United States Patent [19]

Araki

[11] **3,813,758**

[45] **June 4, 1974**

[54] **EXPLOSIVE WELDING PROCESS**

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[73] Assignees: **Nippon Oils and Fats Company Limited; Showa Senko Kabushiki Kaisha**

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[21] Appl. No.: **207,873**

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Dec. 15, 1970 Japan 45/111180

[52] **U.S. Cl.** **29/470.1,** 29/472.3
[51] **Int. Cl.** **B23k 21/00**
[58] **Field of Search** .... 29/421 E, 470.1, 486, 497.5, 29/472.3

[56] **References Cited**

UNITED STATES PATENTS

3,233,312	2/1966	Cowan et al.	29/470.1 X
3,313,021	4/1967	Wright et al.	29/421 X
3,434,197	3/1969	Davenport	29/470.1
3,474,520	10/1969	Takizawa et al.	29/497.5 X

Primary Examiner—J. Spencer Overholser
Assistant Examiner—Ronald J. Shore
Attorney, Agent, or Firm—Waters, Roditi, Schwartz & Nissen

[57] **ABSTRACT**

An explosive welding process for bonding at least one cladding metal sheet to a base metal sheet, by driving one of the two metallic sheets toward the other by the collision impact of a driver plate to said one sheet. The collision of the driver plate is actuated by the detonation of an explosive layer disposed on its surface.

14 Claims, 13 Drawing Figures

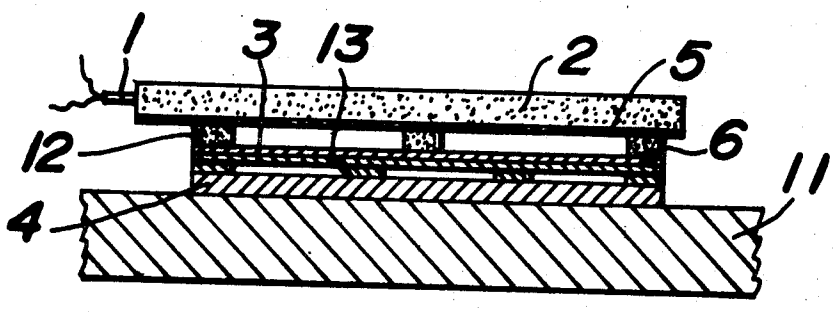


FIG. 1

Prior art

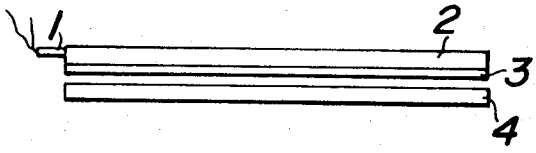


FIG. 2

Prior art

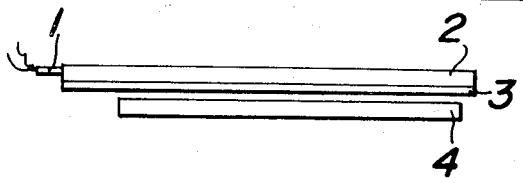


FIG. 3

Prior art

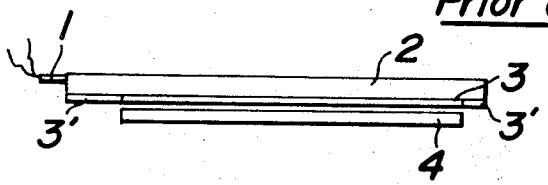


FIG. 4

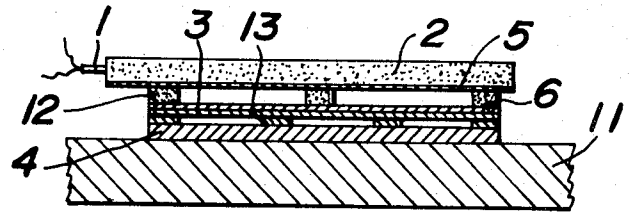


FIG.5

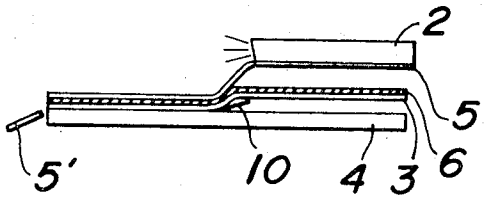


FIG.6

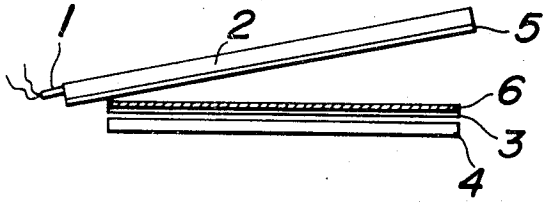


FIG.7

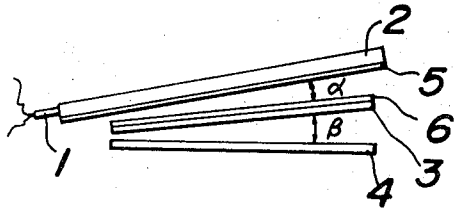


FIG.8

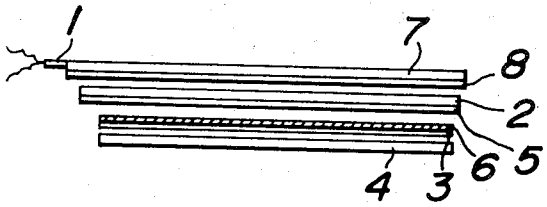


FIG.9

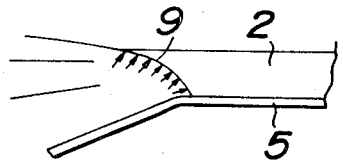


FIG.10

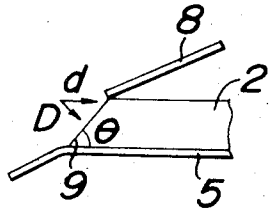


FIG.11

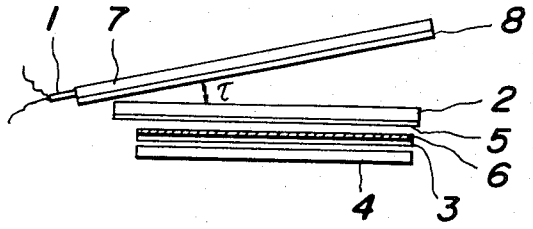


FIG.12

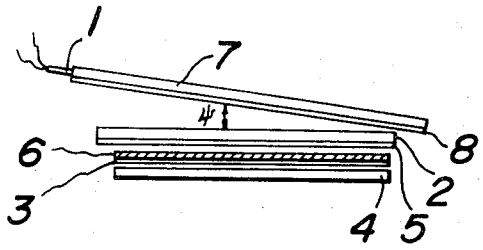
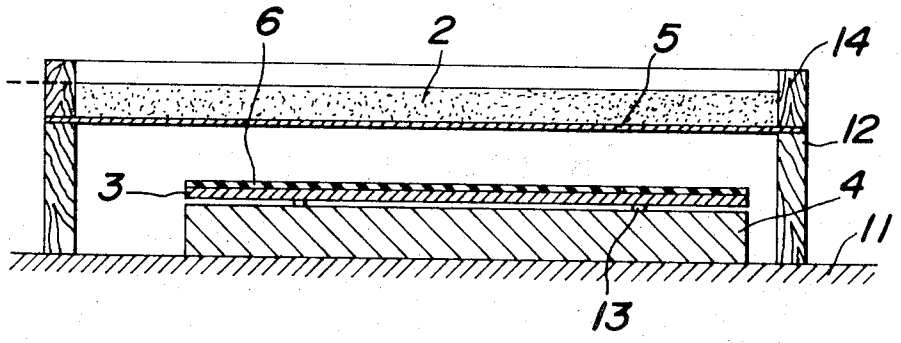


FIG.13



EXPLOSIVE WELDING PROCESS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a process for bonding metal sheets by high-speed projectile impact, and more particularly to a process of bonding metallic layers by high-speed projectile impact caused by detonation of an explosive layer, which explosive layer is disposed in parallel to one of said metallic layers with an intermediate driver sheet inserted between the explosive layer and the metallic layer to be driven by the impact of the explosion.

2. Description of the Prior Art

A number of different processes have heretofore been proposed for generating metallurgical bond between two metallic members by causing one of the metallic members to collide with the other member at a high speed, which collision is actuated by detonation of an explosives disposed on one of the metallic members.

Stanford Research Institute, Poulter Laboratories Technical Report 012-58, "PERMANENT PERIODIC SURFACE DEFORMATIONS DUE TO A TRAVELLING JET," dated March 18, 1958, has reported that when a high-speed bullet having a flat head obliquely collides a target metallic sheet and penetrates through the metallic sheet, that part of the target sheet which is pierced by the bullet is bonded to the bullet head with a waved boundary surface between the target sheet and the bullet head. This Poulter Report also disclosed that, when a copper sheet is propelled at a high speed by the detonation of an explosive so as to cause the copper sheet to obliquely collide a steel member, the copper sheet is bonded to the steel member with a waved boundary surface therebetween.

H.P. Tardif disclosed in a Canadian Technical Journal, "METAL PROGRESS," Volume 77 (1960), Number 1, pages 128–130, that when a small pellet of explosive is placed and detonated at a point a few inches above an assembly of metallic sheets, e.g., aluminum sheets or copper sheets which are overlaid one on the other, the metallic sheets in the assembly are bonded with a waved boundary surface therebetween.

It has been disclosed in a technical journal, "THE IRON AGE," published in the U.S.A., on May 4, 1961, pages 83–85, that two metallic sheets can be bonded by explosive welding process, by supporting the two metallic sheets so as to face with each other with an angle therebetween, placing one or two explosive layers on the outer surface of one or both of the two metallic sheets, initiating said explosive layer or layers at the side where the spacing between the two metallic sheets is smallest, so that detonation is propagated toward the opposite ends of the metallic sheets for causing the metallic sheets to collide with each other at a high speed. In this case, the bond of the two metallic sheets is established by jets formed on the facing surfaces of the metallic sheets.

A method was disclosed in a U.S. technical journal, "Light Metal Age," April, 1962, pages 6–9, for producing a subsonic propagating velocity of the point of collision between two metallic sheets being bonded, by disposing the two sheets so as to obliquely face with each other, which propagating velocity of the point of collision depends on the detonation velocity of the explosive used, the travelling velocity of the metallic sheets relative with each other, and the angle between the two metallic sheets.

