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L. A. COOK

2,790,656

ALUMINUM-DISSIMILAR METAL JOINT AND METHOD OF MAKING SAME

Filed March 31, 1953

FIG. 1.

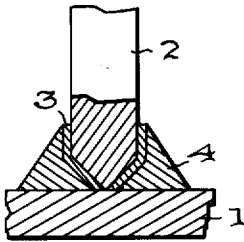


FIG. 2.

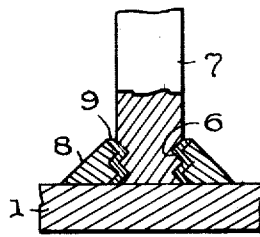


FIG. 3.

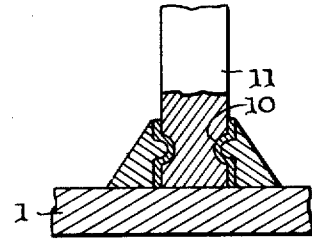


FIG. 5.

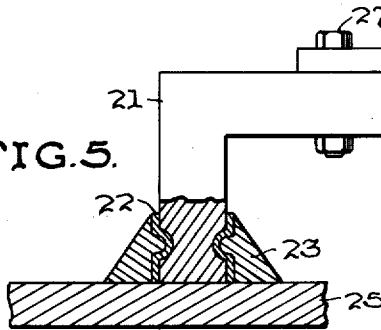


FIG. 4.

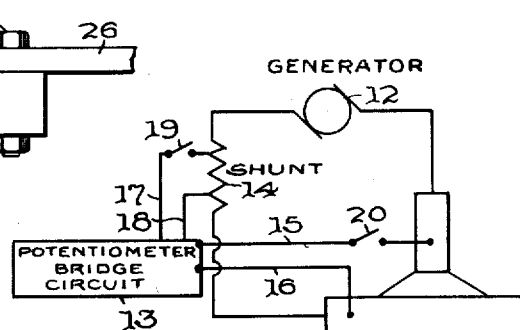


FIG. 6.

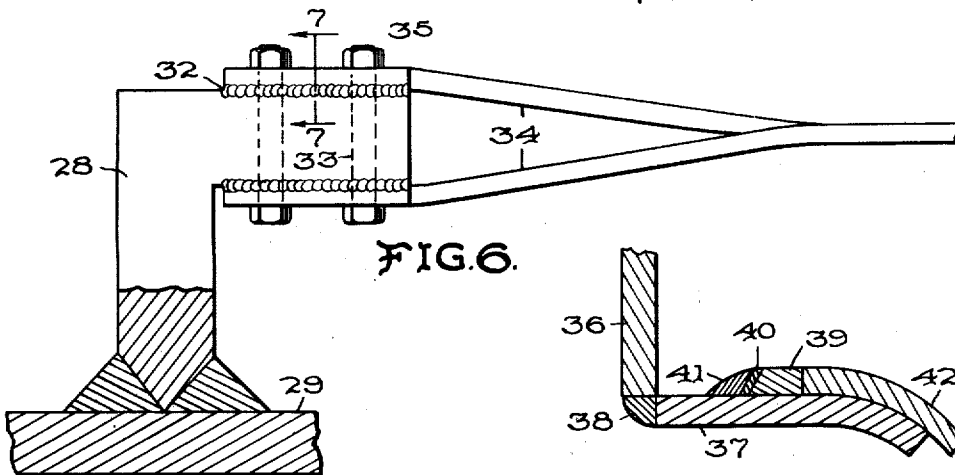


FIG. 8.

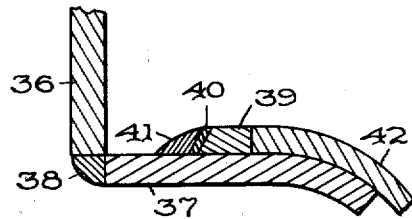
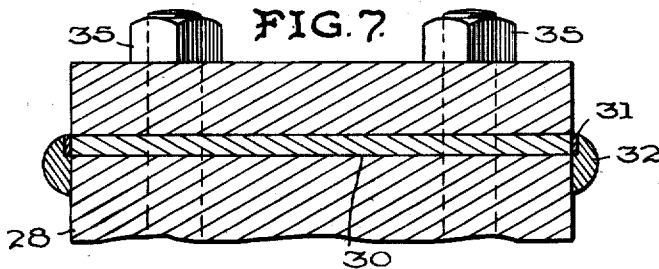


FIG. 7.



