

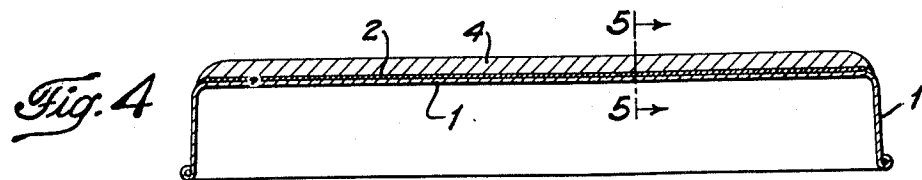
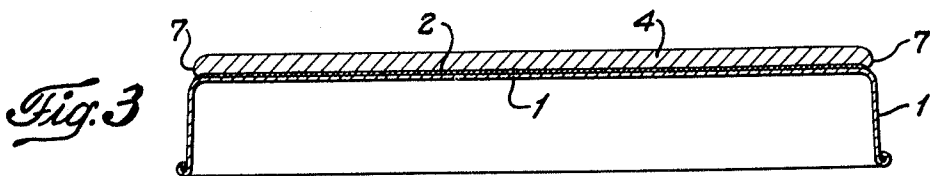
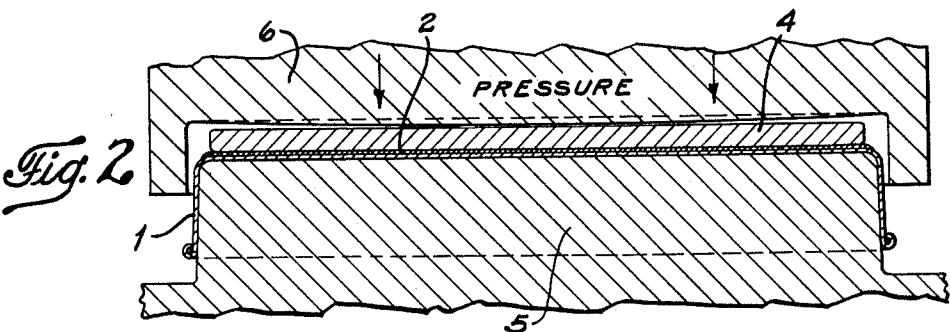
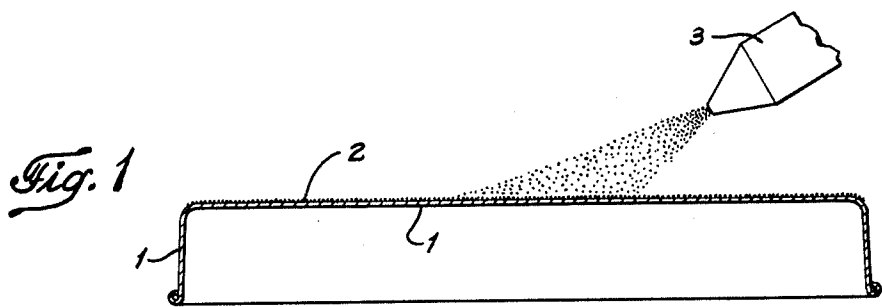
March 16, 1965

M. H. FARBER
ALUMINUM CLADDING

3,173,202

Filed Aug. 10, 1961

4 Sheets-Sheet 1



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4 Sheets-Sheet 2

Fig. 5

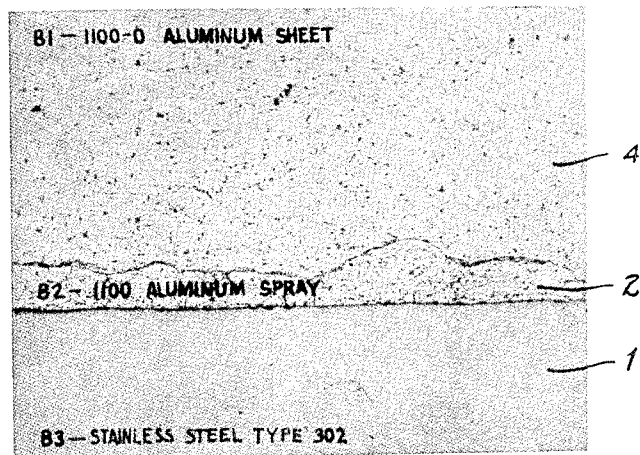
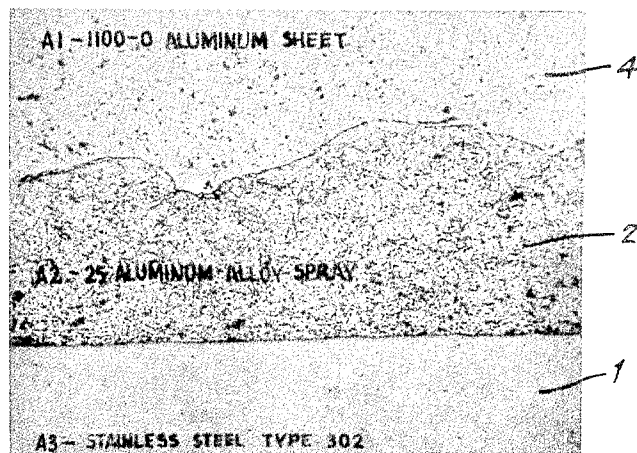


Fig. 6



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4 Sheets-Sheet 3

FIG. 7.

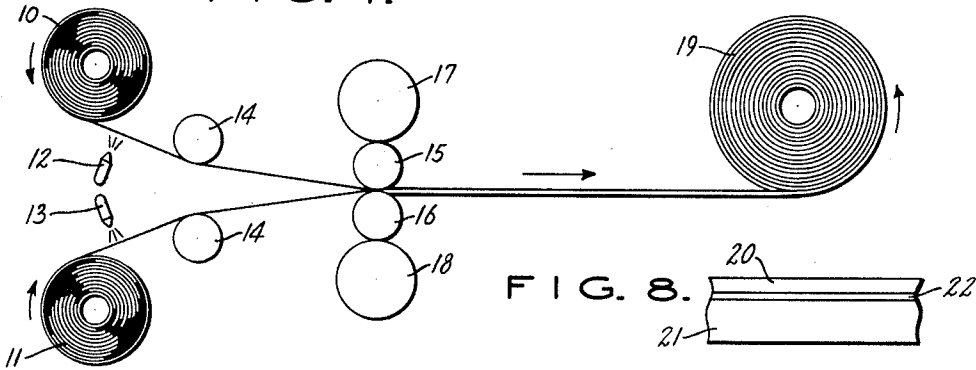


FIG. 9.

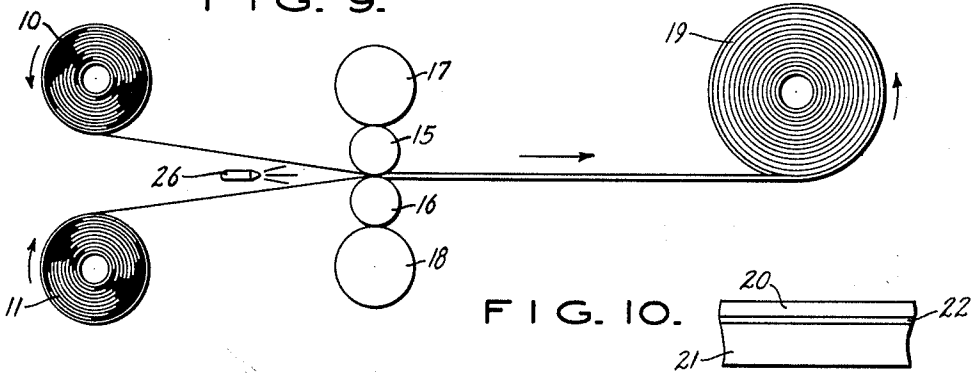
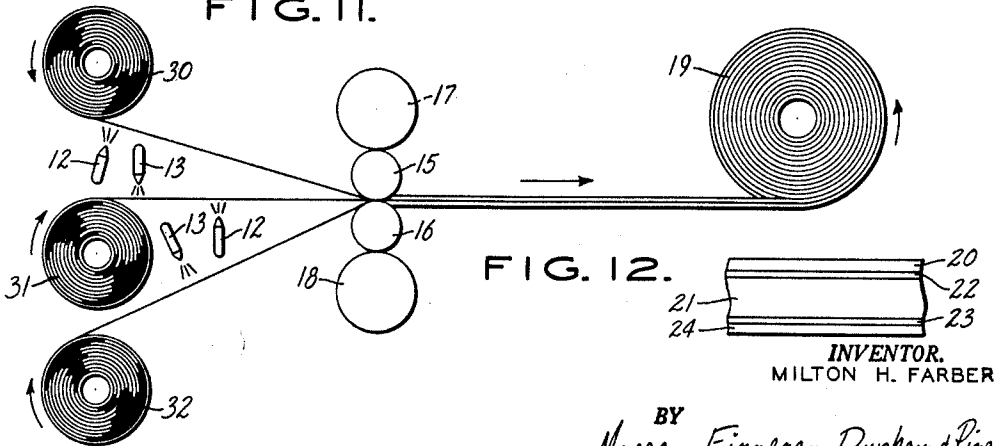


FIG. 11.



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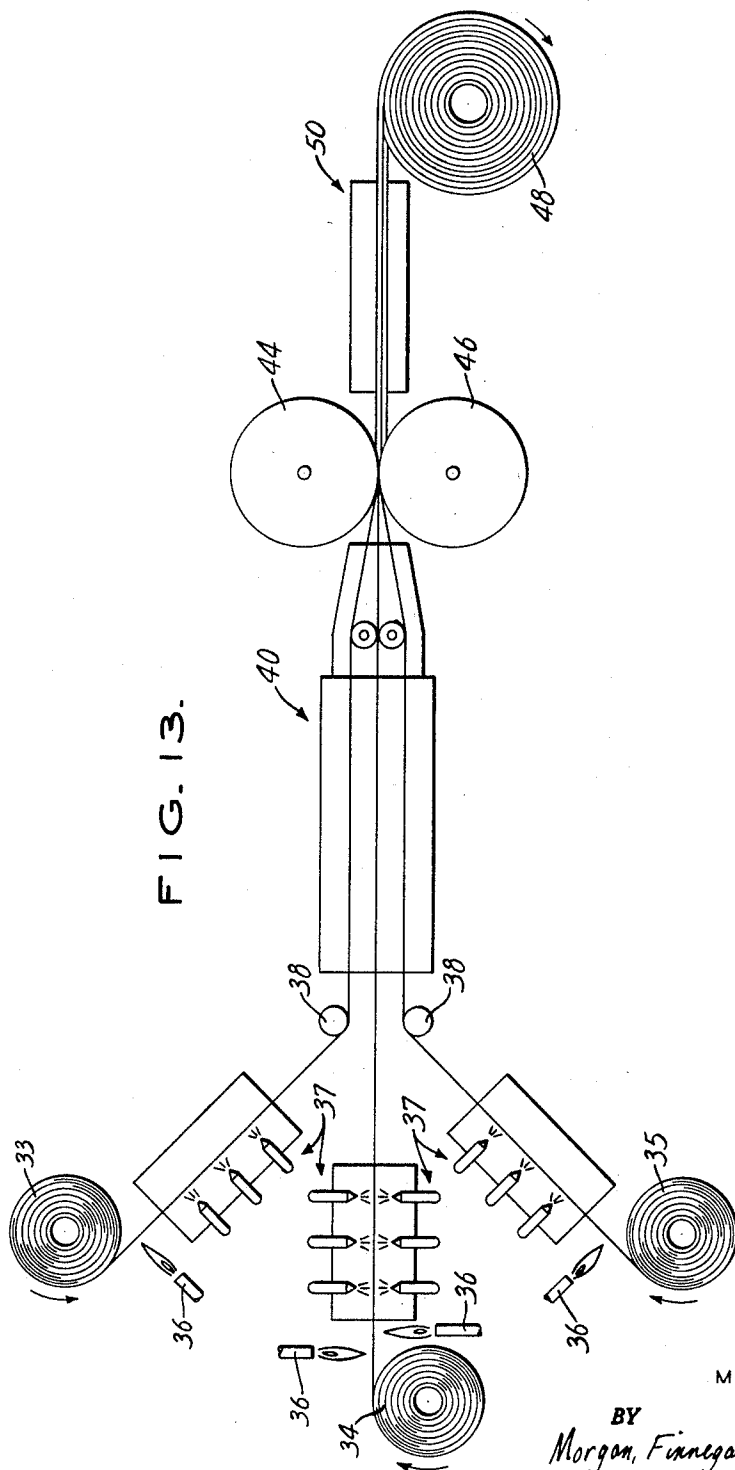
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4 Sheets-Sheet 4



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ALUMINUM CLADDING

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Filed Aug. 10, 1961, Ser. No. 130,578
15 Claims. (Cl. 29—487)

This application is a continuation-in-part of my prior corresponding application Serial No. 821,797, filed June 22, 1939.

This invention relates to methods of bonding two or more pieces of pre-formed stock, including strips, sheets or slabs of metals to each other with a tenacious bond. More particularly, the process of the present invention relates to a process for bonding together two or more sheets or slabs of dissimilar metals which are in substantially finished condition and thickness, and which are not substantially reduced in thickness in the bonding process.

The present invention has for its object the provision of a novel and improved process for the joining together of two or more sheets of metal, usually dissimilar metals, which sheets are in substantially their finished thickness so that substantial further reduction in thickness is not needed, each of the metal sheets being of a metal which has a melting point no lower than that of aluminum. A further object is the provision of a novel and improved process for joining two or more such sheets of metal together which produces a product without substantial waste. Still another object is the provision of a novel and improved process which requires much less pressure than has ordinarily been required for the rolling of composite metal sheets from thicker stock and which also produces a stronger bond than has usually been produced by other processes in which the composite sheet is bonded from its component sheets without substantial reduction in thickness of the assembled component sheets.

The metals which are suitable for use in the process of the present invention include the various ferrous alloys, stainless steels, aluminum and aluminum base alloys, copper, bronze, brass, silver and its alloys, gold and its alloys, titanium, zirconium, cobalt and its less brittle alloys, nickel and its alloys, platinum and palladium, and in general those metals which have a melting point at or above the melting point of aluminum, which are sufficiently ductile so that they may be formed into sheet material, either as slabs or coils, and which have the characteristic of alloying with aluminum.

Aluminum as used herein is to be taken as meaning aluminum metal and aluminum alloys consisting principally of aluminum, especially those alloys which contain about 90% or more of aluminum.

It is a well known and desirable objective to fabricate various articles made up of aluminum bonded with a different metal. The heat conducting and retaining properties of aluminum are highly desirable in various heat conductive devices and vessels in which certain materials may be heated, such as cooking utensils. The use of aluminum in such applications is often limited, however, because of its softness and rather high chemical activity. A particularly desirable combination in making vessels for heating various materials is a relatively inert metal inner liner such as stainless steel bonded to an aluminum outside member to give good heating properties.

Products which have aluminum bonded to them are normally fabricated in one of the following manners:

(a) Molten aluminum is molded directly onto a clean different metal surface, which is a relatively expensive process;

(b) An aluminum slab is brought into contact with a surface of a different metal having a higher melting point than the aluminum slab, then the different metal and the

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aluminum slab are heated until the aluminum slab melts in contact therewith, and is then allowed to cool, which process has proved to be unreliable and requires heavy equipment; or

(c) Separate sheets of aluminum and a different metal are heated and pressed into contact with one another whereby they are intended to become bonded to one another, which produces a relatively high percentage of non-uniformly bonded products.

In these processes there is generally a great deal of finishing required, and the articles formed by these processes initially are relatively crude and must be further finished before they are ready for sale and use. The present invention is further highly desirable in that it is carried out at readily attainable temperatures and pressures and with relatively conventional equipment.

The present invention basically consists of preparing a sheet of a different metal by cleaning it and "flame-spraying" it with aluminum by any of the well-known processes, such as the Schoop process, in which aluminum metal or alloy is fed into an arc or any oxy-acetylene flame and the resultant hot particles are directed against the surface to be coated so that a thin adherent coat of aluminum is deposited upon that portion of the different metal sheet to which the aluminum sheet is to be bonded. An aluminum blank or sheet is prepared so that the surface to which a different metal sheet which may have been formed into a vessel is to be bonded is clean, is raised in temperature up to just below its temperature of incipient fusion but preferably to at least 550° F. Thereafter, the aluminum and different metal sheets are subjected to pressure while so heated, the pressure being sufficient to cause only a small reduction in the thickness of the aluminum sheet and in the thickness of the sprayed aluminum. The article is then allowed to cool and preferably may be reheated and carefully cooled to stress relieve the finished product if desired. After cooling it is dipped in caustic solution to remove random specks of aluminum which may adhere to those areas outside the bonded aluminum sheet such as the sidewalls of the vessel or pan. The aluminum sheet is then wire brushed or lightly abraded to give it a uniform and attractive appearance.

The pressure used to bond the aluminum sheet or blank to the sprayed aluminum on the different metal sheet may be applied in various manners such as by a high energy press, by a drop hammer, by pressing or squeezing between two opposed rollers such as are employed in a rolling mill, or by a rotatable ball applied preferably from the center outwardly in a spiral path to the aluminum sheet or blank as it and the different metal sheets are rotated.

Where neither of the metals to be joined is aluminum, the clean adjacent faces of the sheets of metal to be joined are each sprayed, while hot, with aluminum by the flame spraying process, by a spray using an electric arc as the heating means or by feeding aluminum powder to a plasma jet, but when a plasma jet is used for depositing the aluminum on the surfaces of the metal sheets it is not always necessary to preliminarily heat the metal sheets, due to the intense heat developed by the plasma jet. Where one of the metal sheets to be joined is aluminum, it is only necessary to direct the spray against the non-aluminum sheet of metal. Also, where three sheets of metal are to be joined into a single composite sheet, the two pairs of adjacent faces of the metal sheets are each sprayed with aluminum, except that an aluminum surface need not necessarily be coated.

Thereafter, and while the sheets are still hot, and with the adjacent surfaces coated with the aluminum spray, the sheets are passed between the rolls of a rolling mill and subjected to powerful pressure, the pressure, however, being limited so that substantial reduction in thickness

of the metal sheets is largely avoided. Rolling between rolls which can exert such a powerful pressure is especially preferred where the sheets of metal are being supplied from coils, but where the sheets are in smaller pieces, and especially where one of the pieces is already a formed object, the pressure is most preferably exerted by a sufficiently high energy press or by a drop hammer, or even by a small travelling roller or ball which is uniformly worked over the surface of the metal as in a spiral pattern from the center outwardly to the edges of the composite blanks to be joined together.

Of the drawings:

FIGURE 1 shows a cross-section of a vessel being flame-sprayed with aluminum;

FIGURE 2 shows a cross-section of a press in which is positioned the heated aluminum sprayed vessel and the heated aluminum slab which is to be bonded to it;

FIGURE 3 is a cross-section through the vessel after application of pressure;

FIGURE 4 is a cross-section of the FIGURE 3 vessel after it has been finished;

FIGURE 5 is a photomicrograph at 250 $\times$ of a portion of 5—5 of FIGURE 4 showing the relation between the vessel of different metal, the flame-sprayed aluminum layer and the bonded aluminum sheet;

FIGURE 6 is a photomicrograph at 250 $\times$ of a portion of 5—5 of FIGURE 4 showing the relation between the vessel of different metal, the flame-sprayed aluminum alloy layer and the bonded aluminum sheet;

FIGURE 7 is a schematic top plan view illustrating the steps of the present invention;

FIGURE 8 is a fragmentary, enlarged cross section of a sheet of composite metal as produced by the process illustrated in FIGURE 7;

FIGURE 9 is a schematic top plan view illustrating a modified process of the present invention;

FIGURE 10 is a fragmentary, enlarged cross section of a sheet of composite metal as produced by the process illustrated in FIGURE 9;

FIGURE 11 is a schematic top plan view illustrating a further modification of the process of the present invention; and

FIGURE 12 is a fragmentary, enlarged cross section of a composite metal as produced by the process illustrated in FIGURE 11.

FIGURE 13 is a schematic plan view of another modification of the process of the present invention.

Referring now to the detailed description of the invention and the figures of the drawings, illustrating the preferred process of the invention, modifications thereof, and some of the composite metal articles produced thereby;

FIGURES 1 to 6 illustrate the present invention where one of the metals is aluminum to be bonded to the surface of another metal having a higher melting point than the melting point of aluminum.

FIGURE 1 shows a vessel 1 of different metal the surface of which is having applied to it a layer 2 of aluminum from a flame-sprayer 3.

FIGURE 2 shows the vessel 1 now provided with a layer 2 of aluminum on its outer bottom surface positioned in a press, relatively thick aluminum sheet 4 slightly smaller in diameter than the vessel positioned on top of a flame-sprayed layer 2, the composite of parts being supported on the lower die portion 5 of a press which has a flat upper surface, the upper die portion 6 of a press being slightly greater in diameter than vessel 1, thereby allowing slight clearance at the sides of said vessel and also being very slightly convex at its central portion.

FIGURE 3 shows the vessel 1 after bonding of the thick aluminum sheet 4 to the surface on which the flame-sprayed layer 2 of aluminum was provided, the edge 7 of the aluminum sheet 4 is now approximately coincident with the sides of vessel 1 as a result of its flowing under the pressure necessary for accompanying its bonding.

FIGURE 4 shows the vessel of FIGURE 3 after finishing.

FIGURE 5 shows a photomicrograph (250 $\times$) of a typical cross-section of the vessel wherein the sheet of different metal which forms vessel 1 carrying the flame-sprayed layer 2 of aluminum to which is bonded the thick aluminum sheet 4, and

FIGURE 6 shows a photomicrograph (250 $\times$) of a cross-section of the sheet of different metal which forms vessel 1 carrying the flame-sprayed layer 2 of aluminum alloy to which is bonded aluminum sheet 4.

The present invention is based on the discovery that under certain conditions even a relatively thick sheet or slab of aluminum can be bonded to a sheet of different metal at easily attained temperatures and at relatively low pressures. The pressures involved are generally in the order of about several thousand pounds per square inch. This is more definitely expressed, however, in the decrease in the thickness of the aluminum sheet or slab during its bonding to the different metal. The pressure used must be such that it will cause some lateral flow or area enlargement and reduce the thickness of the more ductile slab of aluminum less than 8% and preferably by less than 5%, but at least 1%, to which is added the additional reduction of thickness of the sprayed layer of aluminum.

The general method of carrying out the present invention is as follows: A sheet of the different metal which may be of the general shape desired in the final product, such as a cooking pan or vessel, is treated on the surface to which the aluminum sheet or slab is to be attached to remove substantially all of the foreign matter which may exist thereon. The method of cleaning may be a mechanical one, such as abrasion; a chemical one, such as detergent action; or washing in a solvent or a combination of any of those. The different metal must have a melting point not lower than that of aluminum or heat of incipient fusion than that of the aluminum which is to be bonded to it. Among those metals which are particularly preferred for use in the present invention are cast iron sheet steel, stainless steel, titanium and alloys thereof, copper and copper alloys, nickel and nickel alloys, or a zirconium metal or alloy thereof.

The different metal is coated with a thin layer of sprayed aluminum applied in a manner similar to that described in various patents to Schoop. This process of causing a thin layer of aluminum to adhere to a surface consists generally of spraying the molten aluminum metal which is to form the layer in the form of finely divided particles in a hot stream of gas with such force that the small particles are in effect fused onto the surface at which they are directed. An inert gas may be used to protect the surface at which the oxy-acetylene stream containing the aluminum particles is directed during this application but such inert gas is not necessary in the present process.

The area covered by the sprayed metal may be and preferably is restricted to that particular portion of the surface by conventional means such as masking the remaining surface.

A blanked sheet or slab of aluminum is cut to the approximate size and shape of the surface to which it is to be bonded. It is usually and preferably from about 0.100" in thickness to less than 0.250" thick, although thicker or thinner sheets of aluminum may be used. It too is cleaned to remove foreign substances from the surface to be bonded by mechanical, chemical or solvent means. The aluminum sheet and the base different metal which is coated with a layer of aluminum ranging in thickness from 0.001" to 0.010" and preferably 0.004", as a result of the "flame-spraying" step, are then heated to a temperature up to the incipient fusion point of the particular aluminum or aluminum alloy being dealt with. Preferably the parts are heated to at least 550° F. and usually 750° F. The aluminum blank is preferably a piece of rolled metal but may be obtained by casting. Rolled aluminum sheet is preferred because the melting

point thereof is about 50° F. higher than usual aluminum alloys from which the molded slab would be cast. After the two pieces have been brought together sufficient pressure is applied such that the aluminum slab is caused to be reduced in thickness at least 1% preferably about 5%, and less than 8%, plus some reduction in the thickness of the sprayed aluminum. This causes exceptionally good bonding between the two pieces of metal.

It is usually preferred to stress relieve the product thus formed by heating it up to the incipient fusion of the aluminum or aluminum alloy; usually above 550° F. and preferably about 750° F. to relieve stresses after which it is allowed to cool slowly to room temperature. When cooled to room temperature the product is placed in a caustic bath from 5 to 15% sodium hydroxide or potassium hydroxide in water, which removes random bits of aluminum resulting from the spraying step, which may have landed on portions of the different metal where it was not needed. The product thus cleaned is rinsed, allowed to dry and is finished by belt grinding the edges at the joint between the sheets of different metal and the bonded aluminum sheet.

This method is particularly desirable since it conserves aluminum, using little more than the amount which is necessary to cover the desired portion of the article produced. The bonding is accomplished at relatively low pressure. The loss of thickness of the aluminum slab is relatively little, about 5% and not more than 8%. The method is further desirable in that the amount of finishing required by the product is much less than that required in conventional methods for obtaining such bonding.

As a specific example of the method described above, a stainless steel vessel having bonded to its outer bottom surface a sheet of aluminum alloy was formed in the following manner:

Stainless steel sheet, 18-8 Type 302, used to form a fry-pan having a wall thickness of 0.025". This stainless steel pan was heated to a temperature of 700° F. and given an adherent sprayed coating 0.004" thick of aluminum alloy 25 or alloy AA-1100 onto the heated surface. All but the fry-pan bottom was masked and the aluminum coated onto the exposed bottom by feeding wire into a Schoop gun heated with acetylene and oxygen. An aluminum blank of alloy AA-1100 which was 0.125" thick, cut to the size of the fry-pan bottom, planed and cleaned with an abrasive belt on the side which is to be bonded and both the aluminum sprayed base and blank were heated to 800° F. The die which is used to apply the pressure to the aluminum blank is formed with a slight bulge toward the center of the die so that the center of the die is raised about 0.010" from its edges and is smoothly curved towards the edges. This is to insure that any air which might lie between the blank and the different metal would be squeezed out before the full force of the pressure is applied to the combination.

As an alternative to the use of a die which is slightly concave toward the center for contacting the aluminum sheet or slab which is to be bonded, the aluminum sheet or slab itself may be preformed in such manner that one of its surfaces or both may be somewhat concave and the die itself be flat. An important consideration in using a preformed aluminum sheet or slab is that at least one surface of it be concave and that that surface be the one which is in contact with the flame-sprayed layer of aluminum on the vessel. Pressure is applied at a sufficient force so that the aluminum blank is reduced in thickness from 1% to 8% and preferably by 5%. The product thus formed is heated until the aluminum slab portion reaches a temperature of 750° F. and is then allowed to cool at room temperature. The cooled fry-pan is immersed for a few minutes in caustic (100 grams—NaOH/liter of water) which insures the complete removal of specks of aluminum from the spraying step outside of the bonded area. The fry-pan is then finished by belt

grinding the surface at which the aluminum sheet and the fry-pan are joined.

FIGURE 7 schematically illustrates a form of the process in which sheet metal in substantially its final thickness is fed from two coils 10 and 11, while in a heated condition and preferably heated to a temperature not exceeding the melting point of the aluminum or aluminum alloy to be sprayed and preferably at about 750° F. Each of the two adjacent faces of the metal sheets or strips drawn from the rolls 10 and 11 is uniformly sprayed with a coating of aluminum in a thickness of from about 0.001" to 0.008" and preferably about 0.004". Where one of the sheets from roll 10 or 11 is of aluminum, or an aluminum alloy, the spraying of the adjacent face of that sheet may be omitted.

The thickness of either of the sheets drawn from the rolls 10 and 11 may vary widely, for instance from about 0.005" to 0.250".

Across the width of the sheets or strips of metal being drawn from the rolls 10 and 11 are positioned a plurality of flame-spray mechanisms 12, 13, so arranged as to deposit a substantially uniform layer of aluminum on each of the travelling sheets or strips, after which the sheets or strips are guided by guide rollers 14 to the bite of the heated pressure rolls 15, 16, which are heated to about 600° F., are powerfully pressed together by their respective back-up rolls 17, 18, and are suitably driven in the conventional manner of a rolling mill. The sheets or strips are then coiled by suitable take up to form a large coil 19, or may be sheared into desired lengths.

When the more ductile sheet of the metal sheets being joined is aluminum or a metal softer than aluminum, it has been found that a reduction in the total thickness of the more ductile sheet of preferably above 1% and below 8% produces the best results. However, if both sheets are formed of metals relatively harder than aluminum, there need not necessarily be any reduction in the thickness of the sheets, although some reduction may occur without adverse effect.

During the bonding operation, the relatively porous and somewhat irregular surface of the sprayed aluminum layer becomes a substantially homogeneous layer if forced against another sprayed layer or a layer of aluminum with a thickness reduction preferably not exceeding 40% of the thickness of the sprayed layer. Thickness reduction of the sprayed layer or layers in excess of 40% may result in poor bonds due to the sprayed aluminum layer being laterally displaced on its support.

Where the rolls 15 and 16 are heated, and where one of the metal sheets or strips being rolled is aluminum, it is preferable to coat the side of the strip to be in contact with the roll with a release material, such as a suspension of graphite, molybdenum disulfide or other material, to prevent even temporary adhesion of the aluminum sheet to the surface of the roll.

The relatively small reduction in the combined thickness is of special importance where the metal sheets being joined are of dissimilar metals such as a relatively hard metal and a relatively soft metal (for example stainless steel and copper). Excessive reduction would cause a considerable amount of scrap due to the trimming which is necessary, and also results in a weaker bond due to the shearing of the aluminum spray from one or both of the sprayed metal surfaces. Additionally, the reduction in thickness is generally irregular so that in portions along the length of the composite sheet, one or both of the metals have been irregularly thinned, contrasted with the almost complete uniformity in thickness which is effected by the present process.

FIGURE 8 schematically illustrates on a greatly enlarged scale a fragmentary section of a composite sheet in which a relatively thin sheet of one metal 20 has been bonded to a thicker layer of another metal 21, and the intermediate layer or layers of sprayed aluminum 22 have become homogenized and bonded together. In the

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event that the layer 21 is of aluminum, of course the aluminum spray can be omitted on that surface and the sprayed aluminum bonded to the surface of the sheet 20 bonds directly to the aluminum of sheet 21, forming a composite of the type shown in FIGURES 5 and 6.

FIGURE 9 similarly illustrates a modification in which the aluminum spray on the surfaces of the sheets from rolls 10 and 11 is sprayed on these surfaces by means of plasma jets 26 fed with aluminum or aluminum alloy powder. Thus a single row of a plurality of plasma jets may serve to apply the aluminum spray to the adjacent faces of both strips of metal just prior to their being pressed together by the heated pressure rolls 15 and 16, and may also serve to avoid the necessity of preheating the coils 10 and 11.

Instead of preheating the coils 10 and 11, they may be heated by ovens, induction heaters, flames or otherwise located between the position where the sheets are drawn from the coils and where the aluminum spray is applied to the surface of the metal strips.

The product of the process illustrated in FIGURE 9 may be identical with that shown in FIGURE 8.

FIGURE 11 illustrates, in a similar manner, apparatus for joining three layers of metals together in a process according to the present invention. As shown, metal sheet or strip is drawn from the three rolls. As shown, three separate metal sheets or webs are drawn from the three rolls 30, 31, 32 and have preferably been preheated to a temperature of about 750° F. and are fed at sufficiently rapid rate so that they do not substantially cool prior to being pressed into powerful contact with each other. The two pairs of adjacent faces of the metal sheets or strips are sprayed with aluminum either by flame spraying from four sets of flame spraying apparatus, or from two sets of plasma jets fed with aluminum powder (as with FIGURE 9), and also except that if any of the coils of metal 30, 31 or 32 are of aluminum the adjacent face of aluminum need not be sprayed with aluminum spray. As previously described, the sheets or strips of metal are drawn and pressed powerfully together by means of the heated rollers 15 and 16 so as to effect preferably up to an 8% reduction in the thickness of the more ductile layers in the combined thickness of the sprayed aluminum, while they are still heated to 550° F. or more, preferably at about 750° F. and not in excess of the temperature at which the aluminum spray or the metal of any one of the strips reaches incipient fusion temperature. Thereafter, the composite material is sheared or coiled into a coil 19 which is of a sufficiently large diameter so that excessive bending does not occur.

The composite material resulting from the process illustrated in connection with FIGURE 11 is shown in enlarged section in FIGURE 12 and comprises the two outer layers of metal 20 and 24 which are firmly bonded to an intermediate layer of metal 21 by means of the homogenized layers of sprayed aluminum 22 and 23.

FIGURE 13 illustrates in more detail a process similar to that shown in FIGURE 11 where three layers of metals are joined together. Three coils 33, 34 and 35 of preferably strip or sheet metal are provided. The metal sheets may each be separately preheated, as by heater means 36, as they are withdrawn from their respective rolls. Preferably the pre-heat temperature is approximately 750° F., but such temperature must be below the incipient fusion temperature of metals and preferably above 550° F. The heated metals are fed from their respective rolls at a sufficiently rapid rate so that they do not substantially cool prior to being pressed into contact with each other. The two pairs of adjacent faces of the metal sheets or strips are suitably sprayed by spray apparatus 37 with aluminum either by flame spraying equipment or by plasma jets fed with aluminum powder. Because of the nature and operating characteristics of the plasma spray apparatus, it has been found that

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the pre-heating step may be omitted when plasma jets are employed without adverse effect.

As with the process illustrated in FIGURE 11, in the event any of the metals to be joined are of aluminum, the adjacent face of aluminum need not be sprayed with aluminum spray.

The sprayed sheets of metal are guided in spaced relation by rollers 38 into a suitable heating chamber 40, such as, an oven or kiln, where the metals are subjected to a pre-joining heat of preferably above 550° F. and more preferably about 750° F. but not in excess of the incipient fusion temperature of the metals or aluminum spray. The metals, still spaced, are drawn through oven 40 and past a pair of brushes or cleaning elements 42 which engage the aluminum surface only, removing any undesirable particles thereon, such as loose or random bits of aluminum from the spraying step.

As previously described, the sheets or strips are drawn and pressed or squeezed together by means of heated rollers 44 and 46 so as to effect preferably up to an 8% reduction in the thickness of the more ductile layer and some reduction in the thickness of the sprayed aluminum layer while the metal sheets or strips are still heated to 550° F. or more, preferably at about 750° F. and not in excess of the temperature at which the aluminum spray or the metal of any one of the strips reaches incipient fusion temperature. Thereafter the composite material is sheared or coiled as into roll 48 of a sufficiently large diameter to preclude excessive bending thereof.

It is usually desirable and preferable to stress relieve the composite sheet prior to shearing or coiling. To accomplish this, the composite sheet is drawn through a second heating chamber 50 where it is subjected to a stress-relieving heat of approximately 550° F. but below the incipient fusion temperature of the aluminum or aluminum alloy, preferably about 750° F. The composite material is then permitted to cool slowly to room temperature.

Prior to coiling of the composite sheet, it may, if desired, be subjected to further finishing operations such as color buffing or polishing or caustic bathing.

As stated above, the process of the present invention is applicable to a wide variety of metals and alloys, all of which have the common property that they have a melting point at least as high as the melting point of aluminum or of the aluminum alloy used for spraying their surfaces prior to bonding. Thus aluminum, an aluminum alloy or any higher-melting metal sheet may be used for one or both of the strips forming the composite material.

With certain readily oxidizable metals, such as copper, it is preferable to use a reducing flame with the flame spraying apparatus, or a reducing gas, such as hydrogen, with an arc-heated spray apparatus; or, when using an arc or a plasma jet to use an atmosphere of hydrogen, nitrogen, argon or a mixture of hydrogen, nitrogen and/or argon so as to prevent excessive oxidation of the copper surface. Similarly, the same precautions may be observed where both of the metals are easily oxidized at the operating temperatures.

Among the wide variety of metals which may be joined together are the following:

(1) Stainless steel, type 302, 0.025" thick bonded to a sheet of aluminum 0.125" thick, the stainless steel being coated by a sprayed coating of 0.004" thick of aluminum alloy or alloy AA-1100. Such a composite sheet (about 0.146" final thickness) may be formed into cooking utensils.

(2) Stainless steel type 430, 0.030" thick bonded to a sheet of annealed copper 0.080" thick, the adjacent faces of the stainless steel and copper each being provided with a sprayed coating of aluminum about 0.003" thick, the superimposed sheets being rolled to reduce their combined thickness to 0.108" combined thickness.

Blanks of this composite material may be drawn into kitchen pots, fry pans, or similar articles.

(3) A strip of steel, S.A.E. 1040, 0.150" thick may be bonded to a sheet of bronze alloy suitable as a bearing surface, the bronze sheet being 0.103" thick, each of the adjacent faces being sprayed with a 0.003" layer of aluminum and the composite material being subjected to rolling pressure to give a final thickness of 0.250", from which sleeve bearings may be blanked and shaped.

(4) Composite material for use in jewelry or as picture molding may be formed from a sheet of sterling silver 0.005" thick bonded to a sheet of stainless steel, type 302, 0.020" thick, by a sprayed layer of aluminum on the adjacent faces of the silver and stainless steel, each aluminum sprayed layer being about 0.002" thick to give a composite material 0.027" thick. In making this material, the sterling silver sheet and the stainless sheet may be heated to a temperature in the range of 700° to 850° F., although a good bond is obtained above 600°, and up to temperatures as high as 1100° F.

(5) Fine silver (99.9% or better) 0.010" thick in the form of a sheet or strip may be bonded to a sheet or strip of copper 0.090" thick with 0.002" aluminum spray on both adjacent surfaces, using spraying and bonding temperatures of about 750° F. to form composite material 0.092" thick, from which good electrical contact may be blanked.

(6) For jewelry, a sheet of gold of the desired degree of fineness, about 0.005" thick may be bonded to a base sheet of nickel silver 0.030" thick, using 0.003" sprayed aluminum on the two adjacent surfaces of the sheet.

(7) Building panels, especially suited for use as the exterior of a curtain wall building may be formed by using a sheet of aluminum 0.015" thick bonded to a sheet of mild steel 0.060" thick, the steel being sprayed with a layer of aluminum spray 0.005 to 0.007" thick, and the two metal sheets being heated prior to spraying and bonding to a temperature of about 650° F., yielding a composite sheet 0.081" thick.

(8) A bimetal thermostat element may be made from the composite sheet material of the present invention by bonding together a sheet of Invar and a sheet of an aluminum alloy composed of 95% aluminum and 5% copper, both sheets being 0.025" thick, and the adjacent face of the Invar being sprayed with an aluminum spray layer 0.003" thick and bonded at a temperature of about 650° F.

(9) For use as reaction vessels, crucibles and other laboratory ware, a sheet of pure nickel may be bonded to a sheet of stainless steel, the nickel sheet being about 0.010" thick and the stainless steel being about 0.020" thick, with bonding layers of sprayed aluminum on the adjacent faces of about 0.003" each.

(10) Economical composite stock for kitchen counters and similar uses may be made by bonding Monel sheet about 0.010" thick to a carbon steel base of the desired thickness, such as 0.020" thick. These layers may be bonded together in the manner described above using about 0.004" of sprayed aluminum on each of the adjacent faces of the metal sheets.

(11) Highly corrosive resistant laboratory ware, such as crucibles and evaporating dishes may be economically made by bonding a sheet of palladium about 0.010" thick to a much heavier sheet of copper, such as a sheet 0.030" thick, using a sprayed coating of aluminum on each of the adjacent faces of the two metals, each layer being about 0.003" thick. This composite sheet is reduced to an overall thickness of about 0.042" using temperatures of about 800° F.

(12) Jewelry stock having a platinum face may be made by bonding a sheet of platinum about 0.003" thick to a sheet of stainless steel about 0.010", using sprayed aluminum layers of about 0.002" thick and bonding temperatures of about 800° F. Such stock may also be

formed into laboratory ware where corrosion resistance is important.

(13) Heavy duty cooking utensils having a heat conductive aluminum body bonded on each of its faces to a relatively thin protective layer of stainless steel, may be made according to the process described in connection with FIGURE 11, and using two sheets of stainless steel, each about 0.010" thick as the exterior layers, and an inner sheet of aluminum about 0.125" thick with a bonding temperature of about 650° F. No sprayed aluminum need be applied to either face of the aluminum sheet, and the sprayed aluminum layer on the inner face of each of the stainless steel sheets is about 0.005" thick. Such a composite sheet 0.144" thick may be drawn to form a pot or a pan.

(14) Another form of composite stock which is also especially adapted for forming into kitchen pots and pans, as well as having many other uses, may be made by following the process of FIGURE 11, and using two sheets of stainless steel each about 0.006" as the outer layers with an inner sheet of annealed steel (S.A.E. 1010) 0.050" thick. In this case, however, aluminum spray (0.004") is applied to the inner face of each of the stainless steel sheets and to both faces of the carbon steel sheet, after which the three sheets with the four spray coats of aluminum are subjected to heavy pressure at a temperature of about 700° F.

While the examples set forth immediately above describe the process with the bonding pressure applied by the pressure rolls 15 and 16, the pressure may be applied in a suitable press or by a drop hammer. In such a case, at least one of the metals to be bonded to another is in the form of a sheet of appropriate size. Thus, a stainless steel cooking vessel, such as a fry pan, may be provided with a securely bonded relatively thick copper bottom, but using a circular sheet of copper of appropriate size. One face of the copper sheet on the bottom of the pan are both cleaned, heated to 600° F. or slightly more, sprayed with a thin coating of aluminum. Thereafter, the copper sheet and stainless steel pan are brought together with their aluminum sprayed surfaces in contact and are then subjected to pressure in a suitable press or by a drop hammer, as described above in connection with FIGURE 2.

The invention in its broader aspect is not limited to the specific steps, methods, compositions and improvements shown and described herein, but departures may be made within the scope of the accompanying claims without departing from the principles of the invention and without sacrificing its chief advantages.