U.S. Pat. No. 3,137,937, which was originally applied on Feb. 4, 1960 and published on June 23, 1964, has disclosed an explosive bonding process comprising steps of supporting at least one metal layer separated from an adjacent metal layer by a space of at least 0.001 inch and in substantially parallel relationship thereto, placing a layer of a detonating explosive on the outside surface of one of the metal layers, said explosive having a detonation velocity of greater than 1,200 meters per second but less than 120 percent of the sonic velocity of the metal having the highest sonic velocity in the system, and initiating said explosive. (The process of this U.S. Patent will be referred to as the "parallel explosive welding process" or simply as the "parallel process," hereinafter, for brevity.)

The parallel process of U.S. Pat. No. 3,233,312, filed on Oct. 26, 1960 and patented on Feb. 8, 1966, also teaches to dispose two cladding metal sheets in the proximity of a base metal sheet with a spacing between the cladding metal sheets and a spacing from the base metal sheet to the cladding metal sheets, as shown in FIG. 4 thereof. In the case of using two cladding metal sheets, the explosive layer is integrally connected to one of the sheets by being overlaid on a buffer adhered to one cladding sheet, according to the process of this U.S. Patent.

The parallel process using the explosive layer integrally adhered to the cladding metal sheet has the following disadvantages: namely, irregularity of detonation waves along the edge of the cladding metal sheet, undesirable effects of instable detonation in the proximity of the detonator, cracking and distortion of the cladding metal sheet along the edges thereof, intrusion of gaseous detonation products into the gap between the cladding metal sheet and the base metal sheet, and ineffective gond and cracks of the clad metal caused by the foregoing difficulties.

U.S. Pat. No. 3,313,021, filed on Mar. 2, 1964 and patented on Apr. 11, 1967, teaches a method of butt welding two metal plates together by using a shock wave pulse, which is caused by firing an explosive layer carried by a movable driver plate. The latter, being actuated by the explosion, strikes those surfaces of the metal plates being welded which are perpendicular to the surfaces being butt-welded. The shock caused by the striking with the driver plate effects the welding of the abutting surfaces of the two metal plates.

This butt welding method, however, does not suggest the welding of wide surfaces of metal sheets, and hence it does not provide any solution to the aforesaid difficulties which are inherent to the parallel welding of metal sheets according to U.S. Pat. No. 3,233,312.

Furthermore, Japanese Patent Publication No. 11,231/1967, based on the Convention Priority of the corresponding U.S. Pat. Application Ser. No. 264,373 of March 11, 1963, has taught another explosive welding process, in which at least two metallic sheets are disposed so as to face with each other with an angle of not smaller than 1 degree therebetween, and an explosive layer is placed on at least one of the two metallic sheets, and detonating the explosive layer, wherein the propagating velocity of the point of collision of the metallic sheets is not greater than 120 percent of the sonic velocity of the metallic sheets (to be referred to as the "oblique explosive welding process," hereinafter, for

brevity). In this process of the Japanese Patent Publication, when the aforesaid propagating velocity of the point of collision of the metallic sheets exceeds the sonic velocity of the metallic sheets, the angle between the two metallic sheets is suitably controlled.

Although the different explosive welding processes, as quoted above, have provided certain improvements over conventional welding techniques in some respects, such explosive welding processes have inherent shortcomings. For instance, in the case of the explosive welding process using a bullet, the area available for the welding is limited to the size of the bullet, which size is in turn restricted by a gun or cannon necessary for projecting it. The aforesaid Report from the Stanford Research Institute does not teach either a means for substituting the bullet with metallic layers or sheets, or any explosives and detonators suitable for projecting metallic sheets.

With the process of the METAL PROGRESS, only a part of the metallic sheets pre-overlaid one on the other was welded by the detonation of the small pellet of explosive disposed above the metallic sheets. There is no guarantee in the aforequoted METAL PROGRESS on the reproducibility of the welding process, the size of the welded area, and the mechanical strength of the welded bond.

The other four processes, namely those of THE IRON AGE, LIGHT METAL AGE, U.S. Pat. No. 3,137,937, and Japanese Pat. Publication No. 11,231/1967, teach different explosive welding processes of metallic sheets, but it has been difficult to achieve even bond between adjacent metallic layers, because the detonation of an explosive layer is not necessarily uniform to the extent of generating the desired even bond under the setup of the aforesaid four conventional publications.

SUMMARY OF THE INVENTION

Therefore, an object of the present invention is to obviate the aforesaid difficulties of conventional techniques, by providing an improved explosive welding process. According to the present invention, there is provided an explosive welding process, comprising steps of disposing at least one cladding metal sheet so as to face a base metal sheet with a spacing equivalent to one-twentieth to 25 times the thickness of that one of the two sheets which is to be driven toward the other sheet, coating a protective layer on said sheet to be driven at the surface facing away from said other sheet, placing a driver plate so as to face said protective layer with a spacing equivalent to one-twentieth to twenty-five times the thickness of said driver plate, the driver plate being at least as wide as said sheet to be driven, forming an explosive layer on said driver plate on the surface facing away from said protective layer, and igniting said explosive layer to cause said driver plate to collide and drive said sheet to be driven for generating a colliding impact large enough to bond said cladding metal sheet to said base metal, said explosive layer being so related with said spacing between the driver plate and the protective layer that said driver plate collides said protective layer at a velocity faster than 800 m/sec. but slower than the highest sonic velocity of the cladding and base metal sheets.

BRIEF DESCRIPTION OF THE DRAWING

For a better understanding of the invention, reference is made to the accompanying drawings, in which:

FIGS. **1** to **3** are schematic diagrams, illustrating conventional explosive welding processes;

FIG. **4** is a schematic view of an arrangement of metallic sheets, a driver sheet, and an explosive layer, to be used in a process according to the present invention;

FIG. **5** is a diagrammatic illustration of the manner in which the metallic sheets in the arrangement of FIG. **4** are welded by the explosive welding process according to the present invention;

FIGS. **6** to **8** are schematic views of different arrangements, each consisting of metallic sheets, a driver sheet, and an explosive layer, for carrying out the explosive welding process according to the present invention;

FIGS. **9** and **10** are diagrammatic illustrations of the manner in which detonation of the explosive layers of FIGS. **6** and **8** proceeds, respectively;

FIGS. **11** and **12** are schematic illustrations of two modifications of the arrangement of FIG. **8**; and

FIG. **13** is a schematic sectional view, illustrating the arrangement of Example 1.

Like parts are designated by like numerals and symbols throughout the drawings.

DESCRIPTION OF THE PREFERRED EMBODIMENT

One of the practicable explosive welding process of conventional type, i.e., the parallel explosive welding process of U.S. Pat. No. 3,137,937, will briefly be reviewed (see FIG. **1**). In this known explosive welding process, a detonator **1** is mounted on one end of an explosive layer **2** spread on cladding metal sheet **3**, so that upon initiation of the explosive layer **2** by the detonator **1**, the cladding metal sheet **3** is impinged to a base metal sheet **4** so as to bond the former to the latter. The explosive layer **2** should be as wide as the cladding metal sheet **3**, and the detonator **1** is disposed outside the area facing that portion of the cladding metal sheet which is to be bonded to the base metal sheet **4**.

To produce a strong even bond between the cladding metal sheet **3** and the base metal sheet **4**, the detonation of the explosive layer **2** should propagate in parallel to the cladding metal sheet **3** in a uniform fashion. The actual detonation of the explosive layer **2** in the close proximity of the initiating point is somewhat instable, for instance, in an area of several tens to several hundreds millimeters from the detonator **1**, depending on the type of explosives used. Such instable detonation of the explosive layer in the vicinity of the initiating point results in poor quality of the bond between the cladding metal sheet **3** and the base metal sheet **4**.

Furthermore, there are wave reflections along those edges of the cladding or base metal sheet where the propagation of the impulsive waves generated by the detonation of the explosive layer terminate, and such wave reflection tends to weaken the bond between the cladding metal sheet **3** and the base metal sheet **4**. There are similar reflections of the impact waves caused by the impinging impact of the cladding metal sheet **3** to the base metal sheet **4**, and such wave reflection along the edges of the cladding or base metal sheet tends to weaken the bond therebetween. In fact, it has been found to be very difficult to produce a good clad metal having solid bond of the cladding metal sheet to the base metal sheet along the peripheral edges thereof, by means of the process of FIG. **1**. Defects, e.g., cracks,

are frequently found in the cladding metal sheet 3 along the edges of the clad metal made by the parallel explosive welding process of FIG. 1.

Various suggestions have heretofore been made to overcome the aforesaid difficulties of the parallel explosive welding process of U.S. Pat. No. 3,137,937. FIGS. 2 and 3 illustrate two examples of such prior suggestions. In FIG. 2, a cladding metal sheet 3 is suggested to be larger than a base metal sheet, 4, to which the cladding metal sheet 3 is bonded. Those edge portions of the cladding metal sheet 3 of FIG. 2, which lie outside the span of the base metal sheet 4, are cut off at the moment of the collision of the cladding metal sheet 3 to the base metal sheet 4, by the shearing force generated by the detonation of an explosive layer 2 and applied to said edge portions upon the impingement of the cladding metal sheet 3 to the base metal sheet 4.

Thereby, those edge portions of the cladding metal sheet 3, where the bond to the base metal sheet 4 is susceptible to weakening due to the instable detonation in the proximity of the initiating point and the wave reflection at the very edges of the cladding metal sheet, can completely be separated or severed from the cladding metal sheet 3, provided that a proper marginal width is given around the peripheral edges of the starting cladding metal sheet 3 relative to the size of the base metal sheet 4. Consequently, the risk of the weak bond and the cracks around the peripheral edges of the clad metal can greatly be reduced by using a fresh cladding metal sheet which is larger than the base metal sheet to be clad.

Such approach of FIG. 2 is, however, uneconomical, because it wastes considerably large edge portions of expensive cladding metal sheet. More particularly, the clad metal is usually made by cladding a base sheet of comparatively inexpensive metal, e.g., mild steel, with a layer of comparatively expensive metal, e.g., stainless steel, Hastelloy, brass, bronze, copper, titanium, zirconium, nickel, tantalum, gold, silver, platinum, tungsten, niobium, chromium, cobalt, aluminum, molybdenum, magnesium, vanadium, zinc, tin, and their alloys. Since the material is such expensive metal, the use of excessively large cladding sheet or layer results in an unnecessary increase in the cost.

