

April 16, 1968

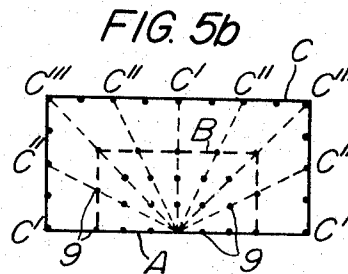
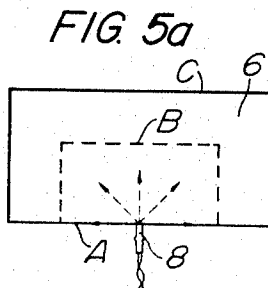
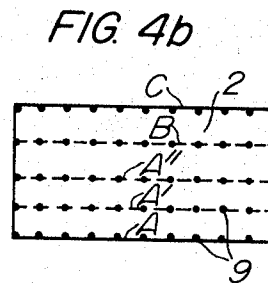
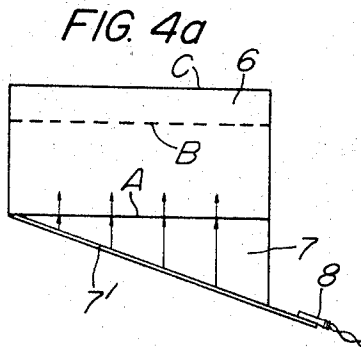
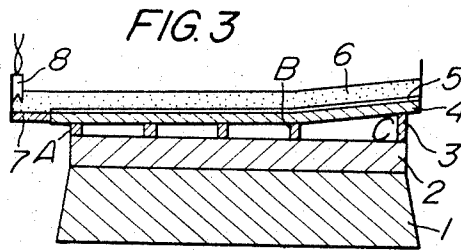
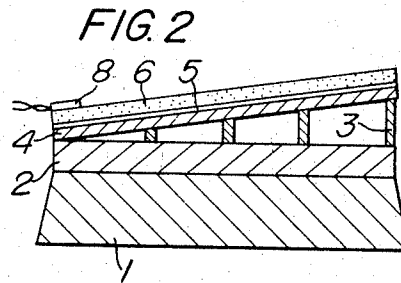
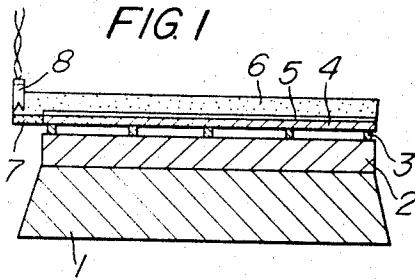
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3,377,693

PROCESS FOR PRODUCING CLAD METAL PLATES BY EXPLOSIVE BONDING

Filed Sept. 22, 1965

2 Sheets-Sheet 1



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PROCESS FOR PRODUCING CLAD METAL PLATES BY EXPLOSIVE BONDING

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2 Sheets-Sheet 2

FIG. 6

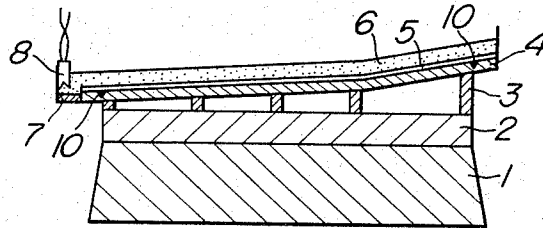


FIG. 7



FIG. 8



FIG. 9

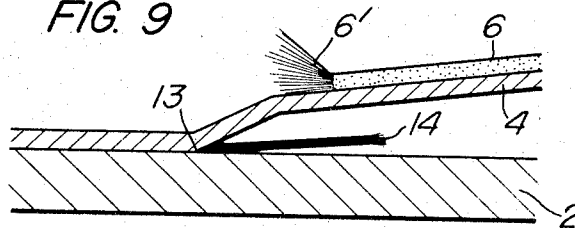
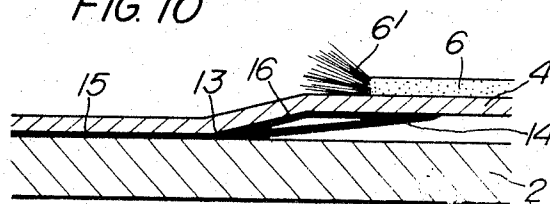


FIG. 10



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PROCESS FOR PRODUCING CLAD METAL PLATES BY EXPLOSIVE BONDING

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6 Claims. (Cl. 29—470.1)

ABSTRACT OF THE DISCLOSURE

A process for bonding the same or different metal plates by the detonation pressure of an explosive wherein an angle is formed between a cladding metal plate and a base metal plate of from 0.1 to 0.5° in a first region, and a larger angle of between 0.3 to 1.2° is formed between the plates in a second region. The cladding plate is superimposed on the base plate so that said first region extends over 45 to 80 percent of the base plate. An explosive is placed on a buffer above the cladding plate and detonation is effected at one end of the first region so that detonation proceeds from the first region to the second region.

The present invention relates to a process for producing clad plates, which comprises bonding a metal plate with a plate of the same or different kind by detonation pressure of an explosive. The conventional processes such as the rolling method, vapor deposition method, face build-up method, fusion welding method, etc. have many faults.

In contrast to this, there is merit in a recently developed process for preparing a clad plate by the detonation pressure of an explosive, as compared with the conventional processes. Therefore, it has been extensively investigated in many places. This process involves preparing clad plates under cold working by superimposing a metal plate (which will be called a cladding metal, hereinafter) and composed for example of corrosion-resistant metal, with a certain spacing, upon a metal plate (which will be called a base metal, hereinafter) and composed for example of low-priced mild steel and the like, and thereafter detonating an explosive placed upon the cladding metal to urge the cladding metal against the base metal at a very high speed by the detonation pressure of the explosion. Such process is called the explosive bonding method.

In order to maintain the space between the cladding metal and the base metal in the widely-known explosive bonding method, there are two known methods; in one method the cladding metal is maintained at an angle of from 1 to 32° relative to the base metal (which will be called the angle method, hereinafter) in the other method the cladding metal and the base metal are maintained parallel with each other (which will be called the parallel method, hereinafter). According to either of the two methods, it is possible to strongly bond a metal plate with another plate of the same or different kind, as compared with conventional processes for preparing clad plates.