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ALUMINUM-DISSIMILAR METAL JOINT AND METHOD OF MAKING SAME

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Application March 31, 1953, Serial No. 345,900

50 Claims. (Cl. 287—20.2)

This invention relates to connections or joints between aluminum and dissimilar metals, e. g. copper and steel, and to methods of producing such joints. More particularly, it concerns connections between aluminum and copper or steel where electrical conductivity and strength are important factors such as in the case of aluminum bus bar connections with copper flex or steel collector bars on electric smelting furnaces for reduction of aluminum, commonly called aluminum pots.

This application is a continuation-in-part of application Serial No. 327,001, filed December 19, 1952, now abandoned.

The making of satisfactory aluminum to copper or steel joints has always posed a difficult problem. Copper and steel have been considered as incapable of being fusion bonded to aluminum to produce a joint possessing low electrical resistance and high mechanical properties. Aluminum oxidizes instantly on contact with the air and the thin layer of oxidation is an effective insulation sheath, such that mechanical connections between aluminum and copper or steel are inefficient, and the copper or steel-to-aluminum connections of the past all show greater electrical resistance than either of the parent metals. Moreover, such joints heretofore have been found to possess extremely low physical properties making them unsuitable for most purposes.

In the field of aluminum production wherein alumina is subjected to electrolysis in a smelting furnace utilizing a carbon anode of the self-baking type, it has been common practice in the past to use massive copper bus bars as the means for furnishing electric power to the anode through copper flex members which are connected at one end to the bus bar and connected to the anode at the other end. Because of the scarcity as well as the high cost of copper, the industry has sought other materials as a substitute for copper. Aluminum was selected due to its high conductivity but the use of aluminum bus bars, particularly with regard to the connection between the bus bar and the copper flex members, has not proved to be satisfactory. One practice presently used comprises welding an aluminum clip to the aluminum bus bar and bolting to the clip one extremity of a copper flex. The other extremity of the copper flex is in turn connected to a solid copper bar which is bolted to the anode studs of the aluminum reduction pot, said copper bar being commonly called a copper anode bar. The electrical resistance of this aluminum to copper joint or connection is extremely important in the production of aluminum for very high currents are normally employed. Where such connections as heretofore discussed are employed it has been found that they develop high contact resistances which materially reduce the electric current passing through the pots. The primary cause for this unsatisfactory operation is creep of the aluminum clip brought about by the heat cycling (raising and lowering of temperature) which occurs during operation of the aluminum pots. By "creep" is meant plastic flow or change in dimension caused by the stress of the tight bolt connection which occurs during

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the heating portion of each heat cycle. Due to this flow of the aluminum, the bolt connection becomes loose on the cooling portion of each heat cycle resulting in high contact resistance. While in normal operation the temperatures of the aluminum pots are not unduly high, there are a number of conditions which may produce excessive temperatures for this type of connection such as when the crust over the surface of the pot is broken to allow addition of further alumina or at times of mal-functioning or failure of the fume exhaust system or other abnormal pot operations. The same problem of high contact resistances has been found in cases where it was desired to replace copper straps bolted to the steel cathode collector bars with aluminum straps. These straps electrically connect the collector bars with the aluminum cathode bus bar.

This condition of creep is further aggravated by arcing across the air spaces produced by the loosening of the connections. Such arcing heats up the metal members still further tending to increase the problem of creep. These loose connections, caused by creep and aggravated by arcing, not only seriously reduces the power input to the pots but may cause the burning of the thin flexible copper components of the copper flexes resulting in the scrapping of same. Such an unsatisfactory condition also necessitates the continuous observation and periodic tightening of the connections.

Another practice is to attach the copper flex to the aluminum bus bar by providing a metallized copper layer on the aluminum clip and then bolting the end of the copper flex to the clip with the end surface of the flex in contact with the metallized copper surface. Such a connection, however, has been found unsatisfactory in that the problem of creep is still present and the metallized copper layer is very brittle and has poor adherence to the aluminum clip. Various other methods have been proposed for connecting the flexes to the bus bars, but for one or more reasons have not proven satisfactory.

According to the present invention, it is proposed to fusion bond copper or steel to aluminum in such manner that the connection possesses the characteristics of low electrical resistance, high mechanical properties, and being able to retain these properties even when subjected to heat cycling operations. Such connections can be advantageously applied to aluminum bus bar connections with copper flex or steel collector bars thereby eliminating the unsatisfactory bolted connections as heretofore used.

