

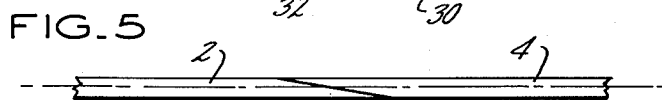
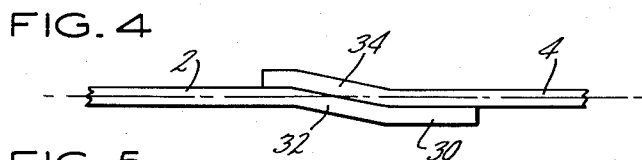
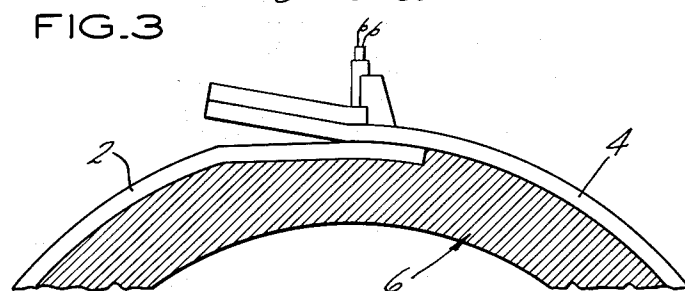
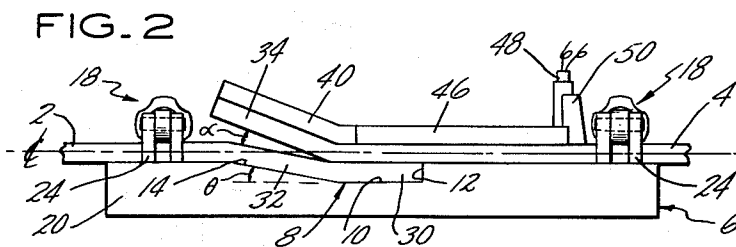
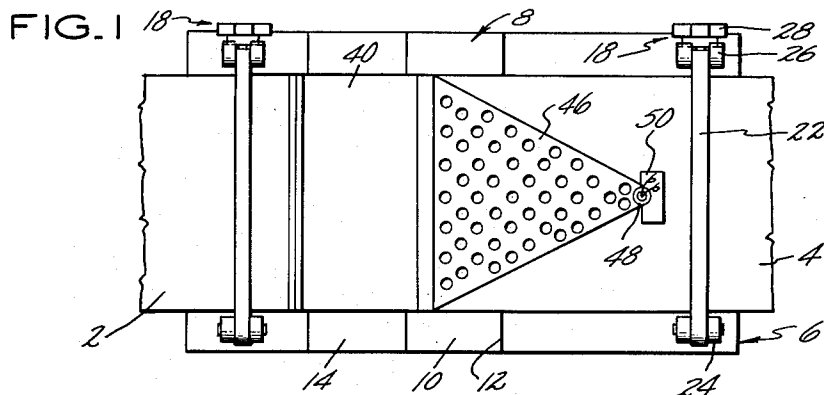
Aug. 3, 1965

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3,197,855

METHOD OF EXPLOSIVELY FORMING A SCARF TYPE JOINT

Filed Dec. 28, 1962



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3,197,855

METHOD OF EXPLOSIVELY FORMING A SCARF TYPE JOINT

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Filed Dec. 28, 1962, Ser. No. 248,002

11 Claims. (Cl. 29—470.1)

This invention relates to the formation of a joint between two materials capable of being joined by an explosive charge.

An object of this invention is to provide a method for connecting two metals which can be easily set up without elaborate preparations, and without costly equipment.

Another object of this invention is to provide a method of connecting two metal plates or sheets whereby the finished weld will be relatively strong in tension.

A further object of this invention is to provide a method whereby the plates or sheets of metal to be joined are each angularly positioned so that an explosive charge placed on the moving plate will bring the two plates or sheets into contact upon explosion and have them fixed together in a desired position.

Another object of this invention is to provide means for holding the metals being joined to obtain a joint having a satisfactory strength in tension.

A further object of this invention is to provide a method of making a seam joint between two metal plates or sheets.

