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PROCESS FOR EXPLOSIVELY BONDING METAL LAYERS

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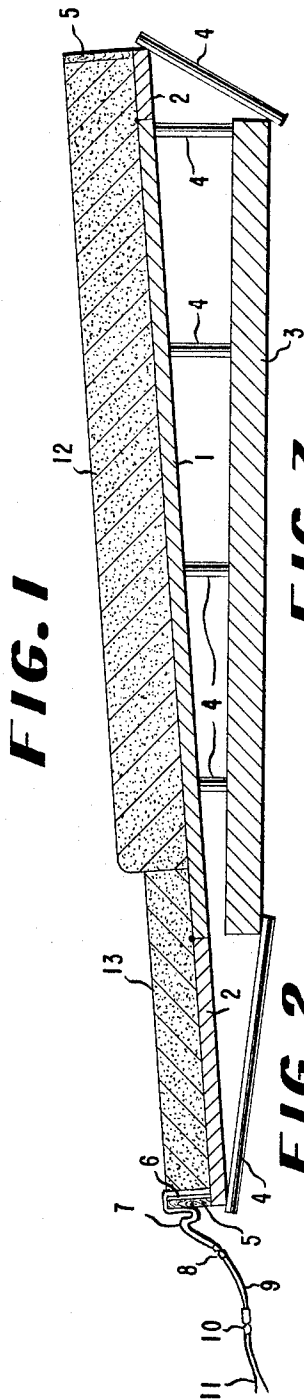


FIG. 2

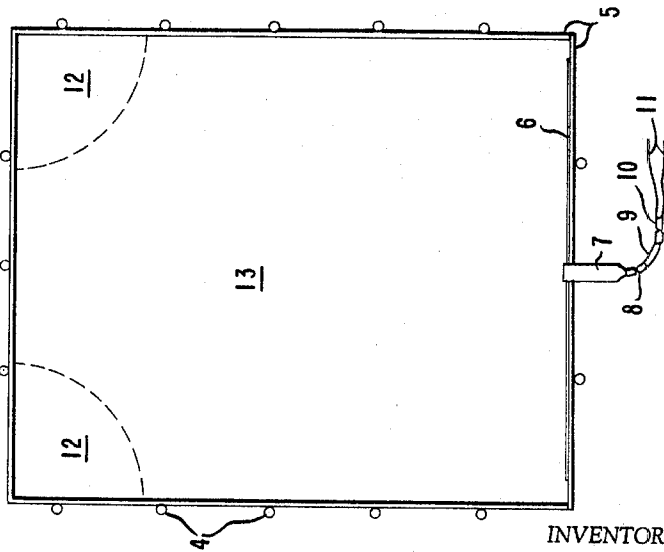


FIG. 3

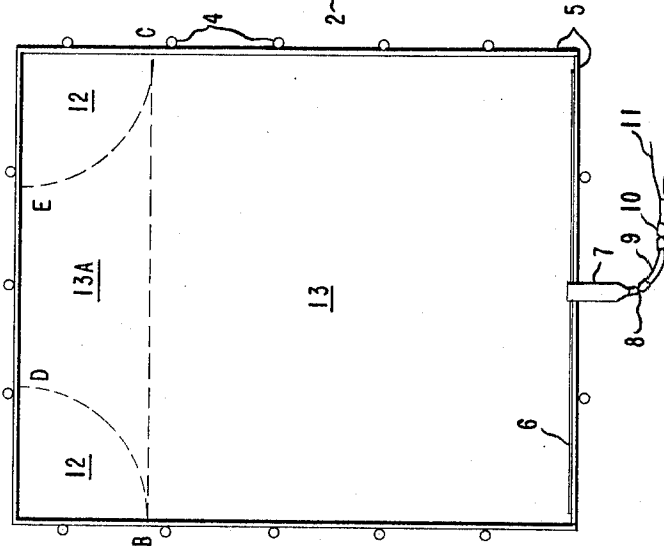
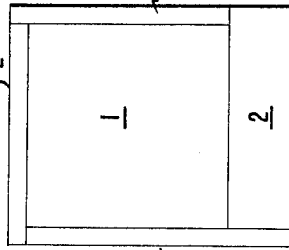


FIG. 4



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PROCESS FOR EXPLOSIVELY BONDING METAL LAYERS

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The present invention relates to an improved method of bonding metals by explosive means.

Co-pending application Serial No. 65,194, now U.S. Patent 3,137,937, teaches a process for bonding metal layers to form a multilayered body by supporting a metal cladding layer a distance of at least 0.001 inch from the metal base layer, placing a layer of an explosive having a detonation velocity less than 120% of the sonic velocity of the metal having the highest sonic velocity in the system on the outside surface of the metal cladding layer, and initiating the explosive so that detonation is propagated parallel to the metal layers.

Although the bonding obtained by this process is excellent, some areas around the periphery of the clad metal system may be left unbonded. In systems in which the metal cladding layer is relatively thick, i.e., about 1/2 inch thick or thicker, and the detonation velocity of the explosive layer is relatively high, i.e., more than about 80% of the sonic velocity of the metals in the system, the problem of unbonded zones is particularly acute over those areas of the clad metal system opposite to the point(s) of initiation of the explosive layer.

The present invention provides a process for explosively bonding metal layers to form a multilayered body which insures essentially complete bonding of the metal layers over those areas of the multilayered body which are opposite to the point(s) of initiation of the explosive which comprises

(1) supporting a substantially rectangular metal cladding layer at least 1/2 inch thick separated by a distance of at least about 1/32 inch from a substantially rectangular metal base layer,

(2) covering the outside surface of said metal cladding layer with a composite explosive layer comprising at least two sections positioned in juxtaposed relationship, at least one of said sections being a first explosive having a detonation velocity between about 1200 meters per second and 80% of the sonic velocity of the metal having the highest sonic velocity in the system, and one section being a second explosive having a detonation velocity higher than that of the first explosive and between about 80% and 120% of the sonic velocity of the metal having the highest sonic velocity in the system, and

(3) initiating said composite explosive layer so that detonation is propagated parallel to the plane of the metal cladding layer, and so that said second explosive initiates but is not initiated by said first explosive.

The process of the present invention can be carried out using metal extension pieces attached to one or more of the edges of the metal cladding layer as described in co-pending application Serial No. 253,485, filed January 23, 1963. If used, each metal extension piece must be contiguous to an edge of the cladding layer for substantially the length of that edge. Further, the extension piece must extend in a direction perpendicular to the length of that edge for a distance of at least 4 times the thickness of the cladding layer, must have an areal density between 50 and 150% of the areal density of the cladding layer, and must be sheared from the cladding layer during the explosive process. Metal extension pieces serve to minimize those unbonded zones around the edges of the clad metal system which are caused by "edge lag"

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and by entry of gaseous detonation products into the bonding zone as is fully explained in the aforementioned co-pending application. The process of the present invention is directed toward completely eliminating unbonded zones and other deleterious conditions such as spalling, etc., specifically over those areas opposite to the point(s) of initiation of the explosive which unbonded zones are caused by dynamic considerations directly concerned with the position of these zones relative to the point(s) of initiation of the explosive. The difficulties overcome by the process of the present invention are above and beyond those associated with "edge lag" and detonation gases for which metal extension pieces represent a satisfactory solution.

For a more complete understanding of the process of the present invention reference is now made to the attached drawings in which like numbers indicate similar elements.

FIGURE 1 illustrates the cross-section of a particular embodiment of an assembly which may be used for the practice of the present invention,

FIGURES 2 and 3 are top views of assemblies which may be used for the practice of the present invention, and

FIGURE 4 is a top view of a portion of the assemblies of FIGURES 1 and 2.

In FIGURE 1, metal layer 1 to which are attached metal extension pieces 2 is supported above metal layer 3 by means of metal rods 4 which are attached to the free edges of the metal extension pieces 2 and metal layer 3. A thin strip 6 of a relatively high velocity explosive is placed on the inside surface of one side of a wooden frame 5. To this are attached a second strip 7 of a relatively high velocity explosive, a first blasting cap 8, a length of a low energy detonating cord 9, and a second, electric blasting cap 10 having lead wires to a source of electric current 11. One rectangular section of the area defined by the upper surfaces of a metal layer 1 and metal extension pieces 2 is covered by a uniform layer 12 of a first explosive having a detonation velocity between about 1200 meters per second and 80% of the sonic velocity of metal layers 1 and 3 and the remaining rectangular section of the area is covered by a uniform layer 13 of a second explosive having detonation velocity higher than that of the explosive layer 12 and between about 80% and 120% of the sonic velocity of metal layers 1 and 3.

FIGURE 2 is a top view of an assembly which is distinguished from the assembly of FIGURE 1 in that two adjacent corners of the area defined by the upper surfaces of metal layer 1 and metal extension pieces 2 are covered with uniform layers 12 of the first explosive and the remainder of the area is covered with a uniform layer 13 of the second explosive.

FIGURE 3 is a top view of an assembly which is distinguished from the assembly of FIGURE 2 in that the section of the area defined by the upper surfaces of metal layer 1 and extension pieces 2 which is covered by the second explosive comprises a uniform layer 13 and a tapered layer 13A of this explosive. Tapered layer 13A decreases in thickness from the thickness of uniform layer 13 along the line BC to one half the thickness of uniform layer 13 along the line DE.

FIGURE 4 shows the configuration in which metal extension pieces 2 are attached to metal layer 1 in the assemblies of FIGURES 1 and 2.

The specific composition and plane dimensions of the metal layers are not critical and the metal base layer can be of any desired thickness.

The means of supporting the metal cladding layer separated from the metal base layer is not critical. The

minimum separation between the layers which results in effective bonding is about $\frac{1}{32}$ inch.

The loading and confinement of the composite explosive charge are not critical provided these conditions are controlled so that the detonation velocities of the explosives which comprise the charge are within the limits defined above.

The term "sonic velocity" as used throughout this application in connection with metals and metallic systems refers to the velocity of the plastic shock wave which forms when a stress which is applied just exceeds the elastic limit for unidimensional compression of the particular metal or metallic system involved. A full discussion of sonic velocity, methods for calculating and for experimentally determining sonic velocity, and values of the sonic velocity for a number of metals are given in co-pending application Serial No. 65,194.

If the detonation velocity of the first explosive which comprises at least one section of the composite explosive charge is below 1200 meters per second, the explosive fails to develop the energy necessary to firmly bond the metals within the sense and scope of the invention. If the detonation velocity of the second explosive which comprises one section of the composite explosive charge exceeds 120% of the sonic velocity of the metal having the highest sonic velocity in the system, oblique shock waves often ensue which prevent formation of a strong, continuous metal-to-metal bond.

Although the reasons for the effectiveness of the process of the present invention in preventing unbonded zones over those areas of a clad metal system opposite to the point(s) of initiation of the explosive layer are not fully understood, the limits within which the novel process can be effectively practiced are understood in terms of the following observations.

First, as the thickness of the cladding layer increases the problems associated with unbonded zones around the periphery of the clad metal system increases. Often when the thickness of the cladding layer is $\frac{1}{2}$ inch or more unbonded zones opposite to the initiation point(s) are not completely eliminated by extension pieces.

Second, as the detonation velocity of the explosive layer approaches the sonic velocity of the metals in the system, the difficulty of obtaining a completely bonded clad metal system increases. Often when the detonation velocity of the explosive layer exceeds 80% of the sonic velocity of the metal having the highest sonic velocity in the system other difficulties such as spalling of the metal layers opposite to the initiation point(s) are observed.

Third, when the thickness of the cladding layer is $\frac{1}{2}$ inch or more and an explosive having a detonation velocity of more than 80% of the sonic velocity of the metals in the system is used, complete bonding over those areas of the clad metal system opposite to the point(s) of initiation of the explosive is achieved by replacing the uniform layer of explosive having a detonation velocity of more than 80% of the sonic velocity of the metals in the system with a composite explosive layer, one section of which comprises the aforesaid explosive having a relatively high detonation velocity and at least one section of which, i.e., that section or those sections covering the areas of the metal cladding layer opposite to the point(s) of initiation, comprises an explosive having a detonation velocity lower than that of the aforesaid explosive and between 1200 meters per second, the minimum velocity effective in cladding, and 80% of the sonic velocity of the metals in the system. This decrease in detonation velocity over the problem areas opposite to the point(s) of initiation apparently is responsible for the complete bonding achieved over those areas by the process of the present invention.

Generally there is a considerable difference between the detonation velocities of the various explosives since the process of the present invention is particularly effective

when the detonation velocity of the higher velocity explosive is at least 10% greater than that of the lower velocity explosive.

The location and means of initiation of the composite explosive charge are not critical provided, however, detonation is propagated parallel to the metal cladding layer and the second or higher velocity explosive initiates but is not initiated by the first or lower velocity explosive. This condition is imposed to insure progression of detonation from that section of the composite explosive layer comprising the higher velocity explosive to that section or sections removed from the point(s) of initiation and comprising the lower velocity explosive. The process of the present invention is designed to insure a good metal-to-metal bond between the metal layers over the area(s) removed from or opposite the point(s) of initiation and, as is apparent in the drawings, it is this area(s) which must be covered with the lower velocity explosive. This condition that the higher velocity explosion is not initiated by the lower velocity explosive also eliminates, for example, a 3-section composite layer comprising 2 sections of the lower velocity explosive in juxtaposed relationship to a center section of the higher velocity explosive wherein detonation is propagated from the lower velocity to the higher velocity and then to the lower velocity explosive. As is well known in the art explosive cladding generally is best effected using a uniform layer of explosive and the fact that change to a lower velocity explosive over those areas of the system removed from the points of initiation is effective in achieving good bonding over those areas represents a surprising aspect of the novel process. Any other non-uniformity in the explosive layer such as, for example, more than one mutually separated section of the higher velocity explosive or a section of the lower velocity explosive contiguous to the point(s) of initiation generally results in deformation of the clad metal system.

Particularly effective and preferred embodiments of the present invention comprise an explosive cladding process as described above wherein the composite explosive charge is initiated at a point or points along one edge of the assembly and the two corners or the entire end of the metal cladding layer away from the point or points of initiation are covered with the lower velocity explosive. When the two corners away from the point or points of initiation are covered with the lower velocity explosive, and the detonation velocity of the higher velocity explosive approaches the sonic velocity of the metals, it is often desirable to taper the layer of the higher velocity explosive substantially as shown in FIGURE 3 to prevent spalling of the metal layers, e.g., along line DE in FIGURE 3. Other composite explosive layers which can be used in the process of the present invention include, for example, a rectangular composite explosive layer wherein a center section comprises the higher velocity explosive and a section around the periphery of the layer comprises the lower velocity explosive. Such a layer would be initiated, for example, in the center of the layer. In practice, if more than one section of the lower velocity explosive is used the sections can comprise different low velocity explosives having substantially equivalent detonation velocities.

As is obvious to one skilled in the art, a great variety of explosive compositions may be used within the sense and scope of this invention. Among the suitable higher velocity explosives are grained amatol explosives comprising mixtures of ammonium nitrate and trinitrotoluene in various proportions and a number of flexible sheet explosives based on pentaerythritol tetranitrate. Among the suitable lower velocity explosives are mixtures of ammonium nitrate and fuel oil or dinitrotoluene in various proportions, mixtures of the above-described amatol explosives with inert diluents such as sodium chloride, and with sodium nitrate, etc.

The following examples illustrate some of the modi-

fications of the process of the present invention. They are intended as illustrative only, however, and are not to be considered as exhaustive or limiting.

Example 1

A carbon steel bar $\frac{1}{2}$ inch thick, 8 inches wide, and 26 inches long is butted along its length against one of the 24-inch edges of a stainless steel plate $\frac{1}{2}$ inch thick, 24 inches wide, and 24 inches long so that a 2-inch segment of the length of the bar extends beyond the end of the 24-inch edge of the plate. A second carbon steel bar $\frac{1}{2}$ inch thick, 2 inches wide and 26 inches long is butted along its length against one of the adjacent 24-inch edges of the plate so that one end of the bar is flush with the 90° angle formed by the extension of the first bar and the second 24-inch edge of the plate. A third carbon steel bar $\frac{1}{2}$ inch thick, 2 inches wide, and 26 inches long is butted along its length against the 24-inch edge of the plate which is parallel to the edge against which the first bar is butted so that one end of the third bar is flush with the 90° angle formed by the extension of the second bar and the third 24-inch edge of the plate, and the other end of the bar extends 2 inches beyond the third 24-inch edge of the plate. A fourth carbon steel bar $\frac{1}{2}$ inch thick, 2 inches wide, and 32 inches long is butted against the remaining 24-inch edge of the plate so that one end of the bar is flush with the 90° angle formed by the third bar and the fourth 24-inch edge of the plate and is flush with the 8-inch edge of the first bar. The four bars are fusion welded in place with poor penetration along the upper surfaces of the bars and the plate at the joints between the bars and between the bars and the plate thus forming an 8-inch extension on one edge of the plate and 2-inch extensions on the remaining 3 edges of the plate substantially as illustrated in FIGURE 4.

The stainless steel plate with extensions as described above is positioned above and at a 2° angle to a carbon steel plate 1 inch thick, 24 inches wide, and 24 inches long. The smallest distance between the adjacent surfaces of the two plates is $\frac{1}{2}$ inch between the edge of the stainless steel plate to which the 8-inch extension is attached and the corresponding, adjacent edge of the second plate. The stainless steel plate is supported by carbon steel rods $\frac{1}{2}$ inch in diameter which are welded to the outside of the extension bars and to the outside edges of the carbon steel plate on 8-inch centers. A rectangular wooden frame, $\frac{1}{8}$ inch in wall thickness, 28 inches wide and 34 inches long is placed on the rectangular perimeter formed by the outside edges of the extension bars. One of the two 28-inch sides of the frame is $\frac{1}{4}$ inches high and a contiguous 10-inch segment of each of the adjacent 34-inch sides is $\frac{1}{4}$ inches high. The other 28-inch side of the frame is 2 inches high and the two remaining 24-inch segments of the 34-inch sides are 2 inches high. The frame is positioned so that the side of the frame which is 28 inches long and $\frac{1}{4}$ inches high is contiguous to the outside edge of the 8-inch extension to the stainless steel plate. A strip .050 inch thick, $\frac{1}{4}$ inches wide and 26 inches long of an explosive composition having a velocity of detonation of 7300 meters per second and comprising 70 parts very fine pentaerythritol tetranitrate and 30 parts of a 50/50 mixture of butyl rubber and a thermoplastic terpene resin which is a mixture of polymers of β -pinene of formula $(C_{10}H_{16})_n$ is centered on the inside surface of that side of the wooden frame which is contiguous to the outside edge of the 8-inch extension to the stainless steel plate. One end of a second strip .050 inch thick, about $\frac{1}{4}$ inches wide, and about 4 inches long of the above-described explosive composition is attached to the center of the first strip of explosive. A blasting cap to which are attached, in turn, a low-energy detonating cord (as described in U.S. Patent No. 2,982,210 issued May 2, 1962) about 10 feet long and an electric blasting cap having lead wires to a source of electric current is at-