In order to avoid the use of costly metal at the edge portions of the cladding sheet, it has been proposed to bond separate edge members 3' of less expensive metal to the cladding metal sheet 3, as shown in FIG. 3. The edge members 3' are, for instance, made of mild steel and bonded to the cladding metal sheet 3 by spot welding or by adhesive, so that the overall size of the cladding metal sheet 3 may virtually become somewhat larger than the base metal sheet 4. The use of such separate edge members 3', however, has a shortcoming in that it is difficult to smoothly bond the separate edge members 3' to the cladding sheet 3, and the labor necessary for effectively bonding the separate edge members 3' to the cladding metal sheet 3 amounts to a level to make the entire explosive welding process uneconomical for practical applications.

Besides the aforesaid difficulties, the conventional explosive welding process has another shortcoming in that it is difficult to bond a metal sheet having a comparatively low ductility to a base metal sheet. For instance, brittle metal sheet, such as tungsten sheet, is apt to be cracked by the impact of the detonation of the explosive layer. Thus, it has been almost impossible to make a practicable clad metal by using a metal whose percent elongation is not greater than about 5 percent.

The conventional oblique explosive welding process, as disclosed by the aforequoted Japanese Patent Publication No. 11,231/1967, has the following shortcoming. With the oblique explosive welding process, the explosive layer is initiated at that end where the cladding metal sheet is located closest to the base metal sheet, so that the detonation proceeds towards the opposite end where the cladding metal sheet and the base metal sheet are widely separated.

If the distance between the cladding metal sheet and the base metal sheet exceeds a certain maximum limit, the sheet driven by the detonation of the explosive layer tends to be distorted or cracked, due to the air resistance and the reflection of the impact waves. The aforesaid maximum limit of the distance between the cladding metal sheet and the base metal sheet, of course, depends on the physical properties and the dimensions of the driven sheet. The excessively large distance between the cladding metal sheet and the base metal sheet also results in a tool large acceleration of the driven sheet, so that the impact of the collision of the cladding sheet and the base sheet becomes excessively high and the bond of the two sheets becomes instable.

The inventors have carried out a series of tests and studies, with the intention of mitigating the aforesaid difficulties of the conventional explosive welding processes. As a result, it has been found that stable and uniform bond between a cladding metal sheet and a base metal sheet can easily be achieved by mounting an explosive layer on a separate plate (to be referred to as a "driver plate," hereinafter) so as to insert the cladding metal sheet (or the base metal sheet) between the driver plate and the base metal sheet (or the cladding metal sheet). With the process of the present invention, the cladding metal sheet may be disposed either in parallel to or in oblique relationship to the base sheet, and the driver plate carrying the explosive layer can be disposed at the back of either the cladding metal sheet or the base metal sheet. A protective layer is secured to that surface of the metal sheet which faces the driver plate.

The explosive welding process according to the present invention will now be described by referring to the accompanying drawings. In FIG. 4, an explosive layer 2 is mounted on a driver plate 5 and a detonator 1 is secured to the left end of the explosive layer 2, as seen in the figure. A cladding metal sheet 3 is disposed in parallel with the driver plate 5 with a suitable spacing therefrom. A protective layer 6 is overlaid on that surface of the cladding metal sheet 3 which faces the driver plate 5. A suitable driver plate spacer means 12 is provided between the driver plate 5 and the protective layer 6 of the cladding metal sheet 3. A base metal sheet 4 is placed on a work table 11 in parallel to the cladding metal sheet 3 with a suitable spacing therefrom, by inserting another spacer means 13 therebetween, such as the dimples as disclosed in the aforequoted U.S. Pat. No. 3,137,937.

With the arrangement of FIG. 4, upon firing by the detonator 1, the explosive layer 2 detonates from the left to the right, as seen in the figure, at a detonation velocity D, which depends on the type of the explosive, the shape of the explosive layer, and the loading conditions of the explosive layer on the driver sheet. The

pressure caused by the detonation of the explosive layer 2 acts to drive the driver plate 5 downwards, as seen in FIG. 4, and the driver plate 5 collides and strikes the protective layer 6 on the cladding metal sheet 3 at a high speed.

The propagating velocity of the point of collision between the driver plate 5 and the protective layer 6 of the cladding metal sheet 3 (to be referred to as the "driver plate collision-propagating velocity V_d", hereinafter) is the same as the detonation velocity D of the explosive layer 2, because the explosive layer 2 is disposed in parallel to the cladding metal sheet 3. In response to the collision impact between the driver plate 5 and the protective layer 6 of the cladding metal sheet 3, the cladding metal sheet 3 is driven downwards and collides the base metal sheet 4 at a high speed.

The propagating velocity of the point of collision between the cladding metal sheet 3 and the base metal sheet 4 (to be referred to as tthe "base metal sheet collision-propagating velocity V_c", hereinafter) is identical with the aforesaid driver plate collision-propagating velocity V_d and the detonation velocity D of the explosive layer 2, because the base metal sheet 4 is disposed in parallel to both the cladding metal sheet 3 and the driver plate 5.

The moving velocity of the cladding metal sheet 3 at the moment of its collision with the base metal sheet 4 will be referred to as the "flying velocity V_p of the cladding metal sheet." When the base metal sheet collision-propagating velocity V_c and the flying velocity V_p of the cladding metal sheet are properly selected, a stable metallurgical bond can be formed between the cladding metal sheet 3 and the base metal sheet 4.

FIG. 5 schematically shows the manner in which the driver plate 5 of FIG. 4 is driven toward the protective layer 6 of the cladding metal sheet 3, in response to the detonation of the explosive layer 2, and the cladding metal sheet 3 strikes the base metal sheet 4 in response to the collision of the driver plate 5 with the protective layer 6 of the cladding metal sheet 3. It can easily be seen from FIG. 5 that the detonation velocity D of the explosive layer 2 is directly transferred to the driver plate collision-propagating velocity V_d and the base metal sheet collision-propagating velocity V_c, so that the two velocities V_d and V_c are substantially identical with the detonation velocity D.

A metal jet 10 is generated from the colliding point between the cladding metal sheet 3 and the base metal sheet 4, as shown in FIG. 5. The metal jet 10 acts to facilitate the metallurgical bond between the base metal sheet 4 and the cladding metal sheet 3 by exposing fresh metallic surfaces thereof. The metal jet 10 also prevents the bond of the base metal sheet 4 and the cladding metal sheet 3 from being separated by the impact wave due to the collision of the two metal sheets and by its reflective wave. The driver plate 5 of the embodiment of FIGS. 4 and 5 is made somewhat greater than the cladding metal sheet 3 and the base metal sheet 4, so that fringe portions of the driver plate 5 are severed by the edges of the cladding metal sheet 3 and the base metal sheet 4 at the time of the collision of the driver plate 5 with the two metal sheets, as shown by a severed edge piece 5' in FIG. 5.

FIG. 6 shows another arrangement suitable for carrying out the explosive welding process according to the present invention. In the figure, a cladding metal sheet 3 is disposed in parallel to but with a suitable spacing from a base metal sheet 4. A driver plate 5 is, however, obliquely disposed relative to the cladding metal sheet 3 with an angle α between the planes of the driver plate 5 and the cladding metal sheet 3. The bottom surface of the driving plate 5 faces a protective layer 6 secured to the top surface of the cladding metal sheet 3, and an explosive layer 2 is disposed on the upper surface of the driver plate 5.

With the arrangement of FIG. 6, the driver plate collision-propagating velocity V_d, as defined for the arrangement of FIG. 4, becomes smaller than the detonation velocity D of the explosive layer 2. If the flying velocity of the driver plate 5 at the moment of its collision with the protective layer 6 on the cladding metal sheet 3 is represented by V_{pd}, the driver plate collision-propagating velocity V_d is given by the following equation (1).

$$V_d = D\{\cos\alpha - [\sin\alpha\cdot\cos(\alpha+\gamma)]/[\sin(\alpha+\gamma)]\} \quad (1)$$

here,

$$\gamma = 2\sin^{-1}V_{pd}/D \quad (2)$$

The base metal sheet collision-propagating velocity V_c, in the case of the arrangement of FIG. 6, is substantially the same as the driver plate collision-propagating velocity V_d, because the cladding metal sheet 3 is disposed in parallel with the base metal sheet 4.

FIG. 7 shows another arrangement for fulfilling the explosive welding process according to the present invention. In this arrangement, the disposition of FIG. 6 is further modified by obliquely disposing the base metal sheet 4 relative to the cladding metal sheet 3, so as to define an angle β between the two metal sheets 3 and 4. The two angles α and β are determined so as to generate proper flying velocity V_p of the cladding metal sheet 3 at the time of its collision with the base metal sheet 4, and proper base metal sheet collision-propagating velocity V_c.

If the flying velocity V_p of the cladding metal sheet 3 at the time of its collision with the base metal sheet 4 is too low, there will not be produced a sufficiently large plastic deformation at the boundary between the base metal sheet 4 and the cladding metal sheet 3 for providing strong metallurgical bond therebetween. Accordingly, with such a comparatively low flying velocity V_p, the cladding metal sheet 3 may resiliently be bounced at the base metal sheet 4, or may be attached to the base metal sheet 4 only very weakly. On the other hand, if the flying velocity V_p of the cladding metal sheet 3 at the time of collision with the base metal sheet 4 is too high, the deformation of the cladding metal sheet 3 and the base metal sheet 4 become excessively large to produce cracks and wrinkles in the final clad metal which deteriorate the commercial value of the clad metal.

Sometimes, the clad metal is cracked due to an excessively high flying velocity V_p of the cladding metal sheet 3. Thus, there is a certain range of the flying velocity V_p of the cladding metal sheet 3 at the time of collsion with the base metal sheet 4, which range depends on the physical properties of the cladding metal sheet 3 and the base metal sheet 4. Those skilled in the art can easily select the proper value of the aforesaid flying velocity V_p of the cladding metal sheet 3, for instance by tests.

As regards the aforesaid collision-propagating velocity V_c, the inventors have found that satisfactory bond

of the cladding metal sheet with the base metal sheet can be achieved as long as the collision-propagating velocity V_c is faster than 800 m/sec. but slower than the fastest sonic velocity in the cladding metal sheet **3** and the base metal sheet **4**. What is meant by the "sonic velocity" here refers to the velocity of the plastic shock wave which forms when a stress which is applied just exceeds the elastic limit for unidirectional compression of the particular metal sheet. Although a collision-propagating velocity V_c slightly above the aforesaid highest sonic velocity of the cladding metal sheet **3** and the base metal sheet **4** can produce metallurgical bond between the two metal sheets, the bond formed under such conditions is instable and comparatively weak, so that such high collision-propagating velocity V_c is not practical.