Other objects and advantages will be apparent from the specification and from the accompanying drawings which illustrate the invention.

FIGURE 1 is a top view showing two metal plates or sheets positioned on a holding die in readiness for ignition of the explosive charge;

FIGURE 2 is a side view of the invention shown in FIGURE 1;

FIGURE 3 is a side view showing the adaptability of the die to a curved surface;

FIGURE 4 is a view showing the two plates or sheets of metal joined just after the firing of the explosive charge; and

FIGURE 5 is a view showing the joint after the excess material has been machined off leaving a smooth scarf joint.

In the field of explosively joining metals, some work has been done which was reported, for example, in an article entitled "Explosive Bonding Gains Ground Through Simplified Setups," which appeared in the May 31, 1962, issue of The Iron Age. Another article of interest is one entitled "Now . . . It's Explosive Welding," and this article appeared in the April 17, 1961, issue of American Machinist/Metalworking Manufacturing.

With reference to FIGURES 1 and 2, two plates 2 and 4 are shown fixedly positioned in a holding die 6. The holding die 6 has a recess 8 located in the face thereof for receiving the end of the plate 2. This recess 8 is formed having a first bottom surface 10 following the top surface of the die at a constant distance therebelow equal to the height of the end wall 12, which extends upwardly from one end of said bottom surface, and having a second bottom surface 14 being inclined and extending upwardly from the other end of the bottom surface 10 to the top surface of the die 6. The length of the bottom surface 10 is made small since it does not form part of the finished joint.

The holding die 6 includes two sheet or plate-engaging devices 18 for fixedly holding each of the plates 2 and 4

to the base 20 of the die 6 during the firing of the explosive charge. Each plate-engaging device 18 comprises a bar 22 which is pivoted to a bracket 24 extending upwardly from the base 20 of the die. Each bracket 24 comprises two upstanding lugs. The free end of each bar 22 has an attach-detach mechanism which engages a bracket 26 on the die. A handle 28 is operable to engage or disengage the attach-detach device. While one specific holding device 18 has been shown; it is to be understood that other desirable devices can be used.

In making a holding die 6 with which to practice the disclosed method of joining two plates, the recess 8 is formed making the end wall 12 of a height approximately equal to the thickness of the plate 2 to be used. After this, the angle θ is determined. Since it can be seen that the sine of θ is equal to the thickness of the plate 2 divided by the finished scarf weld length, as soon as a desired weld length has been selected and the thickness of the plate is known, the angle θ can be easily figured.

In preparing plates 2 and 4 to be placed on the die 6, the end of the plate 2 is formed having an offset portion 30 with an angular connecting portion 32. The offset portion 32 is formed so that the end of the plate 2 will be positioned against the end wall 12 of the recess and the bottom of the offset portion will engage the bottom surface 10 of the recess. The angular connecting portion 32 is constructed to form an angle θ with the offset portion and is formed of such a length so it will engage the second bottom surface 14. The adjacent portion of the plate 2 connected to the angular connecting portion rests on the top of the die 6. The plate engaging device 18 contacts the plate 2 at this point. When the end of plate 2 has been prepared, the lower face of the main portion is located approximately on a plane with the upper face of the offset portion 20.

The plate 4 is then formed having an angular end portion. This angular end portion 34 forms an angle α with the angular connecting portion 32 of the plate 2. It can be seen then that the angular end portion 34 of plate 4 must be formed at an angle of θ plus α to provide the proper angular relationship with the angular connecting portion 32 of plate 2. Plate 4 is positioned so that the line at which the angular end portion extends upwardly is located adjacent the line at which the angular connecting portion 32 extends upwardly. The flat portion of the plate 4 engages the top surface of the die at that point and the other plate-engaging device 18 fixedly holds the plate 4 in place. It is to be noted that the center line of plate 2 is now in line with the center line of plate 4.