tached to the free end of the second strip of explosive. A rectangular segment $2\frac{3}{4}$ inches wide and approximately 9 $\frac{7}{8}$ inches long comprising the upper surface of the 8-inch extension and a 2-inch segment of the upper surface of the stainless steel plate is covered with a layer $\frac{1}{4}$ inches thick of a grained amatol explosive comprising 80 parts ammonium nitrate and 20 parts trinitrotoluene and having a weight distribution of 16 grams per square inch. The remainder of the surface which measures $2\frac{3}{4}$ inches wide and $23\frac{7}{8}$ inches long is covered with a layer 2 inches thick of an explosive composition comprising 94 parts ammonium nitrate prills and 6 parts diesel oil having a weight distribution of ammonium nitrate of 28.4 grams per square inch to form an assembly substantially as illustrated in FIGURE 1. The detonation velocity of the amatol explosive is about 4400 meters per second and that of the ammonium nitrate/diesel oil composition is about 3040 meters per second. The sonic velocity of the carbon steel plate which is higher than that of the stainless steel plate is about 4800 meters per second. The assembly is covered with a sheet of waxed paper and a pile of sand 6 feet deep. The electric blasting cap is actuated by application of electric current and initiates, in turn, the low-energy detonating cord, the second blasting cap, the two explosive strips and the layers of amatol and ammonium nitrate/diesel oil explosives. After detonation all four carbon steel bars and the carbon steel supporting rods are sheared from the assembly and the two plates are uniformly, metallurgically bonded together over the entire area of the interface between the plates. Ultrasonic probing reveals no unbonded zones or bond defects over that end of the composite system opposite the site of the initiation of the explosive layers.

A second stainless steel-on-carbon steel system having no unbonded zones or bond defects opposite to the point of initiation is prepared using the technique described above in Example 1. However in this case no carbon steel extension pieces or bars are used.

Example 2

A stainless steel-on-carbon steel composite of the dimensions described in Example 1 is prepared using a technique similar to that of Example 1. However, in this example all four sides of the wooden frame are $\frac{1}{4}$ inches high. The entire upper surface of the assembly is covered with a $\frac{1}{4}$ inch layer of the amatol explosive of Example 1 with the exception of quarter-circle areas of 8-inch radius on the corners of the assembly opposite that side of the assembly to which the explosive strips, blasting caps, etc., are attached. Each of these corners is covered with a 2-inch layer of the ammonium nitrate prills/diesel oil composition of Example 1 to form an assembly substantially as illustrated in FIGURE 2. In this example the amatol explosive has a weight distribution of 18.5 grams/square inch and a detonation velocity of about 4400 meters per second. The weight distribution of the ammonium nitrate in the ammonium nitrate/diesel oil composition is 29 grams per square inch and the detonation velocity of the composition is about 3040 meters per second. As in Example 1, the sonic velocity of the carbon steel plate is about 4800 meters per second. After detonation it is found that all four carbon steel extension bars and the carbon steel supporting rods are sheared from the assembly and the two plates are uniformly, metallurgically bonded together. Ultrasonic probing reveals no unbonded zones or bond defects in the corners of the composite system on which the ammonium nitrate prills/diesel oil composition is placed.

A second stainless steel-on-carbon steel system having no unbonded zones or bond defects opposite to the point of initiation is prepared using the technique described above in Example 2. However, in this case no carbon steel bars are used.