With the arrangement of FIG. **7**, the collision-propagating velocity V_c may be defined in two ways; namely, the collision-propagating velocity V_{c1} taken on the plane of the cladding metal sheet **3**, and the collision-propagating velocity V_{c2} taken on the plane of the base metal sheet **4**. Such velocities V_{c1} and V_{c2} can be given by the following relations.

$$V_{c1} = V_d\,[1 - (\sin\beta)/\sin(\beta+\epsilon)] \tag{3}$$

$$V_{c2} = V_d\,\{\cos\beta - [\sin\beta\cdot\cos(\beta+\epsilon)/[\sin(\beta+\epsilon)]\} \tag{4}$$

here,

$$\epsilon = 2\sin^{-1}(V_p/2V_d) \tag{5}$$

V_d : the driver plate collision-propagating velocity, as determined by the equations 1 and 2.

Either one of the aforesaid two velocities V_{c1} and V_{c2} can be used as the base metal sheet collision-propagating velocity, depending on which of the cladding metal sheet **3** and the base metal sheet **4** is to be driven by the driver plate **5**.

As being apparent from the equations 1 to 5, suitable base metal sheet collision-propagating velocity V_c can be achieved for a wide range of the detonation velocity D, by properly selecting the aforesaid two angles α and β. With the conventional oblique explosive welding process of the aforequoted Japanese Patent Publication No. 11,231/1967, when the detonation velocity D of the explosive layer is very high, the angle between the cladding metal sheet and the base metal sheet, i.e., the angle β of FIG. **7**, tends to become too large to limit the base metal sheet collision-propagating velocity V_c within a preferable range, because this angle is the only one variable in such conventional process under these conditions.

If such angle corresponding to the angle β of FIG. **7** becomes too large, the flying velocity V_p of the cladding metal sheet at the time of its collision with the base metal sheet may become too high, because the cladding metal sheet is accelerated for an increased period of time, as compared with the case of a smaller angle β. As described in the foregoing, such excessively high flying velocity V_p of the cladding metal sheet may cause uneven bond of the cladding metal sheet **3** and the base metal sheet **4**, and the crackings in the clad metal. On the other hand, with the arrangement of the present invention, as illustrated in FIG. **7**, two variables, i.e., the angles α and β, are available for controlling the base metal sheet collision-propagating velocity V_c for a given detonation velocity D of the explosive layer **2**. Thus, the flying velocity V_p of the cladding metal sheet **3** can properly be limited, and the aforesaid difficulty of the conventional oblique explosive welding process can be eliminated.

FIG. **8** shows another arrangement to be used for fulfilling the explosive welding process according to the present invention, in which an initiator layer is used for initiating the explosive layer of the aforesaid embodiments. More particularly, an initiator layer **7** is spred on a detonating driver plate **8**, and a detonator **1** is connected to the initiator layer **7** at one end thereof. Upon firing the initiator layer **7** by the detonator **1**, the detonating-driver plate **8** obliquely strikes the explosive layer **2** spread on a driver plate **5** similar to driver plate of the preceding embodiments.

With the arrangements of FIGS. **4** to **7** having a detonator **1**, or a linear wave generator, directly connected to one end of the explosive layer, a detonating wave front **9** is formed so as to face upwards, as shown in FIG. **9**. Accordingly, the detonation impact is partly lost to the upper free space, and it is not fully utilized for accelerating the driver plate **5**. Thus, the amount of the explosive spread on the driver plate **5** must be more than what is actually necessary for bonding the cladding metal sheet **3** to the base metal sheet **4**, and hence, the explosive welding process becomes more costly.

The inventors have found that, if the initiator layer **7** is made wider than the explosive layer **2**, the uniformity of evenness of the bond between the cladding metal sheet **3** and the base metal sheet **4** can further be improved, because such wider initiator layer **7** eliminates the irregularity of the detonating wave front **9** at the far end of the explosive layer **2** as seen from the detonator **1**.

The detonator **1**, or a line wave generator, for firing the initiator layer **7** is known. According to the inventors' finding, in order to orient the detonating wave front **9** downwards in the explosive layer **2** in the arrangement of FIG. **8**, wherein the bottom surface of the detonating driver plate **8** is initially disposed in parallel to the top surface of the explosive layer **2**, the explosion velocity d of the initiator layer **7** must be faster than the detonation velocity D of the explosive layer **2**.

Referring to FIG. **10**, the inclination θ of the detonating wave front **9**, i.e., the angle θ between the detonating wave front **9** and the top surface of the driver plate **5**, is given by the following equation.

$$\theta = \sin^{-1}(D/d) \tag{6}$$

$$d = D/\sin\theta \tag{7}$$

As a result of various tests, the inventors have found out that the aforesaid inclination θ of the detonating wave front **9** should preferably be equal to or smaller than 60°, namely $\theta \leqq 60°$. With this condition, the equation 7 can be re-written as follows.

$$d \geqq 1.16D \tag{8}$$

FIG. **11** shows a modification of the arrangement of FIG. **8**, in which a detonating driver late **8** is obliquely disposed with respect to a driver plate **5** carrying an explosive layer **2**, so as to form an angle of τ between the plate **8** and the layer **2**, and a detonator **1** is connected to that edge of the detonating driver plate **8** which is closest to the driver plate **5** amount various edges thereof. Thus, as the detonation of the initiator layer **7** proceeds, its distance from the driver plate **5** increases. In the arrangement of FIG. **11**, the initiation velocity d',

which is the velocity at which the detonating driver plate **8** initiates the explosive layer **2** on the driver plate **5**, is made slower than the detonation velocity d of the initiator layer **7**. The inventors have found out that the aforesaid initiation velocity d' must not be smaller than 116 percent of the detonation velocity D of the explosive layer **2**.

$$d' \geqq 1.16D \tag{9}$$

The suitable value of the angle τ for fulfilling the condition of the equation (9) can easily be determined by the equations (1) and (2), while substituting the angle α of the equations with the angle τ.

FIG. **12** shows another arrangement to be used for fulfilling the explosive welding process according to the present invention, in which an initiation velocity d' satisfying the conditions of the equation 9 can be achieved by using an initiator layer **7** having a detonation velocity d smaller than said initiation velocity d'. In the arrangement of FIG. **12**, a detonating driver plate **8** carrying an initiator layer **7** is obliquely disposed relative to a driver plate **5** carrying an explosive layer **2**, so as to form an angle ψ, and a detonator **1** is connected to that edge of the initiator layer **7** on the detonating driver plate **8** which is farthest from the driver plate **5** among various edges thereof.

The aforesaid initiation velocity d' for the arrangement of FIG. **12** can be expressed as follows, in terms of the flying velocity V_d' of the detonating driver plate **8** at the moment of its collision with the explosive layer **2**.

$$d' = d\{\cos\psi + [\sin\psi/\tan(\phi-\psi)]\} = d\{1 + [\tan\psi/\tan(\phi-\psi)]\} \tag{10}$$

$$\phi = 2\sin^{-1}(V_d'/2d) \tag{11}$$

As can be seen from the equation 10, the value of the initiation velocity d' can be controlled by regulating the angle ψ, while keeping the initiation velocity d' greater than the explosion velocity d, because the term $\tan\psi/\tan(\phi-\psi)$ is always positive.

The arrangement of FIGS. **11** and **12** can also be applied to the disposition including a finite angle α between the driver plate **5** and the cladding metal sheet **3**, as shown in FIG. **6**, as well as to the disposition including another angle β between the cladding metal sheet **3** and the base metal **4**, as shown in FIG. **7**. The conditions of the equations 9, 10, and 11 for the arrangement of FIGS. **11** and **12** must be reconsidered in view of the equations 1 to 8, if the arrangement of FIG. **11** or **12** is combined with that of FIG. **6** or **7**. Such reconsideration can, however, be easily worked out by those skilled in the art, so that its details will not be dealt with here, except the following properties of the base metal sheet cillision-propagating velocity V_c.

More particularly, as long as the cladding metal sheet **3** is disposed in parallel to the base metal sheet **4**, as shown in FIG. **6**, the base metal sheet collision-propagating velocity V_c is identical with the dirver plate collision-propagating velocity V_d, which is determined by the equation 1 while substituting the detonation velocity D with the initiation velocity d' of the equation 10.

On the other hand, when the cladding metal sheet **3** is slanted with respect to the base metal sheet **4**, as shown in FIG. **7**, the base metal sheet collision-propagating velocity velocity V_c is determined by the equation 3 or 4, after determining the driver plate collision-propagating velocity V_d in the aforesaid manner by using the equations 1 and 10.

In the foregoing description, the thickness of the protective layer **6** is assumed to be uniform, and the angle between the bottom surface of the driver plate **5** and the top surface of the protective layer **6** is identical with the angle between the bottom surface of the driver plate **5** and the cladding plate **3**. According to the present invention, it is also possible to use a protective layer **6** which is tapered, so as to provide varying time delays in the delivery of collision impact of the driver plate **5** to the cladding metal sheet **3**, depending on the variation of the thickness of the protective layer **6**.

The driver plate **5** is typically made of aluminum or steel, with or without coating of suitable metallic or resin materal. The material of the driver plate **5** is, however, not restricted to aluminum and steel, and any other impact-resisting metallic material can also be used to form the driver plate **5**; for instance, titanium, zirconium, stainless steel, nickel, duralmin, copper, brass, bronze, zinc, tantalum, or an alloy of elements selected from the foregoing metals. It should be noted here that the use of expensive metals for the driver plate **5** cannot be justified, unless certain properties of such expensive metals are advantageously used in the explosive welding process according to the present invention.

The effective area of the driver plate **5** must be as broad as the cladding metal sheet **3**. What is meant by the effective area of the driver plate **5** is that of the area covered with the explosive layer **2**, so that other areas covered by materials such as wooden framework for holding the explosive layer **2** are excluded from the effective area of the driver plate **5**. The inventors have found out that the driver plate **5** should preferably be larger than the cladding metal sheet **3** by any side thereof, because such large driver plate is effective in eliminating various undesirable phenomena involved in the explosive welding process; namely, the irregularity of detonation waves along the edge of the cladding metal sheet, the undesirable effects of the instable detonation in the proximity of the detonator, the cracking and distortion of the driver plate along the edges thereof, the intrusion of gaseous detonation products into the gap between the cladding metal sheet and the base metal sheet, and the ineffective bond and cracks of the clad metal caused by the foregoing difficulties.

The thickness of the driver plate **5** should preferably fall in a range of 0.3 to 10 times of the thickness of the cladding metal sheet **3**. If the driver plate **5** is too thin, there may be generated such waves from the striking surface and the opposite surface of the driver plate at the time of its collision with the cladding metal sheet, which waves tend to reduce the collision impact of the driver plate, so that the cladding metal sheet **3** may not be accelerated sufficiently for producing strong bond between the cladding metal sheet and the base metal sheet.

On the other hand, if the driver plate **5** is too thick, the amount of the explosive necessary for accelerating the cladding metal sheet **3** to a velocity required for the welding of the cladding metal sheet **3** to the base metal sheet **4** becomes too much to make the process of the invention economically feasible. The suitable thickness of the driver plate **5** can easily be determined for each application by those skilled in the art, depending on the

thickness and the material of the cladding metal sheet 3 and the protective layer 6.

The protective layer 6 is to eliminate the direct collision of the driver plate 5 to the cladding metal sheet which direct collision might cause the bond of the driver plate 5 with the cladding metal sheet 3 and cracks and/or wrinkles on the cladding metal sheet. Accordingly, the protective layer 6 can be made of any suitable material capable of fulfilling the aforesaid functions; for instance, rubber, synthetic resin, paint, water, or gelated product of gelatine or agar or a composite mixture thereof. The suitable thickness of the protective layer 6 can easily be determined by those skilled in the art, for instance, by simple tests while considering the related conditions, such as the material and the thickness of the driver plate 5 and the cladding metal sheet 3, the flying velocity V_{pd} of the driver plate 5 at the moment of its collision with the protective layer 6 on the cladding metal sheet 3, the angle at which the driver plate 5 collides the protective layer 6, and the material of the protective layer 6 per se. The inventors have found out that the preferable material of the protective layer 6 is a foamed layer with an apparent density of 0.01 g/cm^3 to 0.4 g/cm^3, which is made of rubber or synthetic resin such as vinyl chloride, vinyl acetate, polystyrene, polyethylene, epoxy resin, phenol resin, polyurethane, urea, and nylon.

The explosive layer 2 on the driver plate 5 should at least be as wide as the cladding metal sheet 3 to be driven by the driver plate 5. The thickness of the explosive layer 2 can also readily be determined by those skilled in the art, for instance, by simple experiments, while considering related conditions, such as the thickness and material of the driver plate 5, cladding metal sheet 3, and the protective layer 6, the spacing between the driver plate 5 and the cladding metal sheet 3, and the distance between the cladding metal sheet 3 and the base metal sheet 4.

The inventors have found that the suitable range of the spacing between the driver plate 5 and the protective layer 6 on the cladding metal sheet 3 is from one-twentieth to 25 times of the thickness of the driver plate 5. If any part of the driver plate 5 is spaced from the protective layer 6 on the cladding metal sheet 3 by a distance greater than 25 times of the thickness of the driver plate 5, such portion of the driver plate is susceptible to cracking or distortion in the course of its travel to the protective layer 6, due to the compression of air at the high flying velocity of the driver plate. As a result, the bond between the cladding metal sheet 3 and the base metal sheet 4 may become inferior. If any portion of the driver plate 5 is disposed too close to the protective layer 6 on the cladding metal sheet 3 by a gap smaller than the one-twentieth of the thickness of the driver plate 5, that portion of the driver plate 5 cannot be accelerated sufficiently for producing stable bond between the cladding metal sheet 3 and base metal sheet 4.

When it is desired to slant the driver plate 5 relative to the cladding metal sheet 3, as shown in FIG. 6 or 7, the suitable slanting angle α between the driver plate 5 and the cladding metal sheet 3 can be determined by the aforesaid equations 1 and 2. The minimum and maximum distances between the slanted driver plate 5 and the cladding metal sheet 3 should be within the limit of the aforesaid range of one-twentieth to 25 times of the thickness of the driver plate 5.

The driver plate spacer means 12, for providing such spacing between the driver plate 5 and the protective layer 6 on the cladding metal sheet 3, as illustrated in FIG. 4, preferably consists of a plurality of small pieces of foamed rubber or foamed synthetic resin. The configuration and the material of the driver plate spacer means 12 are not restricted to such embodiment alone. For instance, such spacer means 12 can be made of wooden or metallic blocks, provided that such blocks are so pretreated as not to cause any scratch or crack on the surface of the cladding metal sheet 3.

Furthermore, according to the present invention, it is also possible to use the protective layer 6 as the aforesaid driver plate spacer means, by increasing its thickness to a suitable magnitude in the aforesaid range of the one-twentieth to 25 times of the thickness of the drive plate 5. In this case, the protective layer 6 should be wide enough to cover the entire effective area of the driver plate at the surface facing the cladding metal sheet 3, and it is preferably made of a foamed high-molecular compound, such as rubber or synthetic resin, because such foamed protective layer does not provide any substantial resistance to the travel of the driver plate 5 in response to the detonation of the explosive layer 2, until the protective layer 6 is so compressed as to directly transfer the kinetic energy of the driver plate 5 to the cladding metal sheet 3. In effect, such expanded protective layer conveniently fulfills the two functions; namely, providing the proper spacing between driver plate 5 and the cladding metal sheet 3, and protecting the non-bonding surface of the cladding metal sheet 3.

In order to ensure a fuller prorection of the cladding metal sheet 3 against the carbon material generated by the decomposition of the foamed material caused by its compression heat in response to the detonation of the explosive layer 2 and against possible scratching by the driver plate 5, an easily removable coating may be applied to that surface of the cladding metal sheet 3, which faces the foamed material of the expanded protective layer 6, prior to the placing of the protective layer 6 thereon. The use of such expanded protective layer 6 is apparently very attractive, because it eliminates the need of placing separate driver plate spacer means 12 thereon.

When a detonating driver plate 8 carrying the initiator layer 7 is to be used, as shown in FIGS. 8 to 12, the effective area of the detonating driver plate 8 should be at least as wide as the effective area of the driver plate 5, and preferably wider than the effective area of the driver plate 5 by more than about 5 cm at each side thereof. If the effective area of the driver plate 5 itself is considerably wider than the cladding metal sheet 3, the excess size of the effective area of the detonating driver plate 8 over the effective area of the driver plate 5 is not so pressing. What is meant by the effective area of the detonating driver plate 8 is that portion of the plate 8 which is covered by the initiator layer 7, but areas under the framework for holding the initiator layer 7 is excluded from the effective area of the detonating driver plate 8. The inventors have found out that the preferable thckness of the detonating driver plate 8 is 0.3 mm to 3 mm.

The spacing from the bottom surface of the detonating driver plate 8 to the top surface of the explosive layer 2 carried by the driver plate 5 should not be smaller than one-twentieth of the thickness of the deto-

nating driver plate **8** but should not exceed 25 times of the thickness of the detonating driver plate **8.** As in the case of the driver plate **5,** the detonating driver plate **8** may be placed in parallel to the driver plate **5,** as shown in FIG. **8,** or slanted by a suitable angle, such as the angle ψ as shown in FIG. **12** and as given by the equation 10.

The aforesaid preferable range of the spacing between the detonating driver plate **8** and the driver plate **5** is valid regardless of the angular relation between the two plates **5** and **8,** because an excessively large spacing results in an over-acceleration of the detonating driver plate **8** so as to cause uneven bond of the cladding metal sheet **3** to the base metal sheet **4,** while a too narrow spacing results in an insufficient acceleration of the detonating driver plate **8** which may in turn cause ineffective bond of the cladding metal sheet **3** to the base metal sheet **4.** The aforesaid desirable spacing between the detonating driver plate **8** and the driver plate **5** can be provided in the same manner as the spacing between the driver plate **5** and the protective layer **6** on the cladding metal sheet **3,** e.g., by using wooden or metallic blocks, foamed rubber or synthetic resin pieces.

In the foregoing description, only one cladding metal sheet is bonded to the base metal sheet. The present invention, however, is not restricted to the explosion welding of only two metal sheets. For instance, two separate metal sheets may be bonded to a base metal sheet, simply by disposing the two metal sheets between the driver plate **5** of FIG. **4** and the base metal sheet **4** of the figure.

According to the present invention, the driver plate **5** may be used for driving the base plate **4,** instead of driving the cladding metal sheet **3,** as shown in FIG. **4.** Furthermore, it is also possible to drive both the cladding metal sheet **3** and the base metal sheet **4** toward each other by using a pair of driver plates for actuating the two metal sheets from opposite surface thereof.

The spacing between the cladding metal sheet **3** and the base metal sheet **4** can be selected, depending on the type of the metal sheets to be bonded and the thickness thereof. The spacing between the cladding metal sheet and the base metal sheet, according to the present invention, is somewhat different from the teaching of the aforequoted U.S. Pat. NO. 3,137,937 specifying such spacing not smaller than 0.001 inch.

Thus, with the explosive welding process according to the present invention, a driver plate is used for actuating a cladding metal sheet toward a base metal sheet, so that various difficulties of conventional explosive welding processes can easily be mitigated. More particularly, the direct drive of the cladding metal sheet or the base metal sheet with the detonation of an explosive layer, according to the aforesaid conventional explosive welding processes tends to produce cracks in the clad metal produced thereby, and the reflection of the detonating pressure directly applied to the cladding metal sheet tends to weaken the bond of the cladding metal sheet to the base metal sheet along the peripheral edges of the clad metal produced thereby. Accordingly, the yield of conventional processes of making clad metal by explosive welding has been fairly low.

On the other hand, with the explosive welding process according to the present invention, detonation pressure of an explosive layer is transferred indirectly by means of a driver plate, so that the aforesaid risk of causing the cracks and weakened bond along the peripheral edges is completely eliminated. Thus, the yield of the explosive welding process of the present invention, when applied to the process of making clad metals, is improved to practically 100 percent.

With the conventional explosive welding processes, it has been very difficult to bond comparatively brittle metal sheet, such as sintered body of tungsten, because direct impact of the explosion of an explosive layer tends to crack such brittle metal plates. The indirect transfer of the impact of the detonation of an explosive layer, according to he present invention, acts to improve the apparent ductility of the brittle cladding metal sheet by coming in tight contact with the cladding metal sheet, and hence, such brittle metal sheet can easily be bonded to a base metal sheet without producing any cracks thereon.

In addition, metal sheets having holes or having complicated undulations are hardly bondable to base metal sheets, by conventional explosive welding processes, and it has been almost impossible to achieve uniform bond over the entire span of such porous metal sheet with conventional explosive welding processes. The driver plate according to the present invention behaves somewhat like a lining of such porous metal sheet, so that excellent bond can be produced between a metal sheet having holes and a base metal sheet by the explosive welding process according to the present invention.

The invention will now be described in further detail, by referring to Examples. ,

EXAMPLE 1

A 100(width) × 200(length) × 9(thickness) mm (this width-length-thickness order will be followed in the subsequent description of sheet dimensions in all Examples) base sheet **4** made of 41 Kg/mm^2 tensile strength class steel, was placed on ground prepared to act as a worktable **11,** and six aluminum cubes 13 of 1×1×1 mm were disposed on the top surface of the steel sheet so as to support a 100×200×2 mm cladding metal sheet **3** of 50 Kg/mm^2 strength class titanium, in alignment with the steel sheet with 1 mm spacing therefrom, as shown in FIG. **13.** A 1 mm thick protective layer **6** consisting of a pressed black rubber sheet of regular class was secured to the top surface of the titanium sheet **3** by a synthetic rubber adhesive, so as to cover the entire span of the top surface of the titanium sheet **6.**

A driver plate **5** consisting of a 130×270×1 mm mild steel sheet was placed above the protective layer **6** with a spacing of 10 mm, by supporting it on the worktable **11** by wooden blocks **12.** The lengthwise edges and the widthwise edges of the driver plate **5** were disposed in parallel with the corresponding edges of the cladding and base metal sheets **3** and **4,** so that the driver plate widthwise extended 15 mm beyond the cladding and base metal sheets on each side edge thereof, while lengthwise extended 50 mm on one longitudinal edge and 20 mm on the longitudinally opposite edge beyond the corresponding edges of the cladding and base metal sheets.

FIG. **13** schematically shows a longitudinal sectional view of such arrangement of the driver plate **5** relative to the cladding and base metal sheets **3, 4.**

A wooden rectangular frame **14** with an outside dimension of 130(width) × 270(length) mm was placed on the top surface of the driver plate **5,** which wooden

frame was made of wooden blocks having a cross section of 5 mm width and 10 mm height. The outer edge of the wooden frame **14** was aligned with the corresponding four side edges of the driver plate **5** and secured thereto by a suitable adhesive. An explosive layer **2** was disposed on the top surface of the drive plate **5** within the area defined by the wooden frame **14**, by uniformly spreading 310 grams of explosive powder consisting of 10 parts by weight of tetranitromethylaniline and 90 parts by weight of ammonium perchlorate.

The explosive layer thus formed was initiated by detonator (as represented by a heavey dotted line in FIG. **13**) from its edge farthest from the cladding metal sheet **3**. The detonation velocity D of this explosive layer **2** proved to be 2,100 m/sec., and the cladding metal sheet **3** was driven by the drive plate **5** through the protective layer **6**. The flying velocity V_p of the cladding metal sheet **6** at the time of collision with the base metal sheet **4** proved to be 2,100 m/sec., and hence, the titanium sheet was firmly bonded to the steel sheet, so as to produce a clad metal. Combustion and heat decomposition compounds of the protective rubber layer **6** were left on the outer surface of the cladding titanium sheet, but such compounds were completely removed by wiping with a solvent. Consequently, a clean fresh surface of the titanium sheet was exposed.

There were no cracks and wrinkles in the clad metal thus formed, namely in either of the base steel sheet **4** and the cladding titanium sheet **3** bonded thereto. The bond between the cladding titanium sheet and the base steel sheet was checked by a supersonic crack-checking device, but no cracks were found. Accordingly, the clad metal thus prepared was excellent for practical applications. Peeling tests and tensile strength tests showed that the peeling strength and the tensile strength of the clad metal were not smaller than 50 Kg/mm^2 and 35 Kg/mm^2, respectively.

In the following Examples, the spacing between the cladding metal sheet **3** and the base metal sheet **4** was provided by supporting the cladding metal in the same way as the Example 1 by using aluminum cubes of suitable size inserted therebetween.

EXAMPLE 2

An arrangement similar to that of FIG. **6** was formed, by using the folowing elements.

- Base metal sheet **4**: 100×200×15 mm steel plate of 41 Kg/mm^2 tensile strength class
- Cladding metal sheet **3**: 100×200×2 mm stainless steel sheet of SUS-27
- Spacing between the base and cladding metal sheets: 0.5 mm
- Protective layer **6**: 0.05 mm thick peelable synthetic resin coating plus 5 mm thick agar layer overlaid thereon
- Driver plate **5**: 120×250×2 mm aluminum sheet
- Explosive layer **2**: 120×250×3 mm explosive sheet secured to the aluminum drive plate, consisting of 75 parts by weight of trinitrotrimethylenetriamine and 25 parts by weight of a synthetic resin paste, with a detonation velocity D of 7,000 m/sec.
- Angle α between the driver plate **5** and the protective layer **6**: 12°

The driver plate **5** was supported by wooden blocks on the ground, where the base metal sheet **4** was also placed, so that the lower portion of the driver plate **5** was in contact with a 100 mm edge of the agar protective layer **6** while the dirver plate **5** being further extended downwards by 30 mm, as gnerally indicated in FIG. **6**.

Then, the explosive layer **2** was initiated at its lowermost edge by a linear wave generating means. In response to the detaonation of the explosive layer **2**, the drive plate **5** collided with the cladding metal sheet **3** through the protective layer **6**, so as to cause the stainless steel sheet **3** to collide the steel base metal sheet **4** at a base sheet collision-propagating velocity of 3,480 m/sec. Thus, a clad metal sheet consisting of a base steel sheet covered with a stainless steel sheet was produced.

Deposits of the synthetic resin film peeled from the protective layer **6** were noticed on the clad metal surface, but such deposits were easily removed, so that fresh attractive stainless steel surface was achieved. Supersonic tests proved that excellent bond was formed between the cladding stainless steel sheet and the base steel sheet. Bending tests were made on specimens formed by cutting the clad metal and bending it with a radius equivalent to the thickness of the clad metal. Peelings and crackings were not noticed at all in both of the bendings from the front surface and from the back surface of the clad metal.

EXAMPLE 3

An arrangement of FIG. **8** was formed by using the following materials.

- Base metal sheet **4**: 100×200×9 mm steel sheet of S15C
- Cladding metal sheet **3**: 100×200×1 mm Hastelloy C
- Spacing between the sheets **3** and **4**: 0.3 mm

The assembly of the parallel spaced sheets **3** and **4** was placed in a 150×250 mm bag made of 0.1 mm thick polyethylene sheet, and the bag was sealed by a high-frequency sealing machine after de-aerating it. The package thus made was placed in a water vessel of 300×300×50 mm cardboard box, so as to place the Hastelloy sheet upwards in parallel with the water surface in the vessel at a depth of 5 mm from the water surface.

Separately, a driver plate **5** and a detonating driver plate **8** of the following dimensions were prepared.

- Driver plate **5**: 130×260×1 mm mild steel sheet
- Explosive layer **2**: 190 grams of explosive powder consisting of 2 parts by weight of tertranitromethylaniline and 98 parts by weight of ammonium perchlorate, being disposed on the driver plate **5** in the same manner as Example 1 in the form of 120×250×6 mm layer
- Detonating driver plate **8**: 140×270×0.6 mm mild steel sheet
- Initiator layer **7**: 95 grams of initiator powder consisting of 20 parts by weight of tetranitromethylamine and 80 parts by weight of ammonium perchlorate, being disposed on the detonating driver plate **8** in the same manner as Example 1 in the form of 130×260×3 mm layer
- Spacing between the detonating driver plate **8** and explosive layer **2**: 5 mm

Five parallel cotton threads were stretched on the top opening of the cardboard box with a spacing of 10 mm between adjacent threads, so that the assembly of the aforesaid driver plate **5** and the detonating driver plate **8** was supported on the cotton threads thus stretched. The 260 mm edges of the driver plate **5** extended be-

yond the 200 mm edge of the cladding metal sheet 3 by 15 mm on either side thereof, while one of 130 mm edges of the driver plate 5 extended beyond the corresponding 100 mm edge of the cladding metal sheet 3 by 50 mm. The center of the detonating driver plate 8 was vertically aligned with the center of the dirver plate 5, so that each edge of the former extended beyond the corresponding edge of the latter by 5 mm.

The initiator layer 7 of the aforesaid arrangement was fired at the edge farthest from the cladding metal sheet 3 by a No. 6 electric detonator. As a result, the initiator layer 7 was detonated at a detonation velocity d of 1,800 m/sec., so as to fire the explosive layer 2 at an initiating velocity of 1,800 m/sec. Consequently, the 6 mm thick explosive layer 2 was detonated at a detonation velocity D of 1,150 m/sec., with a detonating wave front 9 slanted 40° relative to the bottom surface of the explosive layer 2. Accordingly, the driver plate 5 was driven through the water in the cardboard box, so as to cause the cladding Hastelloy C sheet to the base steel sheet st a base plate collision-propagating velocity V_c of 1,800 m/sec. Thus, the cladding metal sheet was securely bonded to the base metal sheet.

The Hastelloy sheet thus clad on the base steel sheet had an attractive fresh surface, as if it had not been subjected to the explosion welding process. As a result of cutting tests of the clad metal thus formed, only one imperfect bond of about 15 mm length and 2–3 mm width was found at a portion corresponding to one edge of the initiator layer 8. Otherwise, the bond of the cladding metal to the base metal was perfect, without any cracks. Bending tests were made on specimens formed by cutting the clad metal, by bending each specimen with a radius equivalent to the specimen thickness. Neither peeling nor cracking was noticed in both of the bendings from the front surface and from the back surface of the clad metal.

EXAMPLE 4

An arrangement similar to that of FIG. 12 was formed by using the following materials, in which two cladding metal sheets 3 were used so as to sandwich one base metal sheet 4.

Base metal sheet 4: 100×200×1 mm copper sheet
Two cladding metal sheets 3: each being 100×200×1 mm nickel sheet
Spacing between the sheets 3 and 4: each being 0.2 mm

The base metal sheet 4 was sandwiched by the two cladding metal sheets 3, while keeping all the edges of the sheets 3 and 4 in alignment with each other. The assembly of the parallel spaced sheets 3 and 4 was placed on the ground acting as a worktable 11.

Separately, the following driver plate 5 and detonating driver plate 8 were prepared.

Driver plate 5: 150×280×1 mm steel sheet
Explosive layer 2: the same explosive powder consisting of 10 parts by weight of tetranitromethylaniline and 90 parts by weight of ammonium perchlorate, with an apparent density of 1.0 g/cm^3, being disposed on the driver plate 5 in the same manner as Example 1 in the form of 140×270×6 mm layer
Detonating driver plate 8: 150×280×1 mm steel sheet
Initiator layer 7: same as the last mentioned explosive layer 2
Spacer 12 between the top cladding sheet 3 and the driver plate 5: 100×200×15 mm foamed urethane resin with an apparent density of 0.03 g/cm^3

The driver plate 5 carrying the explosive layer 2 was placed in parallel with the aforesaid assembly of the base and cladding metal sheets 3 and 4, while inserting the foamed resin spacer 12 between the assembly and the driver plate 5. The 280 mm edges of the driver plate 5 extended beyond the corresponding 200 mm edge of the cladding metal sheet 3 by 25 mm on either side thereof, while one of 150 mm edges of the driver plate 5 extended beyond the corresponding 100 mm edge of the cladding metal sheet 3 by 50 mm. One of the 150 mm edges of the detonating driver plate 8 was placed vertically 25 mm above the top surface of the explosive layer 2 in parallel with corresponding 150 mm edge of the wooden frame of the driver plate 5, at the side where the driver plate 5 extended beond the cladding sheet 3 by 50 mm. The opposite 150 mm edge of the detonating driver plate 8 was placed vertically 10 mm above the top surface of the explosive layer 2. As a result, the detonating driver plate 8 was inclined by about 3°, relative to the top surface of the explosive layer 2.

The initiator layer 7 of the aforesaid arrangement was fired at the edge farthest from the cladding metal sheet 3 by a linear wave generator. As a result, the initiator layer 7 was detonated at a detonation velocity d of 1,800 m/sec., so as to fire the explosive layer 2 at an initiating velocity of 2,200 m/sec. Consequently, the 6 mm thick explosive layer 2 was detonated at a detonation velocity D of 1,800 m/sec., with a detonating wave front 9 slanted 55° relative to the bottom surface of the explosive layer 2. Accordingly, the driver plate 5 was driven through the foamed urethane spacer 15 at a high speed, so as to collide with the assembly of the base and cladding sheets 3 and 4, for causing the cladding sheets 3 and the base steel sheet 4 to collide at a base plate collision-propagating velocity V_c of 2,200 m/sec. Thus the cladding metal sheet was securely bonded to the base metal sheet.

Deposits of combustion and heat decomposition compounds of urethane spacer 15 were noticed on the outer surface of the nickel-copper-nickel clad metal thus formed, but such deposits were easily removed. The nickel sheet thus clad on the base copper sheet had an attractive fresh surface, as if it had not been subjected to the explosion welding process. As a result of cutting tests of the clad metal thus formed, the nickel-copper-nickel system had perfect bonds between adjacent sheets, without any cracks.

EXAMPLE 5

An arrangement similar to that of FIG. 6 was formed, by using the following elements.

Base metal sheet 4: 20×50×3 mm tantalum sheet
Cladding metal sheet 3: 20×50×3 mm tungsten sheet
Spacing between the base and cladding metal sheets: 0.2 mm
Spacer 12: foamed styrene member, with a 50×80 mm horizontal and a right-angled triangular cross section having a 10° angle facing the vertical edge, apparent density being 0.002 g/cm^3
Driver plate 5: 2 mm thick aluminum sheet of similar size with the inclined surface of the spacer 15
Expolsive layer 2: 3 mm thick explosive sheet secured to the aluminum driver plate, with apparent

density of 1z72 g/cm³ and a detonation velocity *D* of 4,000 m/sec.

The parallel combination of the base sheet **4** and the cladding sheet **3** was placed on the ground with the cladding sheet facing upwards. The horizontal surface of the spacer **15** was placed on the cladding sheet **3**, so that the each edge of the horizontal surface of the spacer extends beyond the corresponding parallel-disposed edges of the cladding sheet **3** by 15 mm. The driver plate **5** was placed on the inclined top surface of the spacer **15** so as to be inclined by 10° relative to the cladding tungesten sheet **3**.

Then, the explosive layer **2** was initiated at the central portion of its lowermost edge by a No. 6 electric detonator. In response to the detonation of the explosive layer **2**, the driver plate **5** collided with the cladding tungsten sheet **3** after flying through the spacer **15**, so as to cause the cladding tungsten sheet **3** to collide the base tantalum sheet **4** at a base sheet collision-propagating velocity V_c of 2,500 m/sec. Thus, a clad metal sheet consisting of a base tantalum sheet covered with a tungusten sheet was produced.

The bond between the base tantalum sheet **4** and the cladding tungsten sheet **3** proved to be satisfactory except two imperfections of about 3 mm width and about 5–10 mm length on edges of the cladding tungsten sheet **3**. Otherwise the bond was perfect, without any cracks.

With conventional explosive welding processes, tungsten is hardly weldable because it tends to be splashed. Even if one succeeds in connecting a tungsten sheet to a base metal sheet by a conventional explosive welding process, the quality of the bond is very poor and a large number of cracks are formed therein.

EXAMPLE 6.

An arrangement similar to that of FIG. **7** was formed, by using the following elements.

- Base metal sheet **4**: 100×200×15 mm steel plate of 41 Kg/mm² tensile strength class
- Cladding metal sheet **3**: 100×200×6 mm titanium sheet of KS—50
- Angle β between the base and cladding metal sheets: 2°
- Protective layer **6**: 1 mm thick pressed black rubber of regular grade
- Driver plate **5**: 150×300×3 mm mild steel sheet
- Explosive layer **2**: 30 mm thick explosive powder layer held by a cardboard frame secured to the mild steel driver plate, consisting of 10 parts by weight of tetranitromethylaniline and 90 parts by weight of ammonium perchlorate, with an apparent density of 1.1 g/cm³
- Angle α between the driver plate **5** and the protective layer **6**: 2°

The angle β between base steel sheet and the cladding titanium sheet was formed by keeping the 100 mm edges thereof in contact with each other while inserting an L-shaped spacer between the opposite 100 mm edges of the two sheets at a suitably inclined posture. The angle α between the driver plate **5** and the protective layer was also made by using a similar L-shaped spacer. One of the 150 mm edges of the driver plate **5** extended slantly downwards beyond the 100 mm edge of the cladding titanium sheet **3**, while extending the two 300 mm edges of the driver plate **5** beyond the 200 mm sides of the cladding titanium sheet by 25 mm on either side thereof.

Then, the explosive layer **2** was initiated at its lowermost edge by a No. 6 detonator. The detonation velocity *D* of the explosive layer **2** was 2,800 m/sec. In response to the detonation of the explosive layer **2**, the driver plate **5** collided with the cladding metal sheet **3** through the protective layer **6** at a driver plate collision-propagating velocity of 2,550 m/sec., so as to cause the titanium sheet **3** to collide the steel base metal sheet **4** at a base sheet collision-propagating velocity of 2,330 m/sec. Thus, a clad metal sheet consisting of a base steel sheet covered with a titanium sheet was produced.

Deposits of the combustion and decomposition compounds produced from the protective layer **6** by the flying of the driver plate **5** were noticed on the clad metal surface, but such deposits were easily removed, so that fresh attractive titanium surface was achieved. Suerpsonic tests proved that excellent bond was formed between the cladding titanium sheet and the base steel sheet, without any cracks and wrinkles. Peeling tests and tensile strength tests showed that the peeling strength and the tensile strength of the clad metal were not smaller than 45 Kg/mm² and 32 Kg/mm², respectively.

The same means for angularly supporting the cladding metal sheet **3** and the driver plate **5** as described above in relation to Example 6 was also used in the following Examples.

EXAMPLE 7

An arrangement similar to that of FIG. **7** was formed, by using the following elements.

- Base metal sheet **4**: 100×200×9 mm steel plate of 41 Kg/mm² tensile strength class
- Cladding metal sheet **3**: 100×200×2 mm stainles steel sheet of SUS—27
- Angle β between the base and cladding metal sheets: 5°
- Protective layer **6**: 2 mm thick agar layer overlaid on the cladding metal sheet
- Driver plate **5**: 120×250×2 mm aluminum sheet
- Explosive layer **2**: 120×250×3 mm explosive sheet secured to the aluminum driver plate, consisting of 75 parts by weight of triminitrotrimethylenetriamine and 25 parts by weight of a synthetic resin paste, with a detonation velocity *D* of 7,000 m/sec.
- Angle α between the plate **5** and the protective layer **6**: 12°

The driver plate **5** was supported by wooden blocks on the ground, where the base metal sheet **4** slantly carrying the cladding stainless steel sheet at 5° was placed, so that the lower portion of the driver plate **5** was supported from the ground by wooden blocks so as to keep the lower surface of the driver plate **5** in contact with a 100 mm edge of the agar protective layer **6** while the driver plate **5** being further extended downwards by 30 mm, as generally indicated in FIG. **7**.

Then, the explosive layer **2** was initiated at its lowermost edge by a linear wave generating means. In response to the detonation of the explosive layer **2**, the driver plate **5** was impinged to the cladding metal sheet **3** at a high speed through the protective layer **6** at a flying velocity of 3,500 m/sec., so as to cause the stainless steel sheet **3** to collide the steel base metal sheet **4** at a base sheet collision-propagating velocity V_c of 2,160

m/sec. Thus, a clad metal sheet consisting of a base steel sheet covered with a stainless sheet was produced.

The outer surface of the cladding stainless steel sheet bonded to the base sheet was as smooth as a fresh stainless steel sheet prior to the explosion welding. Supersonic tests proved that excellent bond was formed between the cladding stainless steel sheet and the base steel sheet. Bending tests were made on specimens formed by cutting the clad metal and bending it with a radius equivalent to the thickness of the clad metal. Peelings and crackings were not noticed at all in both of the bendings from the front surface and from the back surface of the clad metal.

EXAMPLE 8

The explosion welding process of Exmaple 7 was repeated, after applying the following modification.

1. The protective layer **6** consisting of the agar layer was replaced with a peelable synthetic resin coating on the top surface of the cladding stainless steel sheet.
2. The means for angularly supporting the driver plate **5** consisting of an L-shaped member was replaced with a foamed styrene resin member having a wedge-like cross section with a tip angle of 12° and an apparent density of 0.04 g/cm^3. The size of the inclined surface of the foamed styrene resin member was substantially identical with the size of the aluminum drive plate **5.**

The entire arrangement was placed on the ground, and the explosive layer **2** was fired from its lowermost edge by means of a linear wave generator. As a result, the cladding stainless steel sheet **3** was forced to collide with the base steel sheet **4** at a base sheet collision-propagating velocity V_c of 2,500 m/sec. Thus, the cladding stainless steel sheet **3** was firmly bonded to the base steel sheet **4,** throughout the entire span of the base steel sheet **4,** without any cracks or wrinkles.

EXAMPLE 9

An arrangement of FIG. **8** was formed by using the following materials.

Base metal sheet **4**: 100×200×9 mm steel sheet of 41 Kg/mm^2 tensile strength class
Cladding metal sheet **3**: 100×200×2 mm titanium sheet
Spacing between the sheets **3** and **4**: 1 mm
Driver plate **5**: 130×270×1 mm mild steel sheet
Explosive layer **2**: 20 mm thick explosive layer consisting of 2 parts by weight of tetranitromethylaniline and 98 parts by weight of ammonium perchlorate, being disposed on the driver plate **5** in the same manner as Example 1
Protective sheet **6**: 100×200×1 mm pressed black rubber sheet, secured to the cladding titanium sheet **3** by a synthetic resin adhesive
Detonating driver plate **8**: 170×300×0.8 mm mild steel sheet
Initiator layer **7**: 1 mm thick initiator powder layer, consisting of 10 parts by weight of tetranitromethylaniline and 90 parts by weight of ammonium perchlorate, being disposed on the detonating driver plate **8** in the same manner as Example 1
Spacing between the detonating driver plate **8** and the explosive layer **2**: 5 mm

The assembly consisting of the base metal sheet **4,** the cladding metal sheet **3,** and the driver plate **5** was arranged in the same manner as Example 1. The detonating driver plate **8** was disposed in parallel with the driver plate **5,** while keeping all the edges of the two plates **5** and **8** in parallel with each other. One of the 170 mm edges of the detonating driver plate **8** extended beyond the corresponding edge of the driver plate **5** by 30 mm.

The initiator layer **7** of the aforesaid arrangement was fired at the center of the edge farthest from the cladding metal sheet **3** by a No. 6 electric detonator. As a result, the initiator layer **7** was detonated at detonation velocity d of 2,500 m/sec., so as to fire the explosive layer **2** at an initiating velocity of 2,500 m/sec. Consequently, the 6 mm thick explosive layer **2** was detonated, with a detonating wave front **9** slanted by 23,6° relative to the bottom surface of the explosive layer **2.** Accordingly, the driver plate **5** was driven through the protective rubber layer **6** to the cladding titanium sheet **3** at a driver plate collision-propagating velocity V_d of 2,120 m/sec., so as to cause the cladding titanium sheet **3** to collide with the base steel sheet at a base sheet collision-propagating velocity V_c of 1,820 m/sec. Thus, the cladding tiatnium sheet **3** was securely bonded to the base metal sheet.

The same tests as Example 1 were made on the clad metal thus obtained in this Example 9, and excellent properties of the clad metal were proved by such tests.

EXAMPLE 10

An arrangement similar to FIG. **12,** as modified by the disposition of FIG. **7,** was formed by using the following materials.

Base metal sheet **4**: 100×150×15 mm steel plate of SPC 15 class
Cladding metal sheet **3**: 100×150×6.4 mm Hastelloy C sheet
Angle β between base metal sheet **4** and cladding metal sheet **3**: 15°
Protective layer **6**: 100×150×2 mm vinyl acetate layer
Driver plate **5**: 120×170×3 mm mild steel sheet
Explosive layer **2**: 120×170×8 mm explosive layer, consisting of 75 parts by weight of trinitrotrimethylenetriamine and 25 parts by weight of synthetic resin paste
Angle α between driver plate **5** and protective layer **6**: 15°
Detonating driver plate **8**: 150×200×2 mm aluminum plate
Initiator layer **7**: 150×200×3 mm initiator layer, consisting of 75 parts by weight of trinitrotrimethylenetriamine and 25 parts by weight of synthetic resin paste
Angle ψ between detonating driver plate **8** and explosive layer **2**: 10°

The base steel sheet **4** was placed on the ground, and one of the two 100 mm edges of the cladding metal sheet **3** was kept in contact with the corresponding 100 mm edge of the base steel sheet **4,** so as to let the cladding metal sheet **3** extend over the base steel sheet **4** at an angle of 15°. Each edge of the driver plate **5** extended beyond the corresponding edges of the cladding Hastelloy sheet **3** by 10 mm, while the minimum vertical distance between the lower surface of the driver plate **5** and the protective layer **6** was 10 mm. The angle ψ between the bottom surface of the detonating

driver sheet **8** and the top surface of the explosive layer **2** was defined at the uppermost edge of explosive layer **2**, i.e., at the opposite edge to the edge where the angle α of 15° was defined between the bottom surface of the driver plate **5** and the protective layer **6**.

With the aforesaid arrangement, the initiator layer **7** was fired by a line wave generator, at its edge opposite to the edge where the angle ψ of 10° was defined. The initiator layer **7** expolded at a detonation velocity d of 7,000 m/sec., so as to cause the detonating driver plate **8** to collide with the explosive layer **2** at initiating velocity of 24,300 m/sec., with a detonating wave front **9** slanted by 16.7° relative to the top surface of the driver plate **5**. Accordingly, the driver plate **5** was driven through the protective vinyl acetate layer **6** to the cladding metal sheet **3** at a driver plate collision-propagating velocity V_d of 1,870 m/sec., so as to cause the cladding Hastelloy sheet **3** to collide with the base steel sheet **4** at a base sheet collision-propagating velocity V_c of 1,290 m/sec. Thus, the cladding Hastelloy sheet **3** was securely bonded to the base steel sheet **4**.

Tests by a supersonic defects-finder proved that the bond between the base steel sheet **4** with the Hastelloy cladding sheet **3** was satisfactory, except a weakly bonded portion of 2–3 width and a length equivalent to about the half of the clad metal length. The weakly bonded portion was located close to the position of the linear wave generator.

As pointed out in the foregoing, the 100 mm edge of the cladding Hastelloy sheet **3** was in contact with the corresponding 100 mm edge of the base steel sheet **4** in this Example 10. An extra test was made, while separating the 100 mm edge of the Hastelloy sheet from the corresponding 100 mm edge of the base steel sheet by 0.5 mm, and in this case no weakly bonded portion was generated.

In each of the foregoing Examples, the surfaces of the metal sheets to be bonded were polished, mechanically or chemically, so as to remove any oxide film therefrom. In the case of those anti-corrosion metal whose oxide is negligible, the surfaces to be bonded were cleansed by a suitable solvent for removing foreign matters therefrom, prior to the explosion welding tests.

I claim:

1. An explosive welding process, comprising the steps of disposing at least one cladding metal sheet so as to face a base metal sheet with a spacing equivalent to one-twentieth to 25 times the thickness of that one of the two sheets which is to be driven toward the other sheet, coating a protective layer on the sheet to be driven at the surface of the latter facing away from the other sheet, placing a driver plate so as to face the protective layer with a spacing equivalent to one-twentieth to twenty-five times the thickness of the driver plate, the latter being at least as wide as the sheet to be driven, forming an explosive layer on the driver plate on the surface of the latter facing away from the protective layer, and igniting the explosive layer to cause the driver plate to collide with and drive the sheet to be driven, for generating a colliding impact large enough to bond the cladding metal sheet to the base metal, the explosive layer being so related with the spacing between the driver plate and the protective layer that the driver plate collides with the protective layer at a velocity which is fast enough to cause the sheet to be driven to collide with the other metal sheet at a velocity faster than 800 m/sec. but slower than the highest sonic velocity in the cladding and the base metal sheets.

2. The explosive welding process as defined in claim **1**, further comprising the steps of disposing a detonating driver plate so as to face the explosive layer with a spacing equivalent to one-twentieth to 25 times the thickness of the detonating drive plate, providing an initiator layer on the detonating driver plate on the surface of the latter facing away from the explosive layer, and firing the initiator layer to cause the detonating driver plate to collide with and detonate the explosive layer, the initiator layer being so related with said spacing between the detonating driver plate and the explosive layer that the latter is detonated with a detonating wave front which is slanted toward the detonating direction of the explosive layer with an angle not greater than 60° relative to the plane of the driver plate.

3. The explosive welding process as defined in claim **2**, wherein the spacing between the explosive layer and the detonating drive plate is filled with a foamed high-molecular compound with an apparent density of 0.01 g/cm^3 to 0.4 g/cm^3.

4. The explosive welding process as defined in claim **2**, wherein the detonating wave is slanted with an angle not greater than 60° relative to the plane of the explosive layer.

5. The explosive welding process as defined in claim **1** wherein the protective layer fills the spacing between the sheet to be driven and the driver plate, which protective layer consists of a foamed high-molecular compound with an apparent density of 0.01 g/cm^3 to 0.4 g/cm^3.

6. The explosive welding process as defined in claim **1** wherein the sheet to be driven is slanted by 0.5° to 20° relative to the other sheet.

7. The explosive welding process as defined in claim **1**, wherein the driver plate is slanted by 0.5° to 20° relative to the protective layer.

8. The explosive welding process as defined in claim **1**, wherein the base metal sheet consists of mild steel.

9. The explosive welding process as defined in claim **1**, wherein the cladding metal sheet consists of a metal selected from the group consisting of titanium, stainless steel, Hastelloy, brass, bronze, copper zirconium, nickel, tantalum, silver, gold, platinum, tungsten, niobium, chronium, cobalt, aluminum, molybdenum, magnesium, vanadium, zinc, tin and their alloys.

10. The explosive welding process as defined in claim **2**, wherein said detonating driver plate is at least as wide as the effective area of the driver plate and is 0.3 mm to 3 mm thick.

11. The explosive welding process as defined in claim **1**, wherein the thickness of the protective layer is tapered so as to provide varying time delays in the delivery of the collision impact of the driver plate to the cladding metal sheet.

12. The explosive welding process as defined in claim **1**, wherein the driver plate is larger than the cladding metal sheet by any side thereof.

13. The explosive welding process as defined in claim **1**, wherein the thickness of the driver plate is 0.3 to 10 times the thickness of the cladding metal sheet.

14. The explosive welding process as defined in claim **1**, wherein at least two cladding metal sheets are disposed between the driver plate and the base metal sheet for bonding the cladding metal sheets to the base metal sheet.

* * * * *

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,813,758 Dated June 4, 1974

Inventor(X) Masatada Araki

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In the heading of the patent, under (73 "assignees":), change "Senko" to -- Denko --; and

column 2, line 38, change "gond" to -- bond -- .

Signed and sealed this 17th day of December 1974.

(SEAL)
Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents