the bars; and

FIG. 17 is a sectional view, partially in elevation, of bars connected by sleeves having a dovetail joint that allows lateral displacement of the bars.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The arrangement of this invention is used in connecting conventional steel reinforcing bars 10 and 11 used in concrete structures. These bars, as seen in FIG. 1, include external ribs 12 and 13 which form a mechanical interlocking type connection with the concrete when the structure is complete. In accordance with the present invention, the bars 10 and 11 are positioned in an end-to-end relationship, with their end portions being circumscribed by a deformable steel load-transmitting sleeve 14. Through an explosive force, the sleeve 14 is swaged onto the bars 10 and 11, engaging the surfaces of the bars between the ribs 12 and 13 in order securely to hold the bars together.

The arrangement for producing the joint between the reinforcing bars 10 and 11 is illustrated in FIGS. 2-5. This includes an elongated casing 16 which is appropriately made of heat-treated tool steel and is formed to a cylindrical configuration. Such casing forms in effect a protective shield. Extending for the length of the casing 16 along one side is an opening 17 within which fits a door 18. The inner surface 19 of the door 18 has the same curvature and forms a continuation of the inner surface 20 of the casing 16. The door 18 includes outer longitudinal flanges 22 and 23 that overlap flat surfaces 24 and 25 on the exterior of the casing 16. Studs 26 extend through openings 27 and 28 in the flanges 22 and 23 and are engaged by nuts 29 in order releasably to hold the door 18 in position where it covers the side opening 17. Preferably, the nuts 29 are wing nuts so as to allow rapid installation and removal of the door 18.

The ends of the casing 16 are closed by circular or disk-like plugs 31 and 32 which are held to the casing by bayonet connections and constitute closure means for the opposite ends of the casing. The end plugs 31 and 32 have short radially projecting pins 33 and 34, respectively, for entering bayonet slots in the ends of the casing 16. The pins 33 of the upper plug 31 are adapted to be received in bayonet slots 35 in the upper end of the inner cylindrical surface 20 of the casing 16, as shown in FIG. 4. Similar slots are provided in the lower end region of said surface 20 for the bayonet pins 34 of the lower end plug 32. Axial recesses 36 are provided in the outer radial wall of the upper end plug 31 for receiving a spanner wrench used in rotating said upper end plug with respect to the casing 16. Comparable recesses, not shown, are included for turning the lower end plug 32.

The end plugs 31 and 32 are split diametrically, providing two sections that are hinged together so that they may be swung apart for bar-receiving purposes. The radial edges of the two sections 38 and 39 of upper end plug 31 are stepped, as shown in FIG. 4. This provides a short upper flange 40 on one side and a similar lower flange 41 on the other side of the plug section 38. Similarly, there are an upper flange 42 and a lower flange 43 for the section 39 of the upper end plug 31. The flanges 41 and 42, which overlap in the assembled upper end plug 31, are provided with aligned or regis-

tering openings 44 and 45 for receiving a hinge pin 46. The adjacent radial edges of the sections 38 and 39 also are recessed so that, in the closed position of the upper end plug where the flanges 40 and 43 overlap, the end plug 31 defines a circular central opening 47. The bar 10 or 11 can fit in the opening 47, and the end plug 31 may be moved laterally onto or off the bar when it is opened up by pivoting its sections about the hinge pin 46.

The lower end plug 32 is similarly constructed, being made up of sections 48 and 49 which are pivotally held together by a hinge pin 50. When the lower end plug is closed, an opening 51 extends axially there-through for bar-receiving purposes.

When a joint is to be formed by the hereinbefore described arrangement, an explosive package 52 is positioned within the casing 16. This package includes an outer relatively thick cylindrical sleeve 53 of a damping material. The upper end of the sleeve 53 is open, while at the lower end there is a radial flange 54 having a central opening 55. Various materials may be used for the sleeve 53, such as wood, chipboard, sawdust held with a suitable binder or in a bag, paper, such as old newspaper, with a binder, cardboard, porous concrete or any other substance capable of absorbing the energy of an explosion.