The direct welding of aluminum to copper or steel results in a connection possessing very poor mechanical strength due to the formation of brittle intermetallic compounds at the interface. Various other methods have been proposed for bonding these dissimilar metals together as by coating the copper or steel member with a layer of solder material, such as tin or a mixture of tin and lead, and spot welding the aluminum member to the solder-coated copper or steel member. Also, it has been proposed to silver braze these metals together. All of these prior teachings, however, are productive of connections or joints which possess relatively high electrical resistance or low mechanical properties or a combination of both these undesirable features. For example, silver brazing has the disadvantage that the silver alloy forms a low-melting alloy with the aluminum producing a very brittle and mechanically weak zone of bonding. Moreover, it has been found that where the metal members are of relatively massive cross-section, as in the case of reduction pot joints as mentioned hereinbefore, that it is virtually impossible to even make a joint between the members by using silver brazing or the soldering and spot welding techniques.

Accordingly, it is a primary purpose of this invention to provide a novel aluminum to copper or steel joint

and method for making same which overcomes the disadvantages attendant in the prior art.

Another object of the invention is to provide a novel aluminum to copper or steel joint possessing the characteristic of high mechanical strength.

Another object of the invention is to provide a novel aluminum to copper or steel joint possessing the characteristics of high electrical conductivity.

Another object of the invention is to provide a novel aluminum to copper or steel joint possessing the characteristics of high electrical conductivity and high mechanical strength.

A more specific object of the invention is to provide a novel aluminum to copper or steel joint, wherein the electrical resistance of the joint is not greater than that of the parent metal having the higher resistivity and wherein the mechanical strength thereof is equal to or greater than that of a similar aluminum joint.

Another object of this invention is to provide a novel aluminum to copper or steel joint for connections between aluminum bus bars and copper flexes or steel collector bars on aluminum reduction pots characterized by reduced installation and maintenance costs and reduced power loss to the pots with attendant higher production rates.

Another object of the invention is to provide a novel joint between aluminum bus bars and copper flexes wherein creep of the aluminum is eliminated.

A further object of the invention is to provide a novel method of joining aluminum to copper or steel wherein the electrical resistance in the joint is either equal to or less than the resistance of the metal member being joined having the higher resistance.

A further object of the invention is to provide a method of joining aluminum to copper or steel wherein a joint having high mechanical strength is achieved.

A further object of the invention is to provide a method for connecting aluminum bus bars to copper flexes on aluminum reduction pots wherein the connection is characterized by having a resistance in the copper-aluminum joint not greater than that of the parent metal having the higher resistivity, and where the copper-to-aluminum joint has high strength.

Another object of the invention is to provide a method of joining a copper flex member for an aluminum pot to an aluminum bus bar, wherein creep in the aluminum metal is eliminated.

A further object of the invention is to provide a method of joining aluminum bus bars to copper flexes or steel collector bars of an aluminum reduction pot, wherein installation and maintenance costs are decreased and higher production rates are achieved.

Other objects and advantages of the invention will become more apparent from the following description and accompanying drawings.

According to the invention a suitable copper or steel member is faced with a layer of buffer metal on those areas of the surface to be joined to the aluminum member. By "buffer" metal is meant a metal which is capable of forming a finite layer of alloy bond with copper or steel and with aluminum and aluminum alloys, which alloy bond possesses relatively good physical properties. To insure a satisfactory bond between the buffer metal and the copper or steel member it is preferable to first clean the surface of the copper or steel member by any of the common known means, such as degreasing and wire brushing. After the buffer metal layer has been deposited on the member any flux present is removed. This metal layer can be applied by any suitable process as by hot dipping or by depositing by hand with the use of a torch. The coated member is thereafter connected to the aluminum member by welding by means of an inert gas metal arc welding process and utilizing an aluminum or aluminum alloy filler rod. Aluminum to copper or steel connections or joints produced by

this method are found to possess low electrical resistance and high mechanical strength. By this is meant that the joint is characterized by having a strength substantially the same as the parent aluminum metal and a resistance not greater than that of the metal member being joined having the highest resistivity even where the aluminum is joined to copper and the aluminum is of the high purity grade commonly termed "EC" or electrical conductor metal.

As the material of the buffer or facing layer on the copper or steel member, various silver alloys of the high temperature brazing type have been found to produce very satisfactory results. Examples of some suitable alloys are those containing 50% Ag—15.5% Zn—15.5% Cu—16% Cd—3% Ni, 75% Ag—25% Zn, 85% Ag—15% Mn, 45% Ag—15% Cu—16% Zn—24% Cd, 50% Ag—15.5% Cu—16.5% Zn—18% Cd, and 30% Ag—38% Cu—32% Zn. In the selection of the metal of the facing layer, it is preferable that the metal possess a melting point approximately that of the aluminum metal as, for example on the order of 1220° F., in the case of high purity aluminum. High purity silver may be used as the facing metal but it is to be noted that due to the high melting point of around 1700° F., it is extremely difficult to produce a satisfactory bond between the aluminum and the silver layer at a welding temperature satisfactory for the aluminum unless the copper or steel member is preheated to a considerable temperature on the order of 400° to 500° F. The expression "silver metal" as hereinafter used is meant to include silver and silver alloys. For certain applications of the instant invention where the temperature to which the connection may be subjected is relatively low i. e., under about 300° F., low temperature buffer layers may be used. Examples of suitable metals are those containing 5% Ag—95% Cd and 20% Ag—80% Cd. Care must be exercised, however, when dealing with such alloys in view of the toxic vapors given off from the cadmium. As a general rule, where possible, it is preferable to utilize one of the high temperature silver metals mentioned above.

As mentioned hereinbefore, a gas metal arc welding process is used for joining the members. It has been found essential to the success of the invention that such a process be used. It is preferable to use a consumable electrode composed of the weld or filler metal, although a non-consumable electrode can be used. By means of such a welding process the need of a flux is eliminated. The use of fluxes in welding aluminum is very undesirable since they are corrosive and would necessitate the weld being washed immediately after welding. Moreover, even this operation is not always sufficient inasmuch as there is always a possibility of flux being trapped between the weld metal and the aluminum member with consequent corrosion of the aluminum and eventual failure of the joint.

The material of the filler rod used in the welding process may vary depending upon the composition of the aluminum member. As for example, when the aluminum member is aluminum conductor grade (EC) material, as is bus bars, very satisfactory welds have been produced using a filler rod made of the same material or of aluminum base alloys containing predominantly silicon as the alloying constituent such as 43S (4.5–6.0% Si, balance Al and normal impurities). In this example various other aluminum alloys would also be suitable as filler material. The expression "aluminous weld metal" as used hereinafter is meant to include high purity or alloy aluminum as the material of the filler rod. The primary consideration is to use a metal having mechanical properties at least equivalent to those of the aluminum member and possessing a relatively high electrical conductivity. Where the filler metal selected is similar to that of the aluminum member, care must be exercised in the technique of welding used to assure that

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the stresses set up in the weld metal during cooling of the welded joint are not such as to cause cracking of the weld fillet. The term "fillet," as used hereinafter in the specification and claims, is not intended to limit the configuration of the weld to a concave junction between two surfaces as will be obvious from the various configurations of welds as discussed hereinafter in conjunction with the drawings.

In the accompanying drawings are illustrated several preferred embodiments of the instant invention as applied to connections between aluminum bus bars and copper flexes of aluminum reduction pots.

In the drawings:

Figure 1 is a cross section of a T weld between a copper member and an aluminum conductor member, the cross bar of the T being aluminum conductor metal, the copper conductor metal in the weld area having a V-shaped end;

Figure 2 is a weld similar to Figure 1, but modified such that the end of the copper member in the weld area is flat and has saw-tooth sides;

Figure 3 is a weld similar to Figure 2, but modified such that a groove on either side of the end of the copper member is substituted for the saw-tooth sides;

Figure 4 is a diagrammatic illustration of the apparatus used for determining the electrical resistivity of the joints or connections of the invention.

Figure 5 illustrates an embodiment applied in connecting a copper anode bar to an aluminum bus bar by means of a copper flex, wherein a copper clip is welded to the aluminum bus bar and the copper flex is bolted to the copper clip;

Figure 6 illustrates a second embodiment applied in connecting a copper anode bar to an aluminum bus bar by means of a copper flex, wherein an aluminum clip is welded to the aluminum bus bar and the copper flex is joined to the aluminum clip by covering both sides of the aluminum clip with a thin copper metal plate, the aluminum clip being united to the thin copper metal plates by the method of this invention.

Figure 7 is an expanded cross-section of the joint of Figure 6 taken along the line 7—7, showing the silver coating on the edge of the copper plate and the aluminum filler metal;

Figure 8 is a cross-sectional view of another embodiment of the invention for connecting a copper flex to an aluminum bus bar wherein all welded construction is used in place of bolting the copper flex to a clip connected to the bus.

Referring now more particularly to the drawings, the aluminum to copper joint illustrated by Figure 1 may comprise an aluminum bar 1 of electrical conductor (EC) grade aluminum, and a copper bar 2, said copper bar 2 being faced with a layer 3 of silver alloy (e. g. 50% Ag—15.5% Cu—15.5% Zn—16% Cd—3% Ni) up the sides as far as it is intended to weld. The filler metal used to complete the weld, in the form of a fillet 4, may be aluminum or aluminum alloy, for example, 43S wire (5% Si, balance Al). The weld illustrated in Figure 1 is a T-weld, but it is to be distinctly understood that the illustrations are by way of example rather than limitation and that this invention may be applied to other types of welds, for example, butt welds. A specific example of the method for making such a welded joint as shown in Figure 1 and described above, is as follows:

Copper member 2 (e. g. $1\frac{3}{16}$ " x 3" in cross-section) is suitably cleaned as by degreasing and wire brushing and is coated with the silver alloy to form a facing layer 3. The silver alloy layer preferably is from .010 to .035 inch in thickness. It is desirable to wire brush this silver alloy coating after it has hardened. Aluminum member 1 (e. g. 1" x 12" in cross-section) is also preferably wire brushed prior to welding. Members 1 and 2 are thereafter placed in desired position for welding.

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The fillet weld 4 is then made with a plurality of passes with all passes laid down symmetrically in rotation to equalize stresses and minimize distortion. Each pass is wire brushed and preferably cooled before further welding. The weld metal 4 is washed up on the silver surface rather than holding a direct arc on the silver, and the edges of the copper clip are built up to the same height as the sides. An inert gas shielded metal arc welding method is employed. The inert gas is argon with a flow rate of from 60–80 cubic feet per hour. Where helium is used as the inert gas a flow rate of from about 100 to 150 cubic feet per hour is utilized. A current of 250–300 amperes is used with a voltage of from 22–24 volts. The arc length varies from $\frac{3}{16}$ " to $\frac{1}{4}$ ".

It has been found that with the joints of the invention there is prevented a complete alloying of all of the silver metal facing with the aluminum weld metal. Metallographic examination shows that a very distinct layer of silver metal exists between the filler metal and the copper member. It is believed that this result arises from the fast freeze of the filler metal as each pass is laid down thereby preventing excessive dissolving of the silver metal and the formation of a brittle, weak bond. Additionally, the fact that a very distinct silver metal layer exists prevents copper of the copper member from diffusing into the aluminum and forming brittle aluminum-copper compounds.

The aluminum-to-copper bond may be modified as shown in Figure 2 by using a flat end or base 5 and serrating the sides 6 of the copper member 7 where the weld 8 is to be applied, and then coating with silver alloy 9 and welding with aluminum filler metal as previously described. This increases the area of silver bond strengthening the joint. Further, the strength of the joint is not completely dependent on the strength of the aluminum-silver bond having added strength due to the keying action of the aluminum saw teeth. Moreover, the flat base on member 7 gives added resistance to failure in bending with respect to member 1. Still another modification is shown by Figure 3 wherein a groove 10 on each side of the copper member 11 is employed as an alternative to the saw teeth 6 of Figure 2. This is accomplished by placing two copper clips side by side and drilling a hole between them, after which the opposite sides are placed together and a hole drilled between them. Alternatively, the grooves can be milled in each clip separately. The advantages of this modification are essentially the same as the modification employing the saw teeth.

Samples of welded joints of this invention as shown in Figures 1–3 have been subjected to electrical conductance, tensile, and bend tests after heat cycling and prolonged heating with excellent results. The electrical conductance of the joints subjected to heat cycling was tested by means of standard apparatus for measuring voltage drops as illustrated diagrammatically in Figure 4. As shown, the apparatus generally comprises a generator 12, a potentiometer bridge circuit 13, a shunt 14, potentiometer leads 15, 16, 17 and 18, and switches 19 and 20. Each cycle consisted of heating the joint to 400° F., followed quickly by a water quench and an air blast to cool the joint below 150° F. and the cycle was of about four minutes in duration (this simulates, and is actually slightly more severe than, conditions existing oftentimes in aluminum reduction pot operation). Conductance measurements with current density of the order of 1000 amps./sq. inch of copper section were made on each joint at 0, 100, 200, 300, 400, and 500 heat cycles.

The test results showed that the millivolt drop across the aluminum to copper joint is of the order of 0 to 5 millivolts which is not significantly different from voltage drops obtained on similar lengths of aluminum bus bar proper and as such these results showed that heat cycling of this type has little or no effect upon the electrical conductance of the joint. Prolonged heating of these

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joints at 450° F. for two weeks produced no significant change in electrical conductance.

The tensile strength of these joints, when measured at room temperature prior to any heating and then at room temperature after heat cycling and prolonged heating as discussed above, showed a strength on the order of 13,000 p. s. i. or over with no significant change brought about by heating. Experimental joints of these types put into actual operation on aluminum reduction pots for a period of four months exhibited similar properties. Moreover, tensile tests made on these joints while maintained at a temperature of about 400° F. showed them to have similar tensile strength. Accordingly, it will be seen that the joint of the invention possessed a tensile strength equal to or greater than that of the parent aluminum member.

Bend tests were conducted on these joints by securely fixing the aluminum member to a suitable clamping apparatus and then bending the copper either parallel or transversely to the aluminum member. All the joints exhibited excellent bend properties and could be bent approximately 90° away from the vertical axis without failure occurring.

Accordingly, it is thus seen that the aluminum to copper joints of the invention possess excellent electrical and mechanical properties even under extremely undesirable conditions of temperature and load.

Figure 5 illustrates one specific embodiment of this invention as applied in making connections between aluminum bus bars and copper flexes of reduction pots. In this embodiment L-shaped copper clip 21 is faced on one end with a suitable silver alloy layer 22 and aluminous filler metal is employed to form fillet welds 23 to thereby weld the coated copper clip to aluminum bus bar 25. An inert gas electric arc welding method, preferably the Sigma or Aircomatic Welding Processes utilizing a consumable filler metal electrode, is employed. One end of a copper flex 26 is then bolted, by means of bolts 27, to the other end of the copper clip 21 and the other end of the copper flex 26 is bolted to the copper anode bar (not shown).

Where creep in aluminum is not an important factor and heat cycling is not critical, another embodiment of the invention, illustrated by Figures 6 and 7, may be employed in the application for connecting aluminum bus bars to copper flexes on aluminum pots. In this embodiment the conventional aluminum clip 28 is welded to the aluminum bus bar 29, and the end to be connected to the copper flex is faced on both sides with a layer of thin copper sheet or strip 30 approximately $\frac{3}{16}$ to $\frac{1}{4}$ " thick. The copper layers 30 are faced on their edges with a suitable silver alloy 31, and placed on either side of the end of the aluminum clip. The edges are then fusion-welded to the aluminum clip by an edge welding technique wherein aluminous filler metal is employed to form welds 32, the aluminous filler metal contacting the silvered portion 31 of the copper layers 30. Bolt holes 33 are then drilled through the copper-faced aluminum clip 28, and the copper flex 34, also provided with suitable bolt holes, is split and bolted on either side of the copper-faced aluminum clip 28 by means of bolts 35, the copper flex contacting only the copper faces 30 of the aluminum clip 28. In operation the current is carried from the aluminum clip 28 to the copper layers 30 to the surface of the copper flex 34. This joint gives excellent electrical characteristics, and since there is no particular mechanical stress on the copper-to-aluminum joint, it would show similar strength characteristics to the non-copper-faced aluminum clips conventionally used.

The excellent electrical and mechanical properties of aluminum-to-copper joints of this invention now make it possible to utilize all-welded connections between the aluminum bus bars and the copper flexes of reduction pots. Figure 8 illustrates one form of all-welded joint

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including an aluminum bus bar 36 and an aluminum flex guard 37 joined thereto by means of fillet weld 38. A copper lug member 39, having a suitable buffer metal facing layer 40 on the edges to be joined is bonded to the flex guard by means of aluminous weld metal fillets 41. The copper flex 42 is joined at one extremity to the lug 39 by welding while the other extremity is joined to a copper anode bar (not shown). Flex guard 37 functions to prevent too sharp a bend in the flex which might produce failure in some of the flex components. In making this type of joint it has been found desirable to first provide the copper lug with the buffer metal facing, weld one end of the copper flex to the lug, bond these members to the flex guard by means of welding and thereafter secure this assembly to the aluminum bus bar by welding the flex guard and bus bar together. It is to be noted, with regard to lug member 39, that it may be of trapezoidal cross-section with the short parallel back edge surface abutting the end of the copper flex which is welded thereto. Also, it has been found preferable to provide the lug with tapered or slanting front and side edge surfaces (front edge illustrated in Figure 8) and to apply fillet welds on the front and side edges thereof in order to enhance the retention of the lug in electrical conducting relationship with the flex guard. Such an all-welded connection or joint has the advantages of low installation costs since no bolts are used, relatively short length of copper flex needed, low maintenance costs, low power loss and high production rates.

As hereinbefore mentioned, the method of joining copper to aluminum is equally applicable in joining steel to aluminum and is eminently suited for applications such as in making efficient and strong electrical joints between steel cathode collector bars and the aluminum straps which join the collector bars to the aluminum cathode bus bar. A number of steel to aluminum joints made by the process of the instant invention have been subjected to electrical conductance, tensile, and bend tests with excellent results as in the case of the copper to aluminum joints. Additionally, a number of such joints have been put in actual operation in aluminum pots on collector bar-aluminum strap connections with good results.

It is to be noted in the fusion bonding of steel to aluminum by practice of the instant invention that depending upon the cross-section of the steel member it may be necessary to provide additional cooling for the steel member to prevent any tendency for the silver buffer metal to become entirely molten during the welding operation. The necessity of providing additional cooling is due to the lower rate of heat dissipation of steel as compared to copper. Where the rate of heat dissipation is not sufficient there will be a tendency for the buffer metal to melt and flow off giving rise to spots on the steel member not covered by the buffer metal. In such cases the steel would be in direct contact with the aluminum weld metal with the result that brittle intermetallic compounds of iron and aluminum would form in the area of the bond. By providing increased cooling in these instances a continuous layer of buffer metal will remain between the weld metal and the steel member thereby preventing any formation of brittle intermetallic compounds between iron and aluminum. Various means can be used for providing increased cooling where necessary. One suitable practice is to place the steel member in contact with cooling water in areas not being subjected to the welding operation.

It will thus be readily seen that by practice of the instant invention aluminum to copper or steel joints can be readily produced having electrical and mechanical properties of an order heretofore not possible to attain. Although the specific embodiments of the invention described hereinbefore pertain to the aluminum to copper or steel joints as applied to connections between aluminum bus bars and copper flexes or steel collector bars

on aluminum reduction pots, it is obvious that this invention is eminently suited for application wherever an aluminum to copper or steel joint possessing high electrical and mechanical properties is desired.

It is further to be understood that various alterations, modifications or other changes may be made to this invention without departing from the spirit and scope thereof, and as such, the invention is not to be taken as limited except by the appended claims wherein:

What is claimed is:

1. A joint between aluminum and a metal dissimilar to aluminum which is normally incapable of being fusion bonded to aluminum to produce a joint possessing low electrical resistance and high mechanical properties, said joint comprising an aluminum member and a dissimilar metal member in integral bonded relation, the bond comprising a facing of buffer metal on said dissimilar metal in the area of the bond and at least one aluminous weld metal fillet connecting said facing to said aluminum member, said facing being in alloy bond relation with said dissimilar metal and said weld fillet.

2. A joint according to claim 1 wherein said facing metal is silver metal.

3. A joint according to claim 2 wherein said aluminum member is composed of high purity aluminum, said silver metal facing comprises an alloy of 50% silver, 15.5% copper, 15.5% zinc, 16% cadmium and 3% nickel, and said aluminous weld metal is an aluminum alloy comprising 5% silicon, balance aluminum.

4. An aluminum-copper joint comprising an aluminum member and a copper member in integral bonded relation, the bond comprising a facing of buffer metal on said copper member in the area of the bond and at least one aluminous weld metal fillet connecting said facing to said aluminum member, said buffer metal facing being in alloy bond relation with said copper member and said weld metal fillet, said joint possessing low electrical resistance and high mechanical properties.

5. An aluminum-copper joint according to claim 4 wherein the aluminum member and the copper member are in flat surface opposed relation.

6. An aluminum-copper joint according to claim 4 wherein the copper member is provided with irregular surface portions in the area of said buffer metal facing.

7. An aluminum-copper joint according to claim 4 wherein said facing metal is silver metal.

8. An aluminum-copper joint according to claim 7 wherein said aluminum member is composed of high purity aluminum, said silver metal facing comprises an alloy of 50% silver, 15.5% copper, 15.5% zinc, 16% cadmium and 3% nickel, and said aluminous weld metal is an aluminum alloy comprising 5% silicon, balance aluminum.

9. An aluminum-copper joint according to claim 7 wherein the copper member is provided with irregular surfaces in the area covered by the silver metal facing.

10. An aluminum-copper joint comprising an aluminum conductor member and a copper conductor member in integral bonded relation, the bond comprising a facing of silver metal on said copper member in the area of the bond and aluminous weld metal fillets connecting said facing to said aluminum member.

11. An aluminum-copper joint according to claim 10 wherein the weld metal is an aluminum silicon alloy.

12. An aluminum-steel joint comprising an aluminum member and a steel member in integral bonded relation, the bond comprising a facing of buffer metal on said steel member in the area of the bond and aluminous weld metal fillets connecting said facing to said aluminum member, said buffer metal facing being in alloy bond relation with said steel member and said weld metal fillets.

13. An aluminum-steel joint according to claim 12 wherein said facing metal is silver metal.

14. An aluminum-steel joint according to claim 13 wherein said weld metal is an aluminum silicon alloy.

15. An aluminum-steel joint according to claim 14 wherein said aluminum member is composed of high purity aluminum, said facing metal comprises an alloy of 50% silver, 15.5% copper, 15.5% zinc, 16% cadmium and 3% nickel, and said aluminous weld metal is an aluminum alloy comprising 5% silicon, balance aluminum.

16. An aluminum-copper joint characterized by possessing low electrical resistance and high mechanical properties, comprising an aluminum member having a thin copper layer superposed thereon and being bonded at the edges in integral relation therewith, the bond comprising a facing of silver metal on the edges of said copper layer in the bond area and aluminous weld metal fillets connecting said facing to said aluminum member, said aluminum member being affixed to a copper member in the zone of said thin copper layers.

17. An aluminum-copper joint according to claim 16 wherein a thin copper layer is bonded in integral relation to each side of said aluminum member, and wherein one end of a copper member is bifurcated, one portion contacting one side of the aluminum member in the zone of said thin copper layer, the other portion contacting the other side of the aluminum member in the zone of said thin copper layer, with bolts passing through the complete assembly.

18. An aluminum-copper joint between the aluminum bus bar and copper flex of an electric smelting furnace which is characterized by possessing low electrical resistance and high mechanical properties, comprising a copper clip member in integral bonded relation to the bus bar, the bond comprising a facing of silver metal on the end of said clip in the area of bond and aluminous weld metal fillets connecting said facing to said bus bar, the other end of said clip being affixed to one end of the copper flex.

19. An aluminum-copper joint according to claim 18 wherein the copper clip is provided with irregular surface portions in the area of the silver metal facing.

20. An aluminum-copper joint according to claim 19 wherein the aluminum bus bar and copper clip are in flat surface opposed relation.

21. An aluminum-copper joint between the aluminum bus bar and copper flex of an electric smelting furnace and characterized by possessing low electrical resistance and high mechanical properties, comprising an aluminum clip member one end of which is in fusion weld relation to said bus bar, said clip at its other end having thin copper layers superposed thereon and being bonded at the edges thereof in integral relation therewith, the bond comprising a facing of silver metal on the edges of said copper layers in the bond area and an aluminous weld metal fillet connecting said facing to said clip, and one end of said copper flex being affixed to said clip in the area of said copper layer.

22. An aluminum-copper joint between the aluminum bus bar and the copper flex of an electric smelting furnace characterized by possessing low electrical resistance and high mechanical properties, comprising an aluminum bus bar, a copper metal lug in integral bonded relation therewith, the bond comprising a silver metal facing on said copper lug in the area of the bond and an aluminous weld metal fillet connecting said facing to said bus bar, and one end of said copper flex being in fusion weld relation with said copper lug.

23. A method of making a joint between aluminum and a metal dissimilar to aluminum which is normally incapable of being fusion bonded to aluminum to produce a joint possessing low electrical resistance and high mechanical properties, comprising the steps of providing the dissimilar metal with a facing of silver metal in the area to be bonded, placing the silver faced-dissimilar metal member in welding relation to the aluminum member,

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and arc welding the silver facing to the aluminum member by forming fillets therebetween of aluminous weld metal, said welding being conducted in contact with an inert gas.

24. A method according to claim 23 wherein said weld metal is an aluminum silicon alloy.

25. A method according to claim 24 wherein said silver metal facing comprises an alloy of 50% silver, 15.5% copper, 15.5% zinc, 16% cadmium and 3% nickel.

26. A method of making an aluminum-copper joint, comprising the steps of providing a copper member with a facing of silver metal in the area to be bonded, placing the silver faced-copper member in welding relation to the aluminum member, and arc welding the silver facing on the copper member to the aluminum member in the presence of an inert gas by forming fillets therebetween with aluminous weld metal.

27. A method of bonding an aluminum body to a copper body wherein the resultant joint possesses low electrical resistance and high mechanical properties, comprising the steps of cleaning the bonding surface of the bodies, providing the copper body with a continuous silver metal facing in the area to be bonded, placing the silver faced-copper body in welding relation to said aluminum body, and arc welding the silver facing on the copper body to the aluminum body with aluminