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His Attorney.
This invention relates broadly to the art of uniting metals, and more particularly to the art of uniting metallic elements and alloys thereof which will amalgamate with mercury. The invention is particularly directed to various improvements and modifications in the process of uniting metals of the class described, which involves placing a coating of mercury upon the surfaces to be united and then applying heat to vaporize the excess mercury and bond the metals. This invention is especially applicable to uniting silver to copper and its alloys, hereinafter for brevity collectively designated as copper, and for bonding copper to copper.

It is a main object of this invention to provide articles of manufacture, comprising metals, such as copper, silver and the like, rigidly and strongly joined together by a process that is rapid, economical and effective.

Other objects of the invention will be apparent to those skilled in the art as a reading of this specification proceeds.

Before the action of current on metallic solutions was known (by means of which certain metals can be plated from solutions on a given surface) amalgams were used for gliding and silvering. The article to be coated was covered by the amalgam and the excess mercury volatilized by heat, the gold or silver remaining on the surface as a strongly adhering coating. Later, it was proposed to apply heat and pressure simultaneously to the mercury-coated surfaces to form a union of the metals. Unions of lead to lead, tin to tin, lead to tin, or either lead or tin to any other metal which may be provided with a tinned surface, made by so-called "mercury cementation" process, are old and well known.

I have found that in order to obtain a practically effective union of high tensile strength between metals of the class hereinbefore mentioned, it is necessary to follow a procedure substantially as hereinafter described. The extremely strong and improved unions produced by my invention are due in large part to the fact that I treat the metal surfaces to be united both to provide substantially clean surfaces of the metallic elements and for the removal of air bubbles after the parts have been initially assembled, and upon the further fact that, after the assembled parts have been placed in a press having heated plats for simultaneous subjection to pressure and vaporization of excess mercury, I provide a cushion of a suitable material, such as sheet aluminum, pressboard, heavy paper or the like, over the assembled parts to compensate for irregularities in one or the other, or both, of the metals being joined and thereby insure intimate contact over the whole surface.

The novel features which are characteristic of my invention are set forth in the appended claims. The invention itself, however, will best be understood from reference to the following specification when considered in connection with the accompanying drawing in which the single figure is a micrograph (magnification 350 diameters) of a cross-section of a part of a union produced in accordance with the invention and illustrative thereof.

Referring to the drawing, 1, 1' denotes two copper members; 2, an intervening layer of silver; 3, 3', layers of strata of copper amalgam in contact with each of the metallic copper surfaces; 4, 4', layers or strata of silver amalgam in contact with each of the metallic silver surfaces; and 5, 5', layers or strata of an alloy of copper and silver amalgams separating the copper amalgams from the silver amalgams and in contact therewith.

The drawing will also aid in understanding other embodiments of this invention such, for instance, as when merely uniting one metal to another, for example, metallic silver to metallic copper.

Much of the strength of a union such as is produced by this invention is thought to exist in the alloy 5, 5' of the two amalgams. This alloy forms under the heat and pressure employed in practicing my invention. A characteristic of amalgams is that when initially formed and slightly heated they are soft and easily workable, but when set become very hard. There would therefore be some reason to expect that an alloy of, for example, copper and silver amalgams, when solidified, might form an unusually strong bond. That such is actually the case is indicated by the fact that, on tensile-strength tests, breaking of unions produced in accordance with this invention occurred in the silver layer and not at the silver-copper surfaces. I have recognized the practical importance of obtaining and maintaining this alloy of amalgams in a substantially non-ruptured state. Accordingly, my processing operations include steps for obviating blister formation within the joint, thereby obtaining a strongly adhesive, practically rupture-free or continuous film or layer (5, 5') of said alloy of amalgams and a resultant metallic union of substantially improved tensile strength and other improved properties.