What is claimed is:

1. A method for cladding sheets of different metal selected from the group consisting of copper and its alloys, silver and its alloys, gold and its alloys, titanium and its alloys, zirconium and its alloys, nickel and its alloys, platinum, palladium, cobalt, ductile cobalt alloys and ductile ferrous alloys with sheets of an aluminum metal which comprises shaping the aluminum component to a similar shape of the surface to which it is to be bonded, cleaning both the surfaces of the aluminum and the different metal, flame-spraying a layer of aluminum onto the clean surface of the different metal, placing the aluminum in contact with the sprayed surface of the different metal and heating the composite of aluminum sheet and different metal to about 550° F. but below the temperature of incipient fusion of the aluminum sheet and exerting pressure thereon sufficient to cause lateral flow of the aluminum component and a decrease in thickness of the aluminum in a range of from 1 to 8%.

2. A method for bonding a sheet of aluminum to a sheet of different metal, as set forth in claim 1, wherein the unlike metal is approximately 0.025" thick and the coating of aluminum flame-sprayed thereon has a thickness in the range of from 0.001 to 0.010" and the alu-

minum sheet is of a thickness in the range of from 0.100 to 0.250".

3. A method, as set forth in claim 1, wherein the pressure applied to the heated components is exerted from the center of the sheet laterally outward and the decrease in thickness in the overall thickness of the sprayed aluminum layer is maintained below 40%.

4. A method for bonding sheets of aluminum to sheets of a different metal selected from the group consisting of copper and its alloys, silver and its alloys, gold and its alloys, titanium and its alloys, zirconium and its alloys, nickel and its alloys, platinum, palladium, cobalt, ductile cobalt alloys and ductile ferrous alloys which comprises degreasing and abrading both sheets of metal, flame-spraying the sheet of different metal with aluminum to give it a coating of about 0.004" thick, placing the aluminum sheet of a somewhat smaller area than the sheet of different metal in contact with the sprayed aluminum coat on the surface of the different metal, heating the materials thus in contact to a temperature about 550° F. but below the incipient heat of fusion of aluminum, exerting pressure on this combination sufficient to cause the aluminum sheet to flow laterally and decrease in thickness about 5%, heating the composite to about 750° F. and allowing it to cool.

5. A method for bonding sheets of an aluminum metal to sheets of a different metal selected from the group consisting of copper and its alloys, silver and its alloys, gold and its alloys, titanium and its alloys, zirconium and its alloys, nickel and its alloys, platinum, palladium, cobalt, ductile cobalt alloys, and ductile ferrous alloys, which comprises cleaning both sheets of metal, flame-spraying the sheet of different metal with aluminum, placing an aluminum sheet of a somewhat smaller area than the sheet of different metal in contact with the sprayed aluminum coat on the surface of the different metal, heating the materials thus in contact to a temperature above about 550° F. but below the incipient heat of fusion of the aluminum sheet, exerting pressure on this combination sufficient to cause the aluminum sheet to decrease in thickness from 1% to 8% and allowing it to cool.

6. A method for bonding sheets of aluminum metal to sheets of stainless steel, which comprises cleaning both sheets of metal, flame-spraying the sheet of stainless steel with aluminum, placing an aluminum sheet of a somewhat smaller area than the sheet of stainless steel in contact with the sprayed aluminum coated on the surface of the stainless steel, heating the material thus in contact to a temperature above about 550° F. but below the incipient heat of fusion of the aluminum sheet, exerting pressure on this combination from the central portion outwardly, sufficient to cause the aluminum sheet to flow laterally and decrease in thickness from 1% to 8% and allowing it to cool.

7. A method for bonding sheets comprised substantially of aluminum to sheets of stainless steel which comprises cleaning both sheets of metal, flame-spraying the sheet of stainless steel with aluminum to give it a coating of about 0.004 inch thick, placing the aluminum sheet of a somewhat smaller area than the sheet of stainless steel in contact with the sprayed aluminum coat on the surface of the stainless steel, heating the materials thus in contact to a temperature, about 550° F., below the incipient heat of fusion of aluminum, exerting pressure on this combination sufficient to cause the aluminum sheet to flow and decrease in thickness about 5% and allowing it to cool.

8. A method as in claim 1 wherein the different metal is stainless steel.

9. A method of bonding a first metal to a second metal, each of said metals being selected from among aluminum metals and metals from the group consisting of

copper and its alloys, silver and its alloys, gold and its alloys, titanium and its alloys, zirconium and its alloys, nickel and its alloys, platinum, palladium, cobalt, ductile cobalt alloys and ductile ferrous alloys, and at least said first metal being other than an aluminum metal, each of said metals having a clean surface, which comprises flame-spraying aluminum on at least said first metal to provide an aluminum surface which may be brought into contact with said second metal, heating at least the surface of the metal receiving the aluminum spray to a bonding temperature up to the incipient melting temperature of aluminum, contacting the hot aluminum surfaces while still heated to said bonding temperature and exerting pressure on said metals sufficient to cause lateral flow of the aluminum between said metals to bond said metals together.

10. A method as in claim 9 wherein said first metal is stainless steel and said second metal is aluminum, and only said first metal is flame-sprayed.

11. A method of bonding metal sheets together as claimed in 9 in which the adjacent surfaces of said two sheets, both of metals other than aluminum, are sprayed with aluminum.

12. A method of bonding metal sheets together as claimed in claim 9 in which the flame spray is a plasma jet.

13. A method of bonding metal sheets together as claimed in claim 9 in which the aluminum is sprayed to a thickness of 0.001 to 0.010 inch.

14. A method of bonding metal sheets together as claimed in claim 9 in which three sheets of metal are used and those adjacent sheet surfaces of a metal other than aluminum are flame-sprayed with aluminum.

15. A method of bonding a sheet of metal to another sheet of a metal, said metals being selected from the group consisting of aluminum and stainless steel, at least one of said metals being stainless steel, each of said sheets having a clean surface, which comprises flame-spraying aluminum on a surface of each stainless steel sheet to provide a hot aluminum surface which may be brought into contact with the other sheet, the metal receiving the aluminum spray being heated to a bonding temperature up to the incipient melting temperature of aluminum, contacting the metal surfaces while still heated to said bonding temperature and exerting rolling pressure on said sheets sufficient to cause lateral flow of the aluminum between said sheets.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,173,202

March 16, 1965

Milton H. Farber

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

Column 1, line 11, for "1939" read -- 1959 --; column 10, line 37, for "an" read -- and --.

Signed and sealed this 24th day of August 1965.

SEAL)

Attest:

ERNEST W. SWIDER
Attesting Officer

EDWARD J. BRENNER
Commissioner of Patents

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