An explosive 40 is placed over the face of the angular portion of plate 4 located away from the plate 2. This explosive extends over an area including the bend in the plate 4 to a location on said angular portion 34 including the length of the angular connecting portion 32 of plate 2. This distance from the bend including the portion 32, of course, is the finished scarf weld length. This explosive can be of the flexible sheet type. One type is the Du Pont EL-506 series. Further information on this type of explosive is set forth in U.S. Patent No. 2,992,087. To prevent marking, marring, or burning of the plate 4, a fabric tape or other protective layer can be placed between the explosive sheet and the plate 4.

A line wave generator 46 is shown in FIGURES 1 and 2 to initiate an explosion simultaneously over the length of the sheet 40. The generator shown is of the perforated equilateral triangle type. The perforations in the generator are so positioned that a detonation made at any one of the apexes will proceed as a straight line detonation zone to the opposite edge.

As shown in FIGURES 1 and 2, a detonator 48 is

positioned at the apex of the line wave generator 46 which is opposite the side of the generator which is to simultaneously ignite the length of the explosive sheet 40. The detonator 48 is held in position by a support 50. This support can be a block of clay which can be manually kneaded or manipulated to properly fit any location at which a detonator needs support. The detonator 48 can be of the standard commercial type which is ignited by the closing of a circuit at a control point located a safe distance from the detonator and resulting explosion. Other types of detonators can be used such as the fuse initiated type.

In determining a satisfactory angle α and a satisfactory amount of explosives to be placed on the upper face of the angular portion of moving plate 4, it is necessary to know the material of each of the plates 2 and 4. One way of determining a satisfactory angle α and satisfactory amount of explosive is to perform a series of tests as follows:

(1) obtain sample pieces of the materials to be joined representing plates 2 and 4;

(a) for one set of pieces turn up the moving end of plate 4 so that it forms an angle of 5° with plate 2; and

(b) for another set of pieces turn up the moving end of plate 4 so that it forms an angle of 15° with plate 2;

(2) place a sheet of explosive having approximately 19 cal./in.²/.001 sheet thickness over the proper area of each plate 4 having a thickness of approximately twice the thickness of the moving plate 4. It is to be understood that if an explosive sheet is used having approximately 38 cal./in.²/.001 thickness then the sheet is made the thickness of the plate 4; and

(3) detonate each sheet of explosive and examine the joint formed if any;

(a) if either of the tests results in the formation of a joint which is satisfactory, then a predetermined charge and a predetermined angle are known which will explosively join the two metals so tested; and

(b) if one joint was formed, but it is not quite a satisfactory one, then set up two more tests to be run, with an angle of 2° above and 2° below the original angle setting. For example, if the 15° joint was found to be the better of the two, then angles of 13° and 17° should then be tried. As these are inspected, the same considerations are taken into effect for another joint formation in the event a satisfactory one was not obtained by the last two tests.

Changing the angle is not the only variable to be considered, since the thickness of the explosive sheet can also be varied, which is in effect changing the amount of explosive which will react on the face of the moving plate. If a satisfactory joint is not formed by some angle using the explosive sheets above which were approximately twice the thickness of the moving plate, then the angle at which the best test joint was formed can be used while varying the thickness of the sheet on either side of the thickness which was originally used. For example, one test can then be set up with an explosive sheet having approximately 19 cal./in.²/.001 thickness using a thickness of $1\frac{1}{2}$ times the thickness of the moving plate and another test can be set up with an explosive sheet having a thickness of $2\frac{1}{2}$ times the thickness of the moving plate. Here, as before, a comparison can be made between the two tests to determine the better joint formed. Then tests can be made in that direction, that is, in a direction calling for more or less explosive.

Experiments indicate that of the metals capable of being explosively joined, the angle of the moving plate with relation to the fixed plate will range between 2° and 25° for a majority of the cases in which a joint is formed using subject invention. Further, experiments show that a satisfactory charge on the face of the moving plate will fall in the range of from 10 to 85 cal./in.²/.001 plate thickness in a majority of cases.

Materials which have been explosively joined are the following:

Dissimilar metals

- (1) Beryllium Copper/Haynes 25
- (2) Beryllium Copper/6061 Aluminum (T6)
- (3) Beryllium Copper/347 Stainless Steel
- (4) Tantalum/347 Stainless Steel
- (5) Tantalum/Columbium-1% Zirconium
- (6) Tantalum/Haynes 25
- (7) Tantalum/Hastelloy N
- (8) Tantalum/Inconel 718
- (9) Columbium-1% Zirconium/Hastelloy N
- (10) Columbium-1% Zirconium/Inconel 718
- (11) 347 Stainless Steel/6061 Aluminum (T6)
- (12) 347 Stainless Steel/Haynes 25
- (13) 347 Stainless Steel/Inconel X
- (14) 347 Stainless Steel/Hastelloy X
- (15) 347 Stainless Steel/Inconel
- (16) Haynes 25/6061 Aluminum (T6)
- (17) Haynes 25/Greek Ascology
- (18) Haynes 25/Hastelloy X
- (19) Inconel X/Haynes 25
- (20) Inconel X/Waspaloy
- (21) Inconel X/Greek Ascology
- (22) Waspaloy/Greek Ascology
- (23) Greek Ascology/347 Stainless Steel
- (24) Greek Ascology/Haynes 25
- (25) Inconel/Inconel X
- (26) Waspaloy/Hastelloy X

Similar metals

- (1) Inconel/Inconel
- (2) Waspaloy/Waspaloy
- (3) Haynes 25/Haynes 25
- (4) Greek Ascology/Greek Ascology
- (5) 347 Stainless Steel/347 Stainless Steel
- (6) 6061 Aluminum (T6)/6061 Aluminum (T6)
- (7) 7075 Aluminum (T6)/7075 Aluminum (T6)
- (8) Hastelloy X/Hastelloy X
- (9) Hastelloy N/Hastelloy N
- (10) Inconel X/Inconel X
- (11) Inconel 718/Inconel 718
- (12) Tantalum/Tantalum
- (13) Beryllium Copper/Beryllium Copper
- (14) Columbium-1% Zirconium/Columbium-1% Zirconium
- (15) 17-7PH Stainless Steel/17-7PH Stainless Steel

Examples are set forth below showing materials on which subject invention has been used:

- (1) Material: 347 Stainless Steel to 347 Stainless Steel
Thickness of plate: .050"
Angle α used: 20°
Sheet thickness of EL-506A: .200"
- (2) Material: Waspaloy to Waspaloy
Thickness of plate: .050"
Angle α used: 15°
Sheet thickness of EL-506A: .200"
- (3) Material: 17-7PH Stainless Steel to 17-7PH Stainless Steel
Thickness of plate: .048"
Angle α used: 10°
Sheet thickness of EL-506A: .084"

While one way of determining a predetermined angle α and amount of explosive has been set forth, it is to be understood that other ways can also be used. For two plates to be explosively joined, there is a range of satisfactory angles α and of explosive charge amounts.

With reference to FIGURE 3, a holding die 6 is shown which will permit a joint being made on a curved surface. This die can be made circular or of other desired shapes. When made circular or of any other closed or restricted shape which makes the removal of the die difficult, the die is made segmented to move out of engagement with the parts being joined. As in the die shown

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in FIGURES 1 and 2, plate-engaging devices 18 are used to fixedly hold each of the plates together. The explosive charge 40 is located on the moving portion of plate 4 in the same manner as before and the detonator can be positioned with a wave generator or without as shown in FIGURE 3. In this figure, the detonator is located at a corner of the sheet of explosive.

FIGURE 4 shows the two plates or sheets of metal joined after the explosion and FIGURE 5 shows the joint with the weld length extending for a distance equal to approximately the length of the bottom surface 14 of the die 6.

It is to be understood that the invention is not limited to the specific form herein illustrated and described, but may be used in other ways without departure from its spirit as defined by the following claims.

We claim:

1. Method of joining metal plate ends capable of being explosively joined:

- (a) forming a first plate end with an offset portion having an angular connecting portion;
- (b) forming a second plate end with an angular extending portion;
- (c) placing said second plate end on the offset portion of said first plate end with the angular portion forming an angle with the angular connecting portion of the first plate end;
- (d) supporting the first plate end under the offset portion, angular connecting portion, and adjacent plate portion;
- (e) placing an explosive charge over the face of the angular portion of said second plate end remote from said first plate end to move said angular portion of said second plate end into joining engagement with the angular connecting portion of said first plate end;
- (f) fixing said plate ends in position; and
- (g) igniting said explosive charge.

2. Method of joining metal plate ends capable of being explosively joined:

- (a) forming a first plate end with an offset portion having an angular connecting portion;
- (b) forming a second plate end with an angular extending portion;
- (c) placing said second plate end on the offset portion of said first plate end with the angular portion forming an angle with the angular connecting portion of the first plate end;
- (d) supporting the first plate end under the offset portion, angular connecting portion, and adjacent plate portion;
- (e) placing an explosive charge over the face of the angular portion of said second plate end facing away from said first plate end to move said angular portion of said second plate end into joining engagement with the angular connecting portion of said first plate end;
- (f) fixing said plate ends in position;
- (g) igniting said explosive charge; and
- (h) removing the excess portion of the overlapped plate ends to form a scarf joint.

3. Method of joining metal plate ends capable of being explosively joined:

- (a) forming a first plate end with an offset portion having an angular connecting portion;
- (b) forming a second plate end with an angular extending portion;
- (c) placing said second plate end on the offset portion of said first plate end with the angular portion forming a predetermined angle with the angular connecting portion of the first plate end;
- (d) supporting the first plate end under the offset portion, angular connecting portion, and adjacent plate portion;
- (e) placing an explosive charge over the face of the

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angular portion of said second plate end facing away from said first plate end to move said angular portion of said second plate end into joining engagement with the angular connecting portion of said first plate end;

- (f) fixing said plate ends in position; and
- (g) igniting said explosive charge.

4. Method of joining metal plate ends capable of being explosively joined:

- (a) forming a first plate end with an offset portion having an angular connecting portion;
- (b) forming a second plate end with an angular extending portion;
- (c) placing said second plate end on the offset portion of said first plate end with the angular portion forming an angle with the angular connecting portion of the first plate end;
- (d) supporting the first plate end under the offset portion, angular connecting portion, and adjacent plate portion;
- (e) placing a predetermined explosive charge over the face of the angular portion of said second plate end facing away from said first plate end to move said angular portion of said second plate end into joining engagement with the angular connecting portion of said first plate end;
- (f) fixing said plate ends in position; and
- (g) igniting said explosive charge.

5. Method of joining metal plate ends capable of being explosively joined:

- (a) forming a first plate end with an offset portion having an angular connecting portion;
- (b) forming a second plate end with an angular extending portion;
- (c) placing said second plate end on the offset portion of said first plate end with the angular portion forming a predetermined angle with the angular connecting portion of the first plate end;
- (d) supporting the first plate under the offset portion, angular connecting portion, and adjacent plate portion;
- (e) placing a predetermined explosive charge over the face of the angular portion of said second plate end facing away from said first plate end to move said angular portion of said second plate end into joining engagement with the angular connecting portion of said first plate end;
- (f) fixing said plate ends in position; and
- (g) igniting said explosive charge.

6. Method of joining metal plate ends capable of being explosively joined:

- (a) forming a first plate end with an offset portion having an angular connecting portion with a predetermined angular setting;
- (b) forming a second plate end with an angular extending portion;
- (c) placing said second plate end on the offset portion of said first plate end with the angular end portion forming an angle with the angular connecting portion of the first plate end;
- (d) supporting the first plate end under the offset portion, angular connecting portion, and adjacent plate portion;
- (e) placing an explosive charge over the face of the angular portion of said second plate end facing away from said first plate end to move said angular portion of said second plate end into joining engagement with the angular connecting portion of said first plate end;
- (f) fixing said plate ends in position; and
- (g) igniting said explosive charge.

7. Method of joining metal plate ends capable of being explosively joined:

- (a) forming a first plate end with an offset portion hav-

ing an angular connecting portion with a predetermined angular setting;

- (b) forming a second plate end with an angular extending portion with a predetermined angular setting; 5
 - (c) placing said second plate end on the offset portion of said first plate end with the angular portion forming an angle with the angular connecting portion of the first plate end; 10
 - (d) supporting the first plate end under the offset portion, angular connecting portion, and adjacent plate portion; 15
 - (e) placing an explosive charge over the face of the angular portion of said second plate end facing away from said first plate end to move said angular portion of said second plate end into joining engagement with the angular connecting portion of said first plate end; 20
 - (g) igniting said explosive charge.
8. Method of joining metal plate ends capable of being explosively joined: 20
- (a) forming a first plate end with an offset portion having an angular connecting portion with a predetermined angular setting; 25
 - (b) forming a second plate end with an angular extending portion with a predetermined angular setting; 30
 - (c) placing said second plate end on the offset portion of said first plate end with the angular portion forming an angle with the angular connecting portion of the first plate end; 35
 - (d) supporting the first plate end under the offset portion, angular connecting portion, and adjacent plate portion; 40
 - (e) placing a predetermined explosive charge over the face of the angular portion of said second plate end facing away from said first plate end to move said angular portion of said second plate end into joining engagement with the angular connecting portion of said first plate end; 45
 - (f) fixing said plate ends in position; and 50
 - (g) igniting said explosive charge.
9. Method of joining metal plate ends capable of being explosively joined: 55
- (a) forming a first plate end with an offset portion having an angular connecting portion with a predetermined angular setting; 60
 - (b) forming a second plate end with an angular extending portion with a predetermined angular setting; 65
 - (c) placing said second plate end on the offset portion of said first plate end with the angular portion forming an angle with the angular connecting portion of the first plate end; 70
 - (d) supporting the first plate end under the offset portion, angular connecting portion, and adjacent plate portion; 75
 - (e) placing a predetermined explosive charge over the face of the angular portion of said second plate end facing away from said first plate end to move said angular portion of said second plate end into joining engagement with the angular connecting portion of said first plate end; 80
 - (f) fixing said plate ends in position; 85
 - (g) igniting said explosive charge; and 90
 - (h) removing the excess portion of the overlapped plate ends to form a scarf joint. 95

10. Method of joining metal plate ends capable of being explosively joined:

- (a) forming a first plate end with an offset portion having an angular connecting portion so that the offset portion is offset by an amount approximately equal to the thickness of the first plate end; 5
- (b) forming a second plate end having a thickness approximately equal to the thickness of the first plate end with an angular extending portion; 10
- (c) placing said second plate end on the offset portion of said first plate end with the angular portion forming an angle with the angular connecting portion of the first plate end; 15
- (d) supporting the first plate end and second plate end under the offset portion, angular connecting portion, and adjacent plate portions; 20
- (e) placing an explosive charge over the face of the angular portion of said second plate end remote from said first plate end to move said angular portion of said second plate end into joining engagement with the angular connecting portion of said first plate end; 25
- (f) fixing said plate ends in position; and 30
- (g) igniting said explosive charge. 35

11. Method of joining metal plate ends capable of being explosively joined:

- (a) forming a first plate end having first and second plate surfaces with an offset portion having an angular connecting portion so that the first surface of the offset portion is in approximately the same plane as the second surface of the plate having the first plate end; 5
- (b) forming a second plate end having third and fourth plate surfaces with an angular extending portion; 10
- (c) placing said fourth plate surface of said second plate end on the first plate surface of said offset portion of said first plate end with the angular portion forming an angle with the angular connecting portion of the first plate end; 15
- (d) supporting the second plate surface of said first plate end under the offset portion, angular connecting portion, and adjacent plate portion; 20
- (e) placing an explosive charge over the face of the angular portion of said second plate end remote from said first plate end to move said angular portion of said second plate end into joining engagement with the angular connecting portion of said first plate end; 25
- (f) fixing said plate ends in position; and 30
- (g) igniting said explosive charge. 35

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- (Both papers are in Section III of Advanced High Energy Rate Forming, published by American Society of Tool & Manufacturing Engineers.) 65

JOHN F. CAMPBELL, *Primary Examiner*.

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,197,855

August 3, 1965

William A. Carter et al.

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 7, after line 18, insert the following:

(f) fixing said plate ends in
position; and

Signed and sealed this 15th day of February 1966.

(SEAL)

Attest:

ERNEST W. SWIDER

Attesting Officer

EDWARD J. BRENNER

Commissioner of Patents