Within the sleeve 53 of damping material is a thinner cylindrical metal sleeve or jacket 56 which has an inwardly extending radial flange 57 at its lower end, such flange being inside of and in lapped relation with the flange 54 of the sleeve 53 of damping material. The jacket 56 is of a ferrous metal suitable for confining an explosion, such as mild steel or cast iron. The flange 57 has a central opening 58. It is of increased thickness at its outer marginal portion and this provides an upwardly facing circumferential shoulder 59. The opposite end of the jacket 56 is open and stops or terminates short of the upper end of the outer sleeve 53 of damping material.

The load transmitting sleeve 14 for joining the ribbed reinforcing bars 10 and 11 is prior to the swaging operation in the form of an open-ended cylinder, and it fits within the aforementioned explosive package 52. The lower end of the sleeve 14 engages the flange 57 of the metal jacket 56, where it is complementarily received within the aforementioned annular shoulder 59. The sleeve 14 is thereby held in coaxial relationship with the jacket 56, with the walls of these two members or parts separated.

Within the annular space between the sleeve 14 and the metal jacket 56 is a tubular layer of an explosive material 61, which is a secondary high explosive, i.e., one which propagates at from around 5-8 mm/microsecond. An initiator train 62 extends to the upper end of the explosive layer from a detonator 63 which has leads 64 that connect to the battery of a conventional blaster (not shown). The detonator can be connected to the explosive package by insertion through an axial opening 65 in the upper end plug 31.

In preparing to splice or join the bars 10 and 11, in the embodiment illustrated, the lower end plug 32 is first positioned in the casing 16, and then the lower end of explosive package 52 inserted into the casing through the upper end of the casing and until the outer surface of the flange 54 engages said lower end plug 32. The bar 10, with its end 66 sheared or cut nominally square, is introduced into the casing from the bottom through the openings 51, 55 and 58. The bar 10 is extended inwardly a distance which will position its end 66 at the mid-point of the deformable load-transmitting sleeve 14. This positioning of the bar 10 may be accomplished by placing a mark 67 on its surface at a distance inwardly of the bar end 66 which corresponds to the distance between the outer surface of the end plug 32 and the midpoint of the sleeve 14. With the mark 67 in registry with the outer surface 68 of the end plug 32, the bar end 66 necessarily is at the middle of the sleeve 14.

It is particularly easy to accomplish this positioning by gripping the bar 10 with jaws 69 and 70 which are attached to locking pliers 71. The jaws 69 and 70 are a steel angle and a round rod, respectively, and they are welded to the mechanism of the locking pliers 71 in place of the ordinary jaws of the pliers. The edges of the jaws 69 and 70 are positioned in alignment with the mark 67 as the bar 10 is gripped, and the bar is inserted into the casing 16 for a distance sufficient to bring the jaw edges into engagement with the outer surface 68 of the lower end plug 32. This positions the mark 67 in registry with the end plug surface 68 and the end 66 of the bar 10 at the middle of the sleeve 14.

With the end of the bar 10 properly positioned in the explosive package 52, the other bar 11 is inserted into the casing 16 from the opposite end. The bar 11 is moved into the sleeve 14 until its end 72, which also is sheared or cut nominally square, engages the end 66 of the bar 10. After this, the upper end plug 31 is closed around the bar 11, and its bayonet pins 33 are brought into the bayonet slots 35 in the upper end region of the casing 16 in order to lock the upper end plug in position.

The apparatus then is ready to fire, with the resulting explosion reacting directly against the joint sleeve 14 so that it is deformed inwardly into secure gripping relation with the abutting end portions of the bars 10 and 11 and thus forms a strong connecting joint. The sleeve 14 is contracted and experiences plastic flow which brings it into engagement with the outer surfaces of the bars 10 and 11 between the adjacent portions of the ribs 12 and 13. When the bar ends are cleaned of mill scale before the joint is formed, and with proper use of the explosive, it is possible to obtain surface wave interaction between the sleeve and the reinforcing bars. This augments the strength of the joint as a whole. As the explosion takes place, it is confined by the metal jacket 56, while the damping material 53 protects the casing 16 and helps attenuate the energy of the explosion.

After the explosion, the joint is complete and ready for use and consequently it must be removed from the casing 16. This is accomplished by removing one of the end plugs and either sliding the casing longitudinally to expose the joint area or removing both end plugs and subsequently removing the door 18 in order to allow the joint to be moved laterally outwardly from the casing. The damping material 53 and the metal casing 56 become broken up by the force of the explosion and so are separated from the joint without difficulty. In fact, cast iron not only is suitable for the jacket 56 in confining the explosion but also becomes pulverized from the explosion and falls completely away from the joint area upon removal of the casing from the joint.

The metal jacket 56 serves to confine the explosion around the joint sleeve 14 both because of its inertia

and its elastic strength. As a body at rest that must be displaced for the explosive gases to dissipate outwardly, the sleeve **56** possesses inertia and so resists the outwardly directed forces of the explosion. Also, the material making up the sleeve **56** resists being deformed by the force of the explosion, and so acts to confine the explosion. The total impulse delivered to the joint sleeve **14** is a function of the pressure generated and the time of application of the pressure. The presence of the jacket **56** around the layer of the explosive material **61** delays the expansion to atmospheric pressure, thereby increasing the time of application of the explosive pressure to the surface of the deformable load-transmitting sleeve **14.** Thus, the confinement of the explosion as achieved by the jacket **56** increases the effectiveness of the explosive material **61** in deforming the joint sleeve **14.** This means that less explosive is required than otherwise would be the case, which is a significant factor in eliminating hazard from the joint forming operation. Less explosive material also means that the noise of the explosion is reduced.

The completed joint is inspected very easily by measuring the reduction in the diameter of the sleeve **14.** This may be accomplished by a simple gauge. If the sleeve **14** has been contracted to a predetermined size, there is assurance that the joint is sound. By inserting the bars so that the longitudinal ribs are not aligned, the location of the rod ends can readily be observed after firing, appearing as a jog in the longitudinal rib line. From this, it can be determined whether both bars are covered equally by the sleeve **14.**

The joint which is produced in this manner will behave in service virtually the same as an uncut bar. Full ultimate design bar loads can be transmitted both in tension and in compression. These joints easily meet the standards of the American Concrete Institute, producing an ultimate stress of no less than 125 percent of the bar yield stress. The joint also will transmit bending moments at least equal to the capability of the parent bar. This is accomplished without expensive material and by a simple labor-saving procedure that produces a completed joint in a very short time.

Various secondary high explosives are satisfactory for use as the explosive material **61** in swaging the joint sleeve **14.** Sheet explosive such as that marketed as "Detasheet " by E. I. duPont deNemours & Co., Wilmington, Delaware, is conveniently used because of the ease with which it can be wrapped around the exterior surface of the sleeve **14** prior to its insertion into the metal jacket **56.** Castable explosives, such as pentolite or Composition B, are other readily used explosives, as are various explosives in liquid, gel or solid form. In any event, the explosive can be associated with the sleeve **14,** the metal jacket **56** and the damping material **53** at the factory, so that the explosive package **52** is furnished as a unit for use in the field. This means that there is no direct handling of the explosive material by the workmen as the reinforcing bars **10** and **11** are joined together by inward swaging of the sleeve **14.**

Desirable results for the explosive are achieved through the use of a heavy metal powder mixed into the explosive. This powder has an effect similar to the metal sleeve **56** in confining the explosion. This results from the inertia of the metal particles, which, therefore, helps prevent the explosive gases from being dissipated outwardly. The expansion to atmospheric pressure is delayed and the total time of application of high pressure to the sleeve **14** is increased. Even though some reduction in peak pressure is experienced, the net result is the generation of optimum impulse values for a minimum amount of explosive content.

An added advantage from the metal powder comes from an attendant reduction in the detonation velocity from that of a pure explosive. In the absence of the metal powder, with the explosion confined by the metal jacket **56,** there is an increase in length of the region of high pressure as the detonation proceeds down the sleeve from the point of origin. The detonation wave travels faster than the rarefaction wave, which is limited to sonic velocity, so by the time the detonation has reached the end of the sleeve **14** there is a zone of considerable length within which high pressures exist. This can result in too much deformation of the sleeve at the downstream end of the sleeve. The powder reduces the velocity of the detonation wave so that its speed becomes more closely matched with that of the rarefaction wave. The high pressure zone is more nearly constant in length as the explosion travels the length of the sleeve, and, as a result, the deformation of the sleeve **14** is more uniform.

A suitable explosive of this type will include **40%** by weight of composition C-4 explosive and 60 percent by weight of either sponge iron or stainless steel powder **73** of −80 mesh (see FIG. **6**). The stainless steel powder is advantageous because of its low heat-transfer coefficient, which means that a relatively small amount of the heat of the explosion is transferred to the inert material. This, in turn, helps conserve the energy of the explosion. The combination of the explosive material **61** and the metal powder **73** may be used in lieu of the metal jacket **56,** or both may be included to maximize confinement of the explosive. When the metal jacket **56** is omitted, as shown in FIG. **7,** the tube of damping material **53** will have a reduced inside diameter to correspond generally to the exterior dimension of the layer of explosive material **61.**

The casing **16** may be modified in order to facilitate the installation and removal of the door. In the arrangement of FIG. **8,** the casing **74** is provided with longitudinally extending L-shaped flanges **75** and **76** that define a longitudinal opening **77** through the side of the casing. The door **78** has L-shaped side flanges **79** and **80** that overlap the flanges **75** and **76** so as to hold the door in position on the casing. The central portion **81** of the door has an arcuate inner surface **82** that forms a continuation of the inner surface of the casing. The door **78** is installed and removed by longitudinal sliding movement relative to the casing **74,** thereby avoiding the need to rotate a plurality of nuts **29,** as in the embodiment of FIGS. **4** and **5.**

In the casing arrangement of FIG. **9,** the door **83** is attached to the casing **84** by a piano hinge arrangement, through which extends an elongated hinge pin **85.** At the opposite edge of the door, a similar arrangement is provided, with an elongated rod **86** being extended through openings in the spaced flanges **87** projecting outwardly from the casing **84** and intermediate flanges **88** on the door. When the rod **86** is pulled out longitudinally, the door **83** is free to pivot to an open position about the hinge pin **85.** The door **83** may be provided with a separate insert for its inner face to make certain there is adequate clearance for the pivotal movement of the door.

Bars of unequal diameters may be joined by following the same basic technique as described above. In accomplishing this, the bars **90** and **91** of unequal diameters, as shown in FIG. **10**, are fitted into the opposite ends of a deformable joint sleeve **92**. The latter member has a first portion **93** of relatively large diameter that receives the end of the bar **90**, being reduced in diameter at its middle to a second section **94** of smaller diameter that receives the end of the bar **91**. Similarly, the layer of explosive material **95** that fits over the sleeve **92** may be shaped to two diameters so that it is complementary to the exterior of the sleeve **92**. The metal jacket **96** may be formed to two diameters in the same manner. This assembly with the damping material **97** is placed in a casing, such as the casing **16** or the modified casings **74** or **84**, and the layer of explosive material **95** detonated as before. The result is to swage the sleeve **92** over the ends of the bars **90** and **91**, forming a secure completed joint as shown in FIG. **11**.

FIG. **12** illustrates how the invention can be used in securing a reinforcing bar to a base plate or other structural member. Here, a deformable sleeve **99**, which initially is cylindrical, is suitably secured to a plate **100**, such as by a weld **101** or other attaching arrangement. The end of a bar **102** is inserted into the sleeve **99**, which then is swaged to the bar by an explosion in the same general manner as described above.

A variety of attachments may be provided for bars in accordance with the techniques of this invention. In FIG. **13**, a turnbuckle is illustrated with a first sleeve **104** explosively swaged on a bar **105** and a second sleeve **106** similarly attached to a bar **107**. There are oppositely threaded end projections **108** and **109** at the ends of the sleeves **104** and **106**, respectively, which are received within an internally threaded turnbuckle sleeve **110**. Rotation of the sleeve **110** can draw the ends of the bars **105** and **107** closer together, permitting prestressing of the bars.

The turnbuckle of FIG. **14** is similar except that the sleeves **111** and **112** have internally threaded openings which receive threaded pins **113** and **114** interconnected by a hexagonal portion **115** to facilitate rotation of the turnbuckle.

Universal movement is permitted through the connected bars **117** and **118** of FIG. **15**. In this instance, a sleeve assembly **119** secures the bars **117** and **118** together. The assembly **119** is made up of two sleeves **120** and **121**, which at their adjacent ends provide a ball **122** received in a socket **123**, which allows universal movement of the sleeves **120** and **121**. The ends of the bars **117** and **118** are inserted into the sleeves **120** and **121** and attached to them by the type of explosive forming discussed above. The end result is that the bars **117** and **118** may have relative angular motion, but are prevented from any relative longitudinal movement.

Both angular and lateral movement are permitted by the arrangement of FIG. **16** in which a cable **125** interconnects sleeves **126** and **127** which are explosively attached to the ends of bars **128** and **129**, respectively. The ends of the cable **125** are received in the ends of the sleeves **126** and **127** and suitably attached by conventional swaging and furnace brazing at the factory prior to the connections of the sleeves **126** and **127** to the bars **128** and **129**.

In the embodiment of FIG. **17**, a dovetail joint between the sleeves **131** and **132** allows the sleeves to be laterally offset, while still transmitting the full tensile load. The dovetail joint may be provided by a wedge-shaped projection **133** on the sleeve **132**, which fits within a complementary opening in the end of the sleeve **131**. The sleeves **131** and **132** are attached by explosive forming to the reinforcing bars **134** and **135**.

The foregoing detailed description is to be clearly understood as given by way of illustration and example only, the spirit and scope of this invention being limited solely by the appended claims.

What is claimed is:

1. That method of forming a load-transmitting joint with a ribbed concrete reinforcing bar or the like, which comprises

enclosing an end of said bar in a section of a load-transmitting sleeve,

enclosing said sleeve section in a layer of explosive material generating sufficient explosive energy to deform plastically and contract said sleeve section into contact with said bar end between the ribs thereof for interengagement of the sleeve and the bar in a load-transmitting joint,

enclosing said explosive material layer in a layer of frangible material adapted to confine and attenuate the explosive energy and reduce the explosion noise level, while being fractured by the explosion sufficiently to enable ready removal thereof from the formed joint, said frangible material layer including a metal jacket enclosed by a damping material sleeve,

detonating said explosive material, whereby a completed load-transmitting bar and sleeve joint is formed while the frangible material layer confines and attenuates the explosive energy and reduces the explosion noise level and also is fractured sufficiently for removal from the formed joint, and

separating said fractured frangible material layer from said joint.

2. The method of claim **1** employing a steel load-transmitting sleeve and a secondary high explosive material.

3. The method of claim **2** employing a heavy metal powder admixed with the explosive material for confining the explosive energy and reducing the detonation velocity of the explosive material.

4. The method of claim **1** employing a steel load-transmitting sleeve, and employing a ferrous metal jacket as said jacket.

5. The method of claim **1** employing a steel load-transmitting sleeve, and employing a concrete sleeve as said damping material sleeve.

6. The method of claim **1** wherein respective ends of two of said bars are inserted in opposite ends and in adjoining sections of said sleeve, and said sleeve sections are enclosed in said explosive material layer and said frangible material layer, for forming a completed load-transmitting joint comprising said bar ends having said sleeve sections deformed and contracted into contact therewith between the ribs thereof to interengage the sleeve and the bars, upon detonating said explosive material.

7. That method of forming a load-transmitting joint with a ribbed concrete reinforcing bar or the like, which comprises

enclosing an end of said bar in a section of a load-transmitting sleeve,

enclosing said sleeve section in a layer of explosive material generating sufficient explosive energy to

deform plastically and contract said sleeve section into contact with said bar end between the ribs thereof for interengagement of the sleeve and the bar in a load-transmitting joint,

enclosing said explosive material layer in a layer of frangible material adapted to confine and attenuate the explosive energy and reduce the explosion noise level, while being fractured by the explosion sufficiently to enable ready removal thereof from the formed joint, said frangible material layer including a metal jacket enclosed by a damping material sleeve,

removably enclosing said frangible material layer in a protective shield adapted to contain explosively propelled fragments of said frangible material,

detonating said explosive material, whereby a completed load-transmitting bar and sleeve joint is formed while the frangible material layer confines and attenuates the explosive energy and reduces the explosion noise level and also is fractured sufficiently for removal from the formed joint, and

separating said fractured frangible material layer and said shield from said joint.

8. The method of claim **7** employing a steel load-transmitting sleeve, employing a ferrous metal jacket as said jacket sleeve as said layer of frangible material, and employing a steel casing as said protective shield.

9. The method of claim **8** employing a secondary high explosive material.

10. The method of claim **9** wherein respective ends of two of said bars are inserted in opposite ends and in adjoining sections of said sleeve, and said sleeve sections are enclosed in said explosive material layer and said frangible material layer, for forming a completed load-transmitting joint comprising said bar ends having said sleeve sections deformed and contracted into contact therewith between the ribs thereof to interengage the sleeve and the bars, upon detonating said explosive material.

11. An apparatus adapted to form a load-transmitting joint with a ribbed concrete reinforcing bar or the like, and comprising

a load-transmitting sleeve having a section adapted to enclose an end of said bar therein,

a layer of explosive material enclosing said sleeve section, said explosive material generating sufficient explosive energy to deform plastically and contract said sleeve section into contact with said bar and between the ribs thereof for interengagement of the sleeve and the bar in a load-transmitting joint, and

a layer of frangible material enclosing said explosive material layer, said frangible material layer being adapted to confine and attenuate the explosive energy and reduce the explosion noise level, while being fractured by the explosion sufficiently to enable ready removal thereof from the formed joint, said frangible material layer including a metal jacket enclosed by a damping material sleeve,

whereby upon detonating said explosive material, a completed load-transmitting bar and sleeve joint is formed while the frangible material layer confines and attenuates the explosive energy and reduces the explosion noise level and also is fractured sufficiently for removal from the formed joint.

12. The apparatus of claim **11** wherein said load-transmitting sleeve is a steel sleeve, and said explosive material is a secondary high explosive material.

13. The apparatus of claim **12** wherein a heavy metal powder is admixed with the explosive material for confining the explosive energy and reducing the detonation velocity of the explosive material.

14. The apparatus of claim **11** wherein said load-transmitting sleeve is a steel sleeve, and said jacket is a steel jacket.

15. The apparatus of claim **14** wherein said damping material is concrete.

16. The apparatus of claim **11** wherein said sleeve has adjoining sections adapted to enclose abutting ends of two of said bars therein, and said sleeve sections are enclosed in said explosive material layer and said frangible material layer, for forming a completed load-transmitting joint comprising said bar ends having said sleeve sections deformed and contracted into contact therewith between the ribs thereof to interengage the sleeve and the bars, upon detonating said explosive material.

17. An apparatus adapted to form a load-transmitting joint with a ribbed concrete reinforcing bar or the like, and comprising

a load-transmitting sleeve having a section adapted to enclose an end of said bar therein,

a layer of explosive material enclosing said sleeve section, said explosive material generating sufficient explosive energy to deform plastically and contract said sleeve section into contact with said bar end between the ribs thereof for interengagement of the sleeve and the bar in a load-transmitting joint,

a layer of frangible material enclosing said explosive material layer, said frangible material layer being adapted to confine and attenuate the explosive energy and reduce the explosion noise level, while being fractured by the explosion sufficiently to enable ready removal thereof from the formed joint, said frangible material layer including a metal jacket enclosed by a damping material sleeve, and

a protective shield removably enclosing said frangible material layer, said shield being adapted to contain explosively propelled fragments of said frangible material,

whereby upon detonating said explosive material, a completed load-transmitting bar and sleeve joint is formed while the frangible material layer confines and attenuates the explosive energy and reduces the explosion noise level and also is fractured sufficiently for removal from the formed joint.

18. The apparatus of claim **17** wherein said load-transmitting sleeve is a steel sleeve, said jacket is a steel jacket enclosed by a damping material sleeve, and said protective shield is a steel casing.

19. The apparatus of claim **18** wherein said explosive material is a secondary high explosive material.

20. The apparatus of claim **19** wherein said sleeve has adjoining sections adapted to sections are enclosed in said explosive material layer and said frangible material layer, for forming a completed load-transmitting joint comprising said bar ends having said sleeve sections deformed and contracted into contact therewith between the ribs thereof to interengage the sleeve and the bars, upon detonating said explosive material.

21. The apparatus of claim 20 wherein said damping material is concrete.

22. The apparatus of claim 11 and wherein the layer of frangible material includes an inwardly directed flange portion which extends around certain contiguous terminal ends of said sleeve section and the layer of explosive material.

23. An apparatus adapted to form a load-transmitting joint with a ribbed concrete reinforcing bar or the like, and comprising

a load-transmitting sleeve having a section adapted to enclose an end of said bar therein,

a tubular layer of secondary high explosive material enclosing said sleeve section, said explosive material generating sufficient explosive energy to deform plastically and contract said sleeve section into contact with said bar end between the ribs thereof for interengagement of the sleeve and the bar in a load-transmitting joint,

an initiator train contiguous to one terminal end of said explosive material layer,

a detonator contiguous to said initiator train,

said detonator being actuatable to initiate successive detonation of said initiator train and said explosive material,

a tubular layer of frangible material enclosing said explosive material layer, said initiator train and said detonator, said frangible material layer being of such rigidity as to resist deformation by the explosive energy to the end that it is adapted to confine and attenuate the explosive energy and reduce the explosion noise level, while being fractured by the explosion sufficiently to enable ready removal thereof from the formed joint,

said sleeve, explosive material layer, and frangible material layer being disposed in juxtaposed relationship, and

a tubular protective shield removably enclosing said frangible material layer, said shield being adapted to contain explosively propelled fragments of said frangible material,

whereby upon actuating said detonator to detonate said explosive material, a completed load-transmitting bar and sleeve joint is formed while the frangible material layer confines and attenuates the explosive energy and reduces the explosion noise level and also is fractured sufficiently for removal from the formed joint.

24. The apparatus of claim 23 and wherein the tubular layer of frangible material embodies an inwardly directed radial flange portion which extends around the terminal ends of said sleeve section and explosive material layer opposite to said one terminal end of the latter.

25. The apparatus of claim 23 and wherein the tubular protective shield comprises

a casing having door means extending the length thereof and adapted for passing said bar to the exterior of the shield after formation of said joint.

26. The apparatus of claim 25 and including a closure means associated with each of the opposite ends of said casing and having formed therein a central opening adapted to receive a bar the end portion of which is to be enclosed by said sleeve,

and means for removably mounting said closure means on said casing ends so as to withstand the explosive forces.

27. That method of forming a load-transmitting joint with a ribbed concrete reinforcing bar or the like, which comprises

enclosing an end of said bar in a section of a load-transmitting sleeve,

enclosing said sleeve section in a layer of explosive material generating sufficient explosive energy to deform plastically and contract said sleeve section into contact with said bar end between the ribs thereof for interengagement of the sleeve and the bar in a load-transmitting joint,

enclosing said explosive material layer in a layer of frangible material of such rigidity as to resist deformation by the explosive energy to the end that it is adapted to confine and attenuate the explosive energy and reduce the explosion noise level, while being fractured by the explosion sufficiently to enable ready removal thereof from the formed joint,

detonating said explosive material, whereby a completed load-transmitting bar and sleeve joint is formed while the frangible material layer confines and attenuates the explosive energy and reduces the explosion noise level and also is fractured sufficiently for removal from the formed joint, and

separating said fractured frangible material layer from said joint.

28. The method of claim 26 employing a steel load-transmitting sleeve, and employing a ferrous metal jacket as said layer of frangible material.

29. The method of claim 26 including the steps of

removably enclosing said frangible material layer in a protective shield adapted to contain explosively propelled fragments of said frangible material, and

separating both said fractured frangible material layer and said shield from said joint following detonation.

30. An apparatus adapted to form a load-transmitting joint with a ribbed concrete reinforcing bar or the like, and comprising

a load-transmitting sleeve having a section adapted to enclose an end of said bar therein,

a layer of explosive material enclosing said sleeve section, said explosive material generating sufficient explosive energy to deform plastically and contract said sleeve section into contact with said bar end between the ribs thereof for interengagement of the sleeve and the bar in a load-transmitting joint, and

a layer of frangible material enclosing said explosive material layer, said frangible material layer being of such rigidity as to resist deformation by the explosive energy to the end that it is adapted to confine and attenuate the explosive energy and reduce the explosion noise level, while being fractured by the explosion sufficiently to enable ready removal thereof from the formed joint,

whereby upon detonating said explosive material, a completed load-transmitting bar and sleeve joint is formed while the frangible material layer confines and attenuates the explosive energy and reduces the explosion noise level and also is fractured sufficiently for removal form the formed joint.

31. The apparatus of claim 30 wherein said load-transmitting sleeve is a steel sleeve, and said layer of frangible material comprises a ferrous metal jacket.

32. The apparatus of claim 30 including a protective shield enclosing said frangible material layer, said

shield being adapted to contain explosively propelled fragments of said frangible material, said shield also being adapted to be removed laterally from the formed joint, whereby both said fractured frangible material layer and said shield may be separated from said joint following detonation.

33. An apparatus adapted to form a load-transmitting joint with a ribbed concrete reinforcing bar or the like, and comprising

a load-transmitting sleeve having a section adapted to enclose an end of said bar therein,

a tubular layer of explosive material enclosing said sleeve section, said explosive material generating sufficient explosive energy to deform plastically and contract said sleeve section into contact with said bar end between the ribs thereof for interengagement of the sleeve and the bar in a load-transmitting joint,

an initiator train contiguous to said explosive material layer,

a detonator contiguous to said initiator train,

said detonator being actuatable to initiate successive detonation of said initiator train and said explosive material, and

a tubular layer of frangible material enclosing said explosive material layer, said frangible material layer being of such rigidity as to resist deformation by the explosive energy to the end that it is adapted to confine and attenuate the explosive energy and reduce the explosion noise level, while being fractured by the explosion sufficiently to enable ready removal thereof from the formed joint,

said sleeve, explosive material layer, and frangible material layer being disposed in juxtaposed relationship,

whereby upon actuating said detonator to detonate said explosive material, a completed load-transmitting bar and sleeve joint is formed while the frangible material layer confines and attenuates the explosive energy and reduces the explosion noise level and also is fractured sufficiently for removal from the formed joint.

34. The apparatus of claim **33** including a tubular protective shield removably enclosing said frangible material layer, said shield being adapted to contain explosively propelled fragments of said frangible material, whereby both said fractured frangible material layer and said shield may be separated from said joint.

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