However, when the surface area of the cladding metal and the base metal are large as for example, a square of 500 mm. x 500 mm., the following faults have been observed even in said conventional explosive bonding methods. In the clad plate prepared by the parallel method of explosive bonding, there often is produced a poor bonded region in a location distant from the initiation point and, additionally the explosive bond between the cladding metal and the base metal consists of a hard and brittle inferior alloy zone. Thus the bonding strength of

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the cladding metal and the base metal is weak and is hard to be mechanically worked. The reason why the above occurs may be explained as follows. During the explosive bonding, air between the cladding metal and the base metal is pushed to the regions distant from the initiation point and is finally expelled. Air between the cladding metal and the base metal distant from the initiation point is more easily expelled than air near the initiation point. Thus, further the explosive bonded point is from the initiation point, the easier air between the cladding metal and the base metal may be expelled. Therefore, the space between the cladding metal and the base metal tends to be reduced in spite of placing a spacer in the gap. The space becomes gradually smaller and finally becomes smaller than that necessary for the explosive bonding. There thus occurs a poor bond in regions distant from the initiation part. When the cladding metal collides with the base metal, the surfaces thereof facing each other are melted to form the so-called metal jet. It may be considered according to the essence of the bonding mechanism of the parallel spacing method that a part of said metal jet is captured between the cladding metal and the base metal and, at the same time, another part of the metal jet is removed together with air between the cladding metal and the base metal. However, when the space between the cladding metal and the base metal becomes smaller in such a case as described above, the cladding metal collides with the base metal before the metal jet is removed completely. Finally, the metal jet is captured between the cladding metal and the base metal in the form of a further thicker bonding zone (as the hard and brittle inferior alloy zone).

Therefore, there occurs a poor bond in some regions of the clad plate thus obtained and further the cladding metal is connected with the base metal in the bonding zone with a hard and brittle inferior alloy, so that the bonding strength of the clad plate is weak and it is difficult to work the clad plate mechanically.

On the one hand, in the clad plate prepared by explosive bonding according to the angle method, a large internal strain in material property due to work hardening is produced and the workability and the corrosion resistibility are inferior as compared with the inherent properties of the cladding metal and base metal. There are sometimes present cracks in the plate thus obtained. The reason for this may be explained as follows.

For example, even in case the space is maintained by inclining the cladding metal at the angle of 5° relative to the base metal at the juncture, the space of the open-side edge between the cladding metal and the base metal is as great as 87.5 mm., in the preparation of 1000 mm. x 1000 mm. square clad plates. If the cladding metal collides with the base metal at a high speed in the case as mentioned above, the cladding metal is forced to undergo deformation beyond the yield point of the cladding metal itself, and the cladding metal is subjected to excessive workhardening whereby there are sometimes formed cracks. Further, the base metal is subjected under cold working to a tension in the detonating direction by collision with the cladding metal and then subjected to excessive workhardening.

As the periphery of the clad plates is not sufficiently bonded by the conventional explosive bonding processes, the periphery of the plates thus obtained should be removed for practical use.

One object of the present invention is to provide a process for preparing clad plates containing only very small amounts of poor bonded regions, inferior alloy zones, excessive workhardened parts and cracks. Another object is to provide a process for preparing clad plates which have acceptable properties over the whole area

thereof and whose periphery requires no substantial removal.

The said objects of the present invention can be achieved by placing the cladding metal on the base metal, maintaining the space between the cladding metal and the base metal relative so that the angle of the cladding metal to the base metal may be larger (in the detonating direction of the explosive) in the distant regions than in the regions in the neighborhood of the initiation point, placing an explosive on a buffer above said cladding metal and detonating said explosive.

The effect of the present invention can sufficiently be displayed only in case of bonding a metal of plate of a size greater than 500 mm. x 500 mm., with another plate of the same or different kind. In case of using metal plates of less than said area, the present invention has no improved effects as compared with said parallel or angle method. Suitable cladding metal according to the present invention is limited to a relatively thin and flexible material of about 1:2 to 4 mm. in thickness. In the case of bonding the cladding metal with the same metal in the manner as specified above, the cladding metal is maintained above the base so that the angle between the cladding metal and the base metal in the space between the cladding metal and the base metal may be from 0.1 to 0.5° in the neighborhood of the initiation point, that is, in the range of 45 to 80% of the base metal length in the detonating direction of an explosive and may be from 0.3 to 1.2° in the distant region, but larger in the distant region than in the neighborhood of the initiation point.

The space between the cladding metal and the base metal is dependent upon the kind and thickness of the cladding metal and in the kind and amount of the explosive. In general if the cladding metal is thin, it is necessary to increase the base metal length of the initiation point region, that is, the angle range of 0.1 to 0.5° between the cladding metal and the base metal and to use lower values of said angle range. On the one hand, if the cladding metal is thick, desirable results are obtained by decreasing the base metal length of the initiation point region, that is, the angle range of 0.1 to 0.5° between the cladding metal and the base metal and using higher values of said angle range. The reason why the base metal length of the initiation point region in the detonating direction of an explosive is limited to a value between 45 and 80 % is that, if the length of the initiation point region is less than 45%, the open end of the angular space between the cladding metal and the base metal becomes too great and consequently the clad plate thus obtained is subjected to the same excessive workhardening as the clad plate prepared by the explosive bonding of the angle method. Alternatively if said length is more than 80%, the effect of maintaining the cladding metal at two different inclinations is lost. The reason why the angle of the cladding metal to the base metal in the neighborhood of the initiation point in the space between the cladding metal to the base metal is limited within from 0.1 to 0.5° is that, if said angle is less than 0.1°, the metal jet formed between the cladding metal and the base metal during the explosive bonding can hardly be removed with the air between the cladding metal and the base metal and, if said angle is more than 0.5°, the metal and the base metal becomes too great and the clad plate thus obtained is subjected to excessive workhardening.

The reason why the angle of the cladding metal relative to the base metal in the regions distant from the neighborhood of the initiation point is limited to a value within 0.3 and 1.2° is that, if said angle is less than 0.3°, the metal jet formed between the cladding metal and the base metal can hardly be removed with the air between the cladding metal and the base metal, and, if said angle is more than 1.2°, the clad plate is subjected to excessive workhardening. In this case, it is necessary to keep said

angle in the distant regions larger than that in the neighborhood of the initiation point.

Next, as the means of maintaining the space between the cladding metal and the base metal in such a manner as described above, it is possible to freely employ any appropriate means such as placing on the base metal spacers or supporting rods of metal foils or plates of the same kind as either the cladding metal or the base metal or of a different kind from the two, or suspending the cladding metal above the base metal. When the space can not be maintained due to a change in the kind of metal, the bonding can successfully be made by previously forming a part of the cladding metal in to the required shape.

In the practice of the present invention, it is desirable with some metals to remove any dirt from the surfaces of the cladding metal and the base metal which are to be bonded by physical treatments with sand paper or a grinder, or by chemical treatments.

Suitable cladding metal and base metal in the practice of the present invention include mild steel, nickel, chromium, cobalt, titanium, zirconium, tantalum, aluminum, manganese, molybdenum and copper plates and alloy plates containing the above metals as the principal constituent. The thickness of the cladding metal is about 1.2 to 4 mm. and is less than that of the base metal. It is desirable that the area of the cladding metal is larger than that of the base metal, for example, larger by about 30 mm. than that of the base metal along two sides in the case where the cladding metal and the base metal are rectangular. The cladding metal is placed so that each side of the cladding metal protrudes by at least 10 mm. beyond the corresponding edge of the base metal.

A suitable explosive according to the present invention is a powder explosive consisting of 5 to 40% pentaerithrite tetranitrate, 3 to 13% starch, 54 to 87% low density ammonium nitrate and 1 to 3% water. A line wave generator to be used for the initiation of the explosive consists of a triangular plate constituted of plywood, plastic, steel, etc., a primer cord to be attached to the longer side of the triangular plate and an explosive placed on the triangular plate. The shape of said triangular plate is determined by taking into account the detonation velocity of the primer cord attached to the longer side of the triangle and the detonation velocity of the explosive so that the detonating direction at the explosive is parallel with the two side-faces of the cladding metal.

A suitable buffer according to the present invention may be adhesive tape, rubber, lacquer and a plastic-containing paint, etc.

As the modification of the present invention, a notch can be formed in the cladding metal conforming to the shape of the base metal having a slightly larger area than the base metal, the cladding metal above the base metal being placed so that said notch coincides with the periphery of the base metal. Thereby, the periphery of the obtained clad plate can be made in good condition.

For a further understanding of the present invention, a detailed explanation is given below, with reference to the drawing, wherein:

FIG. 1 is a cross-sectional view of an arrangement for producing clad plates by the conventional parallel method;

FIG. 2 is a cross-sectional view of an arrangement for producing clad plates by the conventional angle method;

FIG. 3 is a cross-sectional view of an arrangement for producing clad plates according to the present invention;

FIGS. 4a and 5a are plan views showing a difference in the detonating direction of an explosive due to the initiation method employed by the present invention and illustrating the relations of points A, B and C in the space between the cladding metal and the base metal shown in FIG. 3;

FIGS. 4b and 5b show an example of the disposition

of a spacer placed on the base metal, respectively in FIGS. 4a and 5a;

FIG. 6 is a cross-sectional view similar to FIG. 1 showing a modification thereof;

FIG. 7 is a photomicrograph (magnification of 100) of a bimetallic assembly prepared in accordance with the present invention;

FIG. 8 is a photomicrograph (magnification of 100) of a bimetallic assembly prepared in accordance with the parallel method;

FIG. 9 represents a schematic depiction of the phenomenon which is believed to occur in the course of the present process, and

FIG. 10 represents a schematic depiction of the phenomenon which is believed to occur in the course of the parallel method of the prior art.

FIG. 1 shows a base metal 2 placed on a support 1, a cladding metal 4 is placed on base metal 2 in spaced relation with a gap of at least 0.0254 mm. between the cladding metal and the base metal. The gap is obtained by using a spacer 3. An explosive 6 is placed on a buffer 5 above the cladding metal 4, and a line wave generator 7 and detonator 8 are mounted in contact with the explosive. The explosive 6 is detonated to produce the clad plate.

In FIG. 2 the cladding metal 4 is maintained on the base metal 2 at an angle of 1 to 32° by the spacer 3, and then, in the same manner as in FIG. 1, explosive bonding is effected to produce the clad plate.

In FIG. 3 is shown the process of the present invention, wherein the base metal 2 is placed on the support 1 and the cladding metal 4 is maintained on the base metal 2 by the spacer 3 so that the angle of the cladding metal 4 to the base metal 2 is larger in the region most distant from the initiation point of the explosion (region B-C) as compared to the angle in the neighborhood of the initiation point (region A-B).

In this case, the extent of the A-B region is 45 to 80% of the base metal length in the detonating direction of the explosive 6, the angle of the cladding metal 4 to the base metal 2 being 0.1 to 0.5°. The extent of the B-C region, is 20 to 55% of the base metal length, and the angle of the cladding metal 4 to the base metal 2 is 0.3 to 1.2°. As described above, the angle of the cladding metal 4 to the base metal 2 is larger in the region B-C than in the neighborhood of the initiation point. It is also desirable that the space between the cladding metal and the base metal be 0.8 to 2.0 mm. at point A. Then, the buffer 5 is placed on the cladding metal 5, a frame is provided along the periphery of the cladding metal, the powder explosive 6 is placed, the line wave generator 7 and the electric detonator 8 are mounted and the powder explosive 6 is detonated to produce the clad plate.

Further, in case of detonating the explosive 6 the detonating direction varies with the initiation method employed, so further explanation is given in FIGS. 4 and 5 to make clear at what places on the base metal 2 there are disposed points A, B and C shown in FIG. 3. FIG. 4a represents the case in which a triangular line wave generator 7 consisting of the same explosive as the powder explosive 6 is utilized and the primer cord 7' which is attached to the longer side of the line wave generator (and has about 3 times the detonation velocity of the powder explosive) is initiated by the electric detonator 8. In this case, the detonating direction of the explosive is indicated by the arrows, so points A, B and C on the base metal shown in FIG. 3 correspond to lines A, B and C in FIG. 4. FIG. 4b shows the disposition of the spacers placed on the base metal in FIG. 4a. FIG. 5a illustrates a case in which the electric detonator 8 is mounted in the center of a side of the powder explosive 6, and the detonating direction of the explosive is radial as shown by the arrow heads.

FIG. 5b shows the disposition of the spacers on the base metal in FIG. 5.

FIG. 6 shows an arrangement wherein a notch 10 is previously provided on the cladding metal 4 having a slightly larger area than the base metal, the disposition of the notch being fitted to the periphery of the base metal 2, the space between the cladding metal and the base metal being obtained by maintaining the cladding metal with the spacer 3 so that the angle of the cladding metal 4 with the base metal 2 is larger in the region distant from the neighborhood of the initiation point in the detonating direction. The explosive 6 is placed on the buffer 5 above the cladding metal as in the arrangement of FIG. 3, and the line wave generator 7 and the electric detonator 8 are mounted after which the explosive 6 is detonated to produce the clad plate. In the practice of the process according to the present invention as shown in FIG. 3, the surplus edge of the cladding metal is sheared by the periphery of the base metal when the cladding metal collides with the base metal at a very high velocity during the explosive bonding, so a part of the detonation pressure required for the explosive bonding is spent and consequently there sometimes occur regions of poor bonding in the periphery of the clad plate. This phenomenon tends to be more pronounced with increased thickness of the cladding metal. If the notch 10 is provided in the cladding metal as shown in FIG. 6 when the cladding metal is of 2 to 4 mm. in thickness, the periphery of the clad plate is free of regions of poor bonding. The depth of the notch varies with the thickness of the cladding metal, but is less than 70%, and is preferably 30%, of the thickness of the cladding metal. It is desirable that the notch in the cladding metal be formed in the upper surface thereof as shown in FIG. 6, but the effect is not significantly different from notching the surface facing the base metal.

In the photomicrograph of FIG. 7, A indicates a base layer of carbon steel, B indicates a cladding layer of titanium and C indicates the interface waves. In the photomicrograph of FIG. 8, A indicates a base layer of carbon steel, B indicates a cladding layer of titanium and D indicates the bonding zone composed of material from layers A and B.

In FIG. 9, 2 represents the base metal layer, 4 represents the cladding metal layer, 6 represents the layer of explosive before detonation, and 6' represents the gaseous detonation products following detonation of layer 6, 14 represents a sharp liquid stream of material composed of both layers 2 and 4 which impinges on the underside of layer 2 just ahead of the impact point 13.

In FIG. 10, 16 represents the material immobilized between the layers 2 and 4 and bonding these layers together, 14 represents the jetted material which is recirculated to give intimate mixing of the two metals.

The present invention is further illustrated by the following examples given for the purpose of illustration only, but not limiting the invention, and wherein the percentages are by weight.

Example 1

An explosive is used which is a powder explosive consisting of 10% pentaerithrite tetranitrate, 12% starch, 76% low density ammonium nitrate and 2% water content, and having a detonation velocity of 1900 m./sec. The cladding metal is a titanium plate (2 mm. x 1000 mm. x 2000 mm.) and the base metal is a mild steel plate (16 mm. x 970 mm. x 1970 mm.). A masking tape was applied to the cladding metal surface facing the explosive. First, after the upper surface of the base metal was polished with a grinder, the base metal was placed on a sand support and, as shown in FIG. 4b, V-shaped spacers of 0.15 mm. in height made of 1.0 mm. thick nickel foil were placed at intervals of 200 mm. on line A on the base metal, and similarly, there were placed spacers of 1.5 mm. in height on line A', of 2.0 mm. in height on line A'', of 2.5 mm. in height on line B and of

4.3 mm. in height on line C, respectively. The intervals between lines A, A', A'' and B were 230 mm. respectively and the interval lines B and C was 300 mm. On the spacers thus disposed, said cladding metal was placed. In this case, the distance between lines A and B was equal to 70% of the base metal length in the detonating direction of the explosive, where the angle of the cladding metal to the base metal was 0.18° , while the distance between lines B and C was equal to 30% of the base metal length, where the angle of the cladding metal to the base metal was 0.35° . Then, as shown in FIG. 4, a triangular plate made of 5 mm. thick plywood was attached to the longer side of the cladding metal near line A. A primer cord was fixed with the tape along the longer side of this triangle. Within a card board frame attached to the cladding metal and the outside of plywood, said explosive was uniformly disposed, in the ratio of 7 kg. per square meter, on the masking tape. A No. 6 electric detonator was attached to an end of the primer cord, and thereby the primer cord and the explosive were detonated. By exploding the explosive, mild steel and titanium were found to be firmly and uniformly bonded together to form a composite assembly. The same materials and explosive as in the preparation of clad plates according to the procedure of the present invention were used by the angle method (angle 5°) and the parallel method (space 1.0 mm.) respectively to produce clad plates. Various test pieces were removed from a region distant from the initiation point in the obtained clad plates respectively and the results of various tests are compared in Table 1.

As clearly shown in Table 1, the result of ultrasonic examination on the bonding strength of the clad plates obtained according to the process of the present invention verifies that there are no poor bonded parts. The shear strength of this clad plate was measured according to the ASTM (A263-63), and found to be 35 kg. per square millimeter, more than two times the provided value according to the ASTM. Similarly, no failure was observed in the bend test according to the ASTM. The result of the tension test was also excellent. Further, a strip-like inferior alloy zone was not observed in the bonding surface under a microscope.

In contrast to this, though the clad plates obtained by the parallel method had no apparent defects, there were observed a number of poor bonded regions from the test result on the bonding strength due to the ultrasonic examination. Further, the shear strength thereof measured according to the ASTM was lower than that of the clad plate prepared in accordance with the present invention. In the face bend test, the clad plate was broken away at the bonding surface. By observing the bonding surface part under a microscope, the presence of a 35μ wide strip-like, hard and brittle inferior alloy zone was verified.

In the clad plate obtained according to the angle method, many cracks were observed in the surface of the cladding metal, and a surface projection appeared in the regions where the bonding surface contained large spacers. Further, under the face bend test, many cracks which were assumed to be caused by severe workhardening occurred in the bonding surface region. It was also verified by the tension test that elongation was decreased significantly.

As is clear from the comparison of said test results, the poor bonded part which was observed in the clad plate prepared by the parallel method was not observed in the clad plate in accordance with the present invention. The clad plate in accordance with the present invention was excellent in the face bend test.

In the clad plate prepared according to the parallel method, the cladding metal is connected with the base metal through a strip-like alloy zone. In the clad plate prepared according to the present invention, the cladding metal is directly connected with the base metal without the alloy zone. This may indicate a difference in the bond-

ing mechanism between the parallel method and the process of the present invention.

In other words, as a suitable angle determined by the detailed test results is provided between the cladding metal and the base metal, the jetted material is removed in the detonating direction to the open end in the space between the cladding metal and the base metal, without being recirculated (see FIG. 9).

The surfaces of the cladding metal and the base metal facing to each other are changed to a fresh surface by the occurrence of the metal jet and are pressed by each other due to the high pressure of the explosion, so it may be thought that the metallurgical bonding of the cladding metal with the base metal can be carried out without the bonding zone.

On the other hand, in the parallel method, a jet composed of surface layers of both metals may be produced, this jet being directed into the as yet unoccupied space between the layer of cladding metal and the surface of the metal being clad. This jetted material is recirculated to give intimate mixing of the two metals (see FIG. 10).

As described above, the mechanism in the parallel method is understood by assuming that the cladding metal is connected through the bonding zone with the base metal.

It was also verified that the clad plate prepared according to the present invention had no apparent defects as compared with the clad plate according to the angle method and was an excellent clad plate of little work-hardening.

Example 2

The cladding metal used here is a titanium plate (2.5 mm. x 1000 mm. x 2000 mm.) and the base metal is a stainless steel plate (14 mm. x 970 mm. x 1970 mm.).

After polishing the upper surface of the base metal with a grinder, the base metal was placed on a sand support. As shown in FIG. 5b, on line A-C', V-shaped spacers of 1.0 mm., 1.7 mm., 2.4 mm. and 3.1 mm. in height respectively made of 0.15 mm. thick nickel foil were placed from the initiation point at intervals of 200 mm., and a 5.9 mm. high spacer is placed at point C'. Similarly, spacers of 2.6 mm. and 3.4 mm. in height were respectively placed at points of 40% and 60% of the base metal length from the initiation point on line A-C'', and a 6.5 mm. high spacer was placed at point C''. Moreover, spacers of 2.0 mm., 3.0 mm. and 4.0 mm. in height were respectively placed at points of 20%, 40% and 60% of the base metal length from the initiation point on line A-C''', and a 8.0 mm. high spacer was placed at point C'''. Moreover, at the center of C'-C''-C''', 250 mm. from the initiation point, spacers of 6.2 mm. and 7.2 mm. were respectively placed. On the spacers thus disposed, said cladding metal was placed. In this case, the distance between point A and line B was equal to 60% of the base metal length in the detonating direction of the explosive, where the angle of the cladding metal to the base metal was 0.20° , while the distance between lines B and C was equal to 40% of the base metal length, where the angle of the cladding metal to the base metal was 0.40° . Within a cardboard frame attached to the outside of the cladding metal thus disposed, the same explosive as in Example 1 was placed uniformly in the ratio of 8 kg. per square meter. As shown in FIGS. 5a and 5b, an electric detonator was attached to point A where the space between the cladding metal and the base metal was the smallest, and thereby the explosive was detonated.

Under the explosion of the explosive, the stainless steel and titanium plates were found to be firmly and uniformly bonded together to form a composite, assembly. From the test results on the bonding strength of the obtained clad plate according to the ultrasonic examination, there was observed no poor bonded regions. The shear strength thereof was more than 2 times the provided value in accordance with the ASTM. Further, the results of the bend test and the tension test were also satisfactory. No strip-

like inferior alloy zone was present in the bonding surface region, under microscopic observation.

TABLE 1
[The present invention]

Shear Test, Shear Strength (kg./mm. ²)		Bend Test		Tension Test	
		Face Bend	Reverse Bend	Tensile Strength (kg./mm. ²)	Elongation (Percent)
36.2	41.2	Good	Good	{45.5	32.3
40.9	36.1			{45.4	32.1
[Parallel method]					
Shear Test, Shear Strength (kg./mm. ²)		Bend Test		Tension Test	
		Face Bend	Reverse Bend	Tensile Strength (kg./mm. ²)	Elongation (Percent)
30.7	14.3	Separation	Good	{45.9	31.7
12.1	20.5			{45.2	32.5
[Angle method]					
Shear Test, Shear Strength (kg./mm. ²)		Bend Test		Tension Test	
		Face Bend	Reverse Bend	Tensile Strength (kg./mm. ²)	Elongation (Percent)
30.1	21.0	Crack	Good	{49.8	26.5
28.5	14.1			{49.2	24.8

Example 3

The cladding metal used here is a titanium plate (4.0 mm. x 1000 mm. x 1500 mm.) and the base metal is a mild steel plate (20 mm. x 970 mm. x 1470 mm.). In the cladding metal, there was previously provided a notch of about 1 mm. in depth having a V-shaped cross-section, the notch corresponding to the peripheral shape of the base metal. After polishing the upper surface of the base metal with a grinder, the base metal was placed on the sand support. On said upper surface, as shown in FIGS. 4a and 4b, line B was provided at a distance of 50% of the base metal length in the detonating direction, that is, 485 mm. V-shaped spacers of 0.8 mm. in height made of 0.15 mm. thick nickel foil were placed on line A. Further, said spacers of different height in turns were placed at certain intervals so that the angle of the cladding metal to the base metal is 0.35° in the region between lines A and B and 0.6° in the region between lines B and C. Then, as shown in FIG. 6, the cladding metal was placed on said spacers by coincidence of the notch with the periphery of the base metal. The same line wave generator as in Example 1 was attached, and the powder explosive of the same blending as in Example 1 was uniformly placed in the ratio of 9.5 kg. per square meter on the masking tape covering the cladding metal and was detonated by an electric detonator attached to an end of a primer cord, to obtain a clad plate consisting of titanium and mild steel.

The results of the shear test, bend test and tension test on the obtained clad plate were the same as in Example 1. It was further verified by the ultrasonic examination that the bonding was perfect not only in the middle of the clad plate but also in the periphery where the bonding was difficult in case the thickness of the cladding metal was large. Even under the microscopic observation, there was present no inferior alloy zone.

Example 4

The cladding metal used here is an arms bronze plate (3 mm. x 1000 mm. x 1000 mm.) and the base metal is a mild steel plate (16 mm. x 970 mm. x 970 mm.). In the cladding metal, there was previously provided a notch of about 1 mm. in depth having V-shaped cross-section, notch corresponding to the peripheral shape of the base metal. After polishing the upper surface of the base metal with a grinder, the base metal was placed on the sand support. On said upper surface, as shown in FIGS. 4a and 4b, line B was provided at a distance of 55% of the base metal length in the detonating direction. V-

shaped spacers of 1.0 mm. in height made of 0.15 mm. thick nickel foil were placed on line A. Further, spacers of different height in turns were placed at certain intervals so that the angle of the cladding metal to the base metal is 0.25° in the region between lines A and B, while it is 0.5° in the region between lines B and C. Supporting rods are placed at a point beyond line C. Then, as shown in FIG. 6, the cladding metal was placed on said spacers and supporting rods by coinciding the notch with the periphery of the base metal.

The same line wave generator as in Example 1 was attached, and the powder explosive of the same blending as in Example 1 was uniformly placed in the ratio of 12 kg. per square meter on the masking tape covering the cladding metal and was detonated by an electric detonator attached to an end of a primer cord, to obtain a clad plate consisting of armsbronze and mild steel. It was verified by the same tests as in Example 1 that the whole surface of the obtained clad plate was sufficiently bonded and the mechanical properties of the clad plate were excellent.

Example 5

The explosive used here is a powder explosive consisting of 10% pentaerithrit tetranitrate, 3% starch, 85% low density ammonium nitrate and 2% water. The cladding metal is a tantalum plate (1.2 mm. x 500 mm. x 750 mm.) and the base metal is a mild steel plate (10 mm. x 480 mm. x 730 mm.). After polishing the upper surface of the base metal with a grinder, the base metal was placed on the sand support. As shown in FIGS. 5a and 5b, line B was provided at a distance of 70% of the base metal length in the detonating direction. V-shaped spacers of 0.8 mm. in height made of 0.15 mm. thick nickel foil were placed on line A, so that the angle of the cladding metal to the base metal is 0.1° in the region between point A and line B and 0.3° in the region between lines B and C. For maintaining said angle of the cladding metal to the base metal, V-shaped spacers made of 0.15 mm. thick were placed on the periphery of the base metal and, as for the residual part, a nylon yarn was attached with plastic adhesive to the upper surface and the required angle could be obtained by suspending the nylon yarn. Thus, the required angle of the cladding metal to the base metal could be maintained by using said spacers and nylon. Said explosive was uniformly placed in the ratio of 7 kg. per square meter on a plastic paint covering the cladding metal. An electric detonator was attached to the point A where the space between the cladding metal and the base metal was the smallest and the explosive was detonated to obtain a clad plate consisting of tantalum and mild steel. It was verified by the same tests as in Example 1 that the whole surface of the obtained clad plate was sufficiently bonded and the mechanical properties of the clad plate were excellent.

Example 6

The cladding metal used here is a Monel plate (4.0 mm. x 1000 mm. x 1000 mm.) and the base metal is a mild steel plate (40 mm. x 970 mm. x 970 mm.). In the cladding metal, there was previously provided a notch of about 2 mm. in depth having a V-shaped cross-section the notch corresponding to the peripheral outline of the base metal. After polishing the upper surface of the base metal with a grinder, the base metal was placed on the sand support. On said upper surface, as shown in FIGS. 4 and 4', line B was provided at a distance of 50% of the base metal length in the detonating direction. V-shaped spacers of 1.0 mm. in height made of 0.2 mm. thick nickel foil were placed on line A. Spacers of different height in turn were placed at certain intervals so that the angle of the cladding metal to the base metal is 0.4° and 0.6° in the region between lines A and B and between lines B and C, respectively. The cladding metal which was previously formed to have said angle of about 0.2° at the position distant from the base metal

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edge by 50% of the cladding metal length was placed on said spacers so that the notch of the cladding metal was in coincidence with the periphery of the base metal. The same line wave generator as in Example 1 was attached and the powder explosive of the same blending as in Example 1 was uniformly placed in the ratio of 18 kg. per square meter on the masking tape covering the cladding metal and was detonated by an electric detonator attached to an end of a primer cord, to obtain a clad plate consisting of Monel and mild steel. It was verified that the whole surface of the obtained clad plate was sufficiently bonded and the mechanical properties of the clad plate were excellent.

Example 7

The cladding metal used here is a zirconium plate (2 mm. x 500 mm. x 1000 mm.) and the base metal is a mild steel plate (16 mm. x 480 mm. x 980 mm.). After polishing the base metal surface with a grinder, the base metal was placed on the sand support. As shown in FIGS. 5a and 5b, line B was provided at a distance of 65% of the base metal length in the detonating direction. At the point A, a V-shaped spacer of 0.8 mm. in height made of 0.15 mm. thick nickel foil was placed so that the angle of the cladding metal to the base metal is 0.2° in the region between point A and line B, while said angle was maintained at 0.35° in the region between lines B and C by placing spacers of different height in turn at certain intervals. The cladding metal was placed on said spacers, the explosive of the same blending as in Example 5 was uniformly placed in the ratio of 8 kg. per square meter on masking tape covering the cladding metal, and further a 30 mm. thick sand layer was placed on thin paper covering this explosive so as to use the detonation pressure of the explosive effectively. As shown in FIG. 5a, an electric detonator was attached to point A where the space between the cladding metal and the base metal was the smallest, and thereby the explosive was detonated, to obtain a clad plate consisting of zirconium and mild steel. It was verified that the whole surface of the obtained clad plate was sufficiently bonded and the mechanical properties of the clad plate were excellent.

Example 8

The cladding metal used here is a nickel plate (2 mm. x 1000 mm. x 1000 mm.) and the base metal is a mild steel plate (20 mm. x 970 mm. x 970 mm.). After polishing the base metal surface with a grinder, the base metal was placed on the sand support. As shown in FIGS. 4a and 4b, line B was provided at a distance of 70% of the base metal length in the detonating direction. V-shaped spacers of 1.0 mm. in height made of 0.15 mm. thick nickel foil were placed on line A. Spacers of different height in turn were placed at certain intervals so that the angle of the cladding metal to the base metal is 0.15° in the region between lines A and B and 0.3° in the region between lines B and C.

On the spacers, the cladding metal was placed and the same line wave generator as in Example 1 was attached. The powder explosive of the same blending as in Example 5 was uniformly placed in the ratio of 10 kg. per square meter on masking tape covering the cladding metal, and was detonated by an electric detonator attached to an end of a primer cord, to obtain a clad plate consisting of nickel and mild steel.

The obtained clad plate was of good quality.

Example 9

The cladding metal used here is an aluminum plate (2 mm. x 1000 mm. x 1000 mm.) and the base metal is a mild steel plate (12 mm. x 980 mm. x 980 mm.).

The explosive of the same blending as in Example 5 was used in the ratio of 6 kg. per square meter. By the same procedure as in Example 8, a good-quality

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clad plate consisting of aluminum and mild steel was obtained.

Example 10

The cladding metal used here is a Hastelloy-C plate (1.5 mm. x 1000 mm. x 1000 mm.) and the base metal is a mild steel plate (22 mm. x 980 mm. x 980 mm.).

The explosive of the same blending as in Example 5 was used in the ratio of 10 kg. per square meter. By the same procedure as in Example 8, a good-quality clad plate consisting of Hastelloy-C and mild steel was obtained.

Example 11

The cladding metal used here is a tantalum plate (1.5 mm. x 500 mm. x 1000 mm.) and the base metal is a stainless steel plate (12 mm. x 480 mm. x 980 mm.).

After polishing the base metal surface with a grinder, the base metal was placed on the sand support. As shown in FIGS. 4a and 4b, line B was provided at a distance from the base metal edge of 70% of the base metal length in the detonating direction. V-shaped spacers of 0.8 mm. in height made of 0.15 mm. thick nickel foil were placed on line A. Further, spacers of different height in turn were placed at certain intervals so that the angle of the cladding metal to the base metal is 0.1° in the region between lines A and B and 0.3° in the region between lines B and C.

On these spacers the cladding metal was placed, and the same line wave generator as in Example 1 was mounted. The explosive of the same blending as in Example 5 was uniformly placed in the ratio of 8 kg. per square meter on masking tape covering the cladding metal and was detonated by an electric detonator attached to an end of a primer cord, to obtain a clad plate consisting of tantalum and mild steel. The obtained clad plate was of good quality.

Example 12

The cladding metal used here is a stainless steel plate (2 mm. x 1000 mm. x 1000 mm.) and the base metal is a mild steel plate (16 mm. x 970 mm. x 970 mm.).

The explosive of the same blending as in Example 1 was used in the ratio of 7 kg. per square meter. By the same procedure as in Example 8, a good-quality clad plate consisting of stainless steel and mild steel was obtained.

Example 13

The cladding metal used here is a copper plate (2 mm. x 1000 mm. x 1000 mm.) and the base metal is a mild steel plate (16 mm. x 980 mm. x 980 mm.).

As shown in FIGS. 5a and 5b, line B was provided at a distance of 70% of the base metal length in the detonating direction. V-shaped spacers of 1.0 mm. in height made of 0.15 mm. thick nickel foil were placed on line A. Spacers of different height in turn were placed so that the angle of cladding metal to the base metal is 0.2° in the region between line A and line B and 0.35° in the region between lines B and C.

The cladding metal was placed on said spacers, the explosive of the same blending as in Example 5 was uniformly placed in the ratio of 8.5 kg. per square meter on masking tape covering the cladding metal, and an electric detonator was attached as shown in FIGS. 5a and 5b to point A where the space between the cladding metal and the base metal was the smallest and thereby the explosive was detonated, to obtain a clad plate consisting of copper and mild steel. The obtained clad plate was a good quality.

Example 14

The cladding metal used here is an Inconel plate (2 mm. x 1000 mm. x 1000 mm.) and the base metal is a mild steel plate (20 mm. x 970 mm. x 970 mm.). The explosive of the same blending as in Example 1 was used in the ratio of 8 kg. per square meter. By the same pro-

cedure as in Example 13, a good-quality clad plate consisting of Inconel and mild steel was obtained.

Example 15

The cladding metal used here is a cupronickel plate (2 mm. x 1000 mm. x 1000 mm.) and the base metal is a mild steel plate (30 mm. x 970 mm. x 970 mm.).

The explosive of the same blending as in Example 1 was used in the ratio of 8 kg. per square meter and by the same procedure as in Example 8 a good-quality clad plate consisting of cupronickel and mild steel was obtained.

Example 16

The cladding metal used here is an armsbronze plate (4 mm. x 730 mm. x 730 mm.) and the base metal is a mild steel plate (45 mm. x 700 mm. x 700 mm.). In the cladding metal, there was previously provided a notch of about 1 mm. in depth having a V-shaped cross-section, and corresponding to the peripheral outline of the base metal.

After polishing the upper surface of the base metal with a grinder, the base metal was placed on the sand support. On this upper surface, as shown in FIGS. 4a and 4b, line B was provided at a distance of 50% of the base metal length in the detonating direction. V-shaped spacers of 1.5 mm. in height made of 0.2 mm. thick nickel foil were placed on line A. Spacers of different height in turn were placed at certain intervals so that the angle of the cladding metal to the base metal was 0.5° in the region between lines A and B and 1.2° in the region between lines B and C, with control of the spacers placed on line C at the edge of the base metal.

The cladding metal was placed on said spacers, the notch coinciding with the periphery of the base metal. The same line wave generator as in Example 1 was mounted, and the powder explosive of the same blending as in Example 1 was uniformly placed in the ratio of 15 kg. per square meter on masking tape covering the cladding metal and further a 30 mm. thick sand layer was placed on thin paper covering the explosive. By detonating the explosive with an electric detonator attached to an end of a primer cord, a good-quality clad plate consisting of armsbronze and mild steel was obtained.

Example 17

The cladding metal used here is a stainless steel plate (4 mm. x 930 mm. x 930 mm.) and the base metal is a mild steel plate (50 mm. x 900 mm. x 900 mm.). In the cladding metal, there was previously provided a notch of about 2 mm. in depth having a V-shaped cross-section, and corresponding to the peripheral outline of the base metal.

After polishing the upper surface of the base metal with a grinder, the base metal was placed on the sand support. On this upper surface, as shown in FIGS. 4a and 4b, line B was provided at a distance of 45% of the base metal length in the detonating direction. V-shaped spacers of 1.0 mm. in height made of 0.2 mm. thick nickel foil were placed on line A. Spacers of different height in turn were placed at certain intervals so that the angle of the cladding metal to the base metal was 0.4° in the region between lines A and B while said angle in the region between B and C was kept at 1.0° by placing spacers on line C at the edge of the base metal.

The cladding metal which had previously been formed to maintain an angle of about 0.4° at the 45% position of the cladding metal length was placed on said spacers, the notch coinciding with the periphery of the base metal.

The same line wave generator as in Example 1 was mounted, and the powder explosive of the same blending as in Example 1 was uniformly placed in the ratio of 12 kg. per square meter on masking tape covering the cladding metal and was detonated by an electric detonator attached to an end of a primer cord, to obtain a good-

quality clad plate consisting of stainless steel and mild steel.

Example 18

The cladding metal used here is a titanium plate (4 mm. x 1000 mm. x 1000 mm.) and the base metal is a stainless steel plate (40 mm. x 970 mm. x 970 mm.). In the cladding metal, there was previously provided a notch of about 1 mm. in depth having a V-shaped cross-section, and corresponding to the peripheral outline of the base metal. After polishing the upper surface of the base metal with a grinder, the base metal was placed on the sand support. On this upper surface, as shown in FIGS. 4a and 4b, line B was provided at a distance of 50% of the base metal length in the detonating direction. V-shaped spacers of 1.5 mm. in height made of 0.2 mm. thick nickel foil were placed on line A, so that the angle of the cladding metal to the base metal was 0.45°, and spacers were placed on line C to maintain an angle of 1.0° between lines B and C. The cladding metal was placed on said spacers, with the notch coinciding with the periphery of the base metal.

The same line wave generator as in Example 1 was mounted, and the powder explosive of the same blending as in Example 1 was uniformly placed in the ratio of 9.5 kg. per square meter on a 1 mm. thick rubber sheet adhering closely to the cladding metal and further a 30 mm. thick sand layer was placed on thin paper covering the explosive. By detonating the explosive with an electric detonator attached to an end of a primer cord, a good-quality clad plate consisting of titanium and stainless steel was obtained.

Example 19

The cladding metal used here is a Monel plate (4 mm. x 1000 mm. x 1000 mm.) and the base metal a stainless steel plate (20 mm. x 970 mm. x 970 mm.).

The explosive of the same blending as in Example 1 was uniformly placed in the ratio of 15 kg. per square meter, and further a 30 mm. thick sand layer was placed on a thin sheet covering the explosive. By the same procedure as in Example 6, a good-quality clad plate consisting of Monel and stainless steel was obtained.

Example 20

The cladding metal used here is an armsbronze plate (2 mm. x 1000 mm. x 2000 mm.) and the base metal is a stainless steel plate (12 mm. x 970 mm. x 1970 mm.).

The explosive of the same blending as in Example 1 was used in the ratio of 9 kg. per square meter and, by the same procedure as in Example 1, a good-quality clad plate consisting of armsbronze and stainless steel was obtained.

Example 21

The cladding metal used here is a zirconium plate (1.5 mm. x 500 mm. x 1000 mm.) and the base metal is a stainless steel plate (12 mm. x 480 mm. x 980 mm.).

The explosive of the same blending as in Example 5 was used in the ratio of 8 kg. per square meter and, by the same procedure as in Example 11, a good-quality clad plate consisting of zirconium and stainless steel was obtained.

Example 22

The cladding metal used here is a Hastelloy-C plate (1.5 mm. x 1000 mm. x 1000 mm.) and the base metal is a stainless steel plate (20 mm. x 980 mm. x 980 mm.).

The explosive of the same blending as in Example 5 was uniformly placed in the ratio of 8 kg. per square meter and a 30 mm. thick sand layer was placed on thin paper covering the explosive. By the same procedure as in Example 8, a good-quality clad plate consisting of Hastelloy-C and stainless steel was obtained.

Example 23

The cladding metal used here is an aluminum plate (3 mm. x 1000 mm. x 2000 mm.) and the base metal is a stainless steel (12 mm. x 980 mm. x 1980 mm.).

As shown in FIGS. 5a and 5b, line B was provided at a distance of 70% of the base metal length in the detonating direction. V-shaped spacers of 0.8 mm. in height made of 0.15 mm. nickle foil were placed on line A. Spacers of different height in turn were placed at certain intervals so that the angle of the cladding metal to the base metal was 0.22° in the region between point A and line B and 0.3° in the region between lines B and C. On said spacers, the cladding metal was placed, and the explosive of the same blending as in Example 5 was uniformly placed in the ratio of 7 kg. per square meter on a masking tape covering the cladding metal. An electric detonator was attached as shown in FIG. 5a to point A where the space between the cladding metal and the base metal was the smallest and thereby the explosive was detonated, to obtain a good-quality clad plate consisting of aluminum and stainless steel.

It may be understood that it is possible according to the present invention to effect explosive bonding of mild steel, nickle, chromium, cobalt, titanium, zirconium, tantalum, aluminum, manganese, molybdenum, and copper plates and alloy plates containing said metal as the principal constituent with each other.

What is claimed is:

1. A process for producing a clad plate wherein a cladding plate is mounted in superposed spaced relation above a base plate, and the plates are bonded together under the force of the detonation of an explosive placed on the cladding plate, an improvement for bonding a cladding plate having a thickness of between 1.2 mm. and 4 mm. on a base plate of a size of at least 500 mm. x 500 mm., said improvement comprising supporting the cladding plate in spaced relation above the base plate such that an angle is formed in a first region between the cladding plate and the base plate of between 0.1 and 0.5° over between 45 and 80% of the length of the base

plate, and a larger angle is formed in a contiguous second region of between 0.3 and 1.2° between the remainder of the cladding plate and base plate, and initiating the detonation of the explosive from one end of the first region so that detonation of the explosive proceeds from the first region to the second region.

2. A process as claimed in claim 1 wherein said cladding plate has a minimum spacing with the base plate at the location where the explosive is detonated which is between 0.8 and 2.0 mm.

3. A process as claimed in claim 1 comprising interposing a buffer material between the explosive and the cladding plate.

4. A process as claimed in claim 1 wherein the cladding plate is of greater size than the base plate, the improvement further comprising forming a notch in the cladding plate corresponding to the peripheral outline of the base plate, the cladding plate being superimposed above the base plate with the notch in coincidence with the periphery of the base plate.

5. A process as claimed in claim 1 wherein the cladding plate is supported in spaced relation above the base plate by placing spacers of specific height on the base plate and then placing the cladding plate on the spacers.

6. A process as claimed in claim 1 wherein the cladding plate is supported in spaced relation above the base plate by placing spacers of specific height on the base plate in said first region and suspending the cladding plate over the base plate in the second region with the cladding plate resting on the spacers.

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