The following description of the bonding of sil-
ver to copper is illustrative of how this invention may be practiced:

The surface of the copper article, for example, a piece of copper tubing, is adjusted to render it substantially clean, said treatment comprising, for example, acid dipping or scrubbing with, for instance, pumice. The part of the copper to which the silver is to be applied is coated with mercury in the following manner:

Over an area of the copper surface a little larger than the piece of silver to be applied, a small amount of an aqueous solution of mercuric nitrate and sodium cyanide is swabbed with a pad made of chamois skin, or metallic mercury and sodium cyanide may be similarly applied, in either case subsequently rubbing the surface until the mercury is thoroughly amalgamated with the copper. The metallic mercury is filtered through a chamois skin as it is applied to the copper surface. The surplus mercury and cyanide solution are removed and the article set aside to dry for about one-half hour. The resultant surface is polished with a dry pad of chamois skin. Next, fresh mercury is applied as afore-described and the surplus is subsequently removed.

A strip of silver of the desired thickness, for example, 3 mils thick, and of the shape and size required, is brushed or wiped clean, and the cleaned silver strip is then immersed in a bath of metallic mercury until it is coated. The amalgamated silver strip is removed from the mercury bath and brushed to remove excess mercury and any particles of dirt or other foreign impurities adhering thereto.

The mercury-coated silver strip is now placed upon the previously marked-off spot on the mercury-coated copper surface, and pressed and fixed thereto by hand. It adheres readily to the amalgamated copper surface.

The assembled article, if flat, is now passed slowly and with considerable pressure through rubber rolls such, for instance, as those of an ordinary clothes wringer. When this is impractical due to the shape of the piece, the silver may be patted down with a stiff wire brush, starting the patting operation at one end and continuing to the other end. The object of such operations is to remove any entrapped gas such as the bubbles from the joint. Such bubbles, if not removed, cause blisters to appear in the union and a consequent weakening thereof.

The assembled parts are now placed in a press having heated platens. Sufficient work is spread on the platen so that the pressure will be uniformly distributed and will not crush the copper parts. Steel spacers are used at the sides of the pieces to prevent crushing, that is, deforming, the copper. A cushion of compressible material, for example, a sheet of aluminum, pressboard (about 1/8 inch thick), or heavy paper, is placed over the entire area of the assembled parts. If desired, small individual pieces of such compressible material sufficiently large to cover the silver, at the point where it is bonded to the copper, may be used. Such a cushion compensates for irregularities in the copper surface and insures intimate contact of the copper and silver throughout the entire adjoining surface areas.

Without a cushion of the kind described, the copper must be squeezed to the flow point to get uniform contact with the silver. For economic and other reasons use of pressures no higher then necessary to obtain a strong bond is preferred.

The temperature of the platens is maintained below about 290° C., advantageously between about 225° and 250° C., by any suitable means, for instance, by electric heating units. Temperatures above about 300° C. have a harmful effect upon the copper, for example, detrimentally affecting its hardness. The purpose of applying heat is to remove excess mercury and to assist in the formation of a strong union between the silver and the copper article.

The particular pressure employed depends upon the surface irregularities of the copper and the resistance of particular pieces to displacement, that is, to effecting intimate contact. Too little pressure gives a weak joint. Too high a pressure may set up strains within a metal such as copper sufficient to weaken it materially. Depending upon the size of the article and other influencing factors the pressures used may vary widely, for example, between about 500 and 40,000 pounds per square inch, the lower limit in most cases being about 1,000 pounds. Pressures ranging between about 1,000 and 4,000 pounds per square inch, for example, about 3,000 pounds per square inch, in most cases are effective in producing the desired results and are generally satisfactory in bonding silver to copper by the above-described process. The period of time the united parts are subjected to pressure depends somewhat upon the size of the individual pieces. In any event, the pressure should be applied long enough for the piece to become uniformly heated throughout. For pieces about 1-inch square, about three minutes is required. The press is provided with suction orifices at both sides of the press and in front for withdrawing the mercury as it is vaporized from between the joint.

After pressing, the bonded pieces are removed from the press and the excess mercury brushed off over a suction hood. If desired, the articles may then be placed in a curing oven held at a temperature of about 225° to 250° C., for removal of further amounts of mercury.

In the process hereinafter described, coating the metal surfaces with a film of mercury forms a copper amalgam on the copper and a silver amalgam on the silver. This process consists of applying to the metal parts a layer of amalgam, usually when pressure is applied to form an alloy of said amalgams. This alloy, as shown in the accompanying drawing, appears in the union as a practically rupture-free layer (8, 9') separating the copper and silver amalgams and in contact therewith. The superior quality of the unions produced by a process such as described is due in large part to the elimination of "blisters" from the union and the consequent obtaninment of a practically rupture-free layer of an alloy of the amalgams of the source metals. The formation of such blisters and other defects in the union were particularly noticed (1) when cloth was employed in connection with the application of the mercury to the metals; (2) when little or no care was taken in cleaning the metal surfaces; (3) when the united parts were not treated for the removal of air bubbles; and (4) when no cushion was employed during the pressing operation to compensate for variations in the copper surface and to insure intimate contact throughout the entire surface areas of the metals.

Extensive investigational work disclosed that many of the blisters, especially those of large size, were caused by small particles of cotton lint (used prior to my invention in cleaning the metal surfaces and in applying the mercury) becoming trapped between the silver and copper surfaces during cleaning and assembling. When 78
the assembled parts were placed in a hydraulic press and heated. Water vapor and fixed gases were liberated by the lint, thereby forming blister formation which was eliminated by thoroughly cleaning the metal surfaces, especially the copper surfaces when making a silver-copper union. I have found that most satisfactory and uniform results are obtained if the surfaces are cleaned chemically clean. By the term “chemically clean” I mean a surface freed of impurities to the degree acceptable by chemists, and used in the chemical literature, as descriptive of a surface substantially freed of adhering foreign bodies. A third cause of blister formation was eliminated by removing air bubbles from the union prior to subjecting the same to heat and pressure by passing the united metals through rubber rolls or by rolling with a wire brush, as hereinbefore has been set forth. Use of a compressible cushion upon the work during the pressing operation was also found by extensive experimental work to be advisable for most satisfactory results and for the production of unions of exceptional strength and other improved properties.

My invention makes commercially practical unification of metals of the class described, for example, silver, in thicknesses of 0.01 inch and under to other metals of the same class (e.g., copper).

Another embodiment of my invention comprises forming an amalgam with a thin sheet or strip of a metal capable of so doing, for example, a silver sheet or strip about 3 mils thick, and inserting it between the pieces of metal to be joined, for instance, between two pieces of copper. In all cases the metals to be joined must be capable of amalgamating with mercury. By means of pressure and heat a bond is formed which varies in strength with the metals other than mercury employed in the process. A particularly strong union of copper articles is obtained when sheet silver and mercury are used as bonding metals.

The following description of the preparation of test pieces consisting of copper bars united by means of sheet silver and mercury as bonding metals, and the results of tests on such pieces, is illustrative of this embodiment of my invention.

Copper bars with a rectangular cross-section of 2 by $\frac{3}{4}$ inches were beveled so that they could be fitted together with a 2-inch length of lap. The beveled surfaces were coated with mercury and placed together with a 0.002 inch thick piece of silver between. A pressure of about 40,000 pounds per square inch and a temperature of about 110° C. were applied to the bars for about 5 minutes. After removing the bars from the press, they were heated in an oven for approximately 12 hours at about 110° C. to vaporize any further amounts of excess mercury and to increase the strength of the bond. A tensile strength test was made on the union thus made. A pulling force of twelve thousand pounds was required to break the union at the joint. A second test sample was made in the same form and manner as the one just described. Eight thousand to eleven thousand amperes were put through the joint about thirty times, the temperature of the joint rising to about 150° C. during the process. There was no damage to the joint. The test piece was then vibrated at 60 cycles per second for 394 seconds without damage to the joint. The piece was then pulled in tension and broke through the copper bar at 16,950 pounds. The joint was intact. The joint was then broken apart by driving a chisel between the copper bars. Both sides of the copper were coated with silver, showing that the break was through the silver layer.

Thin laminations of silver were “mercury bonded” to copper bars. They were then placed in a furnace maintained at an elevated temperature. After the bars had reached a temperature of 700° C., they were removed from the furnace and quenched in water. This treatment had no apparent detrimental effect upon the bond.

Lead, tin, silver and copper amalgamated with mercury have been used for bonding the same or other metal articles with varying strengths of the resultant bonds. For bonding copper articles, sheet silver amalgamated with mercury has given the greatest strength in the union. Among the other elements and alloys of these elements which will amalgamate with mercury are barium, bismuth, cadmium, chromium, gold, magnesium, manganese, polassium, sodium, strontium and iron. The practical utility of many such elements in a process of the kind herein disclosed depends upon their cost, the ease or difficulty with which they form amalgams, and the strength and other service requirements of the resultant bonded article. For example, when copper bars are amalgamated and then pressed together, a bond is formed; but a union so made is not sufficiently strong for use in many manufacturing operations, for example, in electrical switch stud construction.

The table shows results obtained in uniting copper to copper using lead, tin and silver amalgamated with mercury as bonding metals:

<table>
<thead>
<tr>
<th>Test sample No.</th>
<th>Description of test sample</th>
<th>Bonding medium</th>
<th>Pulling force required to break the joint (tensile strength) in pounds. (Note: In each instance the bars broke in the joint.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Copper bar 1 inch by 1 inch by $\frac{3}{4}$ inch thick joined to a bar of like dimensions.</td>
<td>Sheet lead, two mils thick, amalgamated with mercury.</td>
<td>635</td>
<td>50</td>
</tr>
<tr>
<td>2. Copper bar 3 inches by $\frac{3}{4}$ inch thick joined to a bar of like dimensions.</td>
<td>Sheet tin, three mils thick, amalgamated with mercury.</td>
<td>910</td>
<td>55</td>
</tr>
<tr>
<td>3. Copper bar 3 inches by $\frac{3}{4}$ inch thick joined to a bar of like dimensions.</td>
<td>Sheet silver, three mils thick, amalgamated with mercury.</td>
<td>2150</td>
<td>60</td>
</tr>
<tr>
<td>4. Copper bar 3 inches by $\frac{3}{4}$ inch thick joined to a bar of like dimensions.</td>
<td>Sheet silver, 5 mils thick, amalgamated with mercury.</td>
<td>13,500</td>
<td>65</td>
</tr>
</tbody>
</table>

The results of the foregoing tests show that in joining articles of copper and its alloys, a silver amalgam forms the strongest union or joint. The red brass bars (test Sample No. 4) bonded with amalgamated silver showed an exceptionally high tensile strength in the union. A direct
and accurate comparison with the other samples cannot be made, however, due to the fact that the test bars in this case were slightly larger in area than the bars used in the samples 1, 2, and 3. A 1.5-inch copper stud had a slot, milled in it to a depth of 1.5 inches. In this slot was inserted a 1.75-inch copper tongue, contacting surfaces of both the stud and the tongue having been coated with mercury, as hereinbefore described, and a sheet of silver foil having been placed between contacting surfaces of the tongue and the stud. This assembly was then placed between two steel blocks and the whole placed between the heated platens of a hydraulic press. Pressure and heat were then simultaneously applied, as previously described herein, until practically all the excess mercury had been vaporized and a firm and permanent bond had been formed. A pulling force of 10,000 pounds per square inch was required to break the bond made in the manner described.

The thickness of silver or metal used for bonding purposes is important where strength is required. Bonding can be done with thin and thick material, but for most work material 3 mils in thickness gives the most generally satisfactory results. The time and temperature of heating are also important. An amount of heat sufficient to soften one or another, or both, of the metals being joined, must be avoided. On the other hand, insufficient heat or heating for too short a period of time does not give a practically satisfactory bond. The time and temperature of heating will vary with parts of different size. In general, when bonding copper to copper with a silver amalgam, the temperature for effective bonding should not exceed about 290° C., and advantageously may be maintained between about 225° and 250° C. Bonding of such parts can be done at a temperature as low as 100° C., but at such a temperature pressure must be applied for a much longer period of time. A practically satisfactory joint depends upon the pressure, heat, and length of time the work is subjected to pressure, and upon following the procedures hereinbefore described for eliminating blister-forming substances and for establishing intimate contact between the contacting metal surfaces throughout their entire areas. In addition to the foregoing use of the particular metal silver, in sheet form and amalgamated, for uniting copper articles, produces a joint of exceptional strength.

The terms "metal", "metallic", and "metallographic" as used hereinbefore, and in claims which follow, include both substantially pure metal of the particular genus or species stated, and alloys thereof.

What is claimed is:

1. In an article of manufacture, a union of at least two different metals the surfaces of which will form an amalgam with mercury, said union comprising amalgams of the respective metals in contact with the said different metals and a practically continuous layer of an alloy of the amalgams separating said amalgams and in contact therewith.  
2. In an article of manufacture, a union of silver and copper articles comprising silver amalgam in contact with the silver article, copper amalgam in contact with the copper article, and a practically continuous layer of an alloy of copper and silver amalgams separating said amalgams and in contact therewith.  
3. In an article of manufacture, a joint uniting metallic copper to metallic copper, said joint comprising an intervening layer of silver, copper amalgam in contact with each of the metallic copper surfaces, silver amalgam in contact with each of the metallic silver surfaces, and practically continuous layers of an alloy of copper and silver amalgams separating said amalgams and in contact therewith.  
4. A method of uniting metal articles the surfaces of which will form an amalgam with mercury, which comprises applying a film of mercury to the clean surfaces to be united, bringing the amalgamated surfaces into intimate contact with each other to join the articles, treating the joined articles for the removal of any entrapped gas, cushioning said articles with a compressible material to compensate for any surface irregularities therein, and subjecting the bonded articles to a simultaneous pressure and heat treatment sufficient to remove excess mercury and to firmly and permanently unite the articles without detrimentally affecting the physical properties thereof.

5. A method of uniting metal articles the surfaces of which will form an amalgam with mercury, which comprises amalgamating the clean surfaces to be joined without introducing thereupon solid foreign contaminants, bringing the amalgamated surfaces into intimate contact with each other to join the articles, treating the joined articles for the removal of any entrapped gas, cushioning said articles with a compressible material to compensate for any surface irregularities therein, and subjecting the bonded articles to a simultaneous pressure and heat treatment, said pressure being sufficiently high to provide intimate contact of the articles throughout their entire adjoining surface areas and to firmly and permanently bond the amalgamated metals, and said heat being sufficiently high to vaporize excess mercury from the metal surfaces without detrimentally affecting the physical properties of the metals.

6. A method of uniting metallic copper members which comprises applying a film of mercury to clean facing surfaces of said members at the point of subsequent union, applying a film of mercury to the joint surfaces of the member, and treating the jointed and amalgamated surfaces, and said heat being sufficiently high to vaporize excess mercury from the metal surfaces without detrimentally affecting the physical properties of the metals.
7. A method of uniting metallic copper members which comprises applying a film of mercury to clean facing surfaces of said members at the point of subsequent union, applying a film of mercury to front and back surfaces of a thin sheet of metallic silver of a size sufficient to cover the copper surfaces at the point of subsequent union, bringing said amalgamated sheet of metallic silver into contact with the copper members at their amalgamated surfaces, and applying pressure and heat simultaneously thereto, said pressure being between about 1,000 and 40,000 pounds per square inch and said heat being between about 100° and 200° C.

8. A method of uniting metallic copper members which comprises applying a film of mercury to clean facing surfaces of said members at the point of subsequent union, applying a film of mercury to front and back surfaces of a thin sheet of metallic silver of a size sufficient to cover the copper surfaces at the point of subsequent union, bringing said amalgamated sheet of metallic silver into contact with the copper members at their amalgamated surfaces, treating the union thus formed for the removal of any entrapped gas, and applying heat and pressure simultaneously thereto, said pressure being sufficiently high to form a firm and permanent union of the members and said heat being sufficiently high to vaporize excess mercury from the metal surfaces without detrimentally affecting the physical properties of the copper members.

9. A method of uniting silver and copper articles which comprises applying a film of mercury to the clean surfaces to be united, bringing the amalgamated surfaces into intimate contact with each other to join the articles, treating the joined articles for the removal of any entrapped gas, and subjecting said articles to a simultaneous pressure and heat treatment, said pressure being between about 1,000 and 40,000 pounds per square inch and said heat being between about 100° and 200° C.

10. A method of uniting silver and copper articles which comprises amalgamating the clean surfaces to be joined without introducing thereupon solid foreign contaminants, bringing the amalgamated surfaces into contact with each other to join the articles, treating the joined articles for the removal of any entrapped gas, cushioning said articles with a compressible material to compensate for any surface irregularities therein, and subjecting the cushioned articles to a simultaneous pressure and heat treatment, said pressure being between about 1,000 and 40,000 pounds per square inch and said temperature being between about 100° and 200° C.

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