Example 3

A stainless steel-on-carbon steel clad metal system of

the dimensions described in Example 1 is prepared using a technique similar to that of Example 1. However, in this example the 8-inch-wide carbon steel extension bar is 28 inches long, i.e., each end of the bar extends 2 inches beyond the stainless steel plate. The 8-inch extension bar is firmly joined to the plate along the 24-inch edge of the plate with a solid fusion arc weld. However, this bar is joined to the ends of the second extension bar and the fourth extension bar (which in this example is 24 inches long rather than 32 inches long as in Example 1) by means of fusion welds with poor penetration as described in Example 1. A fifth carbon steel extension bar 1 inch thick, 4 inches wide, and 24 inches long is butted along its length against the 24-inch edge of the carbon steel plate which is contiguous to the edge of the stainless steel plate to which the 8-inch extension is attached. This extension bar is joined to the plate by means of a solid fusion arc weld as described above. In this example the angle between the two plates is $1\frac{1}{2}^\circ$. The upper surface of the assembly is covered with a layer of the amatol explosive of Example 1 with the exception of the corners opposite the 8-inch extension. These corners are covered with 2-inch layers of the ammonium nitrate prills/diesel oil composition of Example 1, as described in Example 2. The layer of amatol explosive is $1\frac{1}{4}$ inches thick from the edge of the 8-inch extension to a line 8 inches from the opposite end of the assembly. Over the remainder of the surface of the assembly the thickness of the layer of amatol explosive decreases continuously from $1\frac{1}{4}$ inches to $\frac{5}{8}$ inch substantially as illustrated in FIGURE 3. In this example the detonation velocity of the amatol explosive is about 4460 meters per second and that of the ammonium nitrate/diesel oil composition is about 3000 meters per second. As in Example 1, the sonic velocity of the carbon steel plate is about 4800 meters per second. After detonation it is found that the second, third, and fourth carbon steel extension bars and the carbon steel supporting rods are sheared from the assembly. A 2-inch segment of the length of the first extension bar is sheared from each end of the bar and a 4-inch segment of the width of the bars is sheared from the bar. The bond between the remainder of the first extension bar and the stainless steel plate and the bond between the four inch extension bar and the carbon steel plate remains intact. After the remaining extension bars are cut off the two plates are found to be uniformly, metallurgically bonded together over the entire area of the interface between the plates. Ultrasonic probing reveals no unbonded zones and no bond defects in the corners of the composite system on which the ammonium nitrate prills/diesel oil composition are placed.

A second stainless steel-on-carbon steel system having no unbonded zones or bond defects opposite to the point of initiation is prepared using the technique described above in Example 3. However, in this case no carbon steel extension bars are used.

The invention having been fully described in the foregoing, it is intended to be limited only by the following claims.

I claim:

1. A process for explosively bonding metal layers to form a multi-layered body which comprises

(1) supporting a substantially rectangular metal cladding layer at least $\frac{1}{2}$ inch thick separated by a distance of at least about $\frac{1}{32}$ inch from a substantially rectangular metal base layer,

(2) covering the outside surface of said metal cladding layer with a composite explosive layer comprising at least two sections positioned in juxtaposed relationship, at least one of said sections being a first explosive having a detonation velocity between about 1200 meters per second and 80% of the sonic velocity of the metal having the highest sonic velocity in the system, and one section being a second explosive having a detonation velocity higher than that of the first explosive and between about 80% and 120% of the sonic velocity of the metal having the highest sonic velocity in the system, and

(3) initiating said composite explosive layer so that detonation is propagated parallel to the plane of the metal cladding layer, and so that said second explosive initiates but is not initiated by said first explosive.

2. A process as in claim 1 wherein the detonation velocity of said second explosive is at least 10% higher than the detonation velocity of said first explosive.

3. A process as in claim 1 wherein said first explosive comprises a mixture of ammonium nitrate and oil and said second detonating explosive comprises a mixture of ammonium nitrate and trinitrotoluene.

4. A process as in claim 1 wherein a metal extension piece is attached to each edge of said metal cladding layer, each of said metal extension pieces (a) being contiguous to an edge of the metal cladding layer for substantially the length of said edge, (b) extending in a direction perpendicular to the length of said edge a distance at least four times the thickness of the metal cladding layer, and (c) having an areal density of at least 50% and no more than 150% of the areal density of said metal cladding layer, and said metal extension pieces are sheared from the metal cladding layer during detonation of the explosive.

5. A process as in claim 1 wherein two adjacent corners of said metal cladding layer are covered with said first explosive, and said composite explosive charge is initiated along the edge of said metal cladding layer which is opposite said two adjacent corners.

6. A process as in claim 1 wherein one entire end of said metal cladding layer is covered with said first explosive, and said composite explosive charge is initiated along the edge of said metal cladding layer which is opposite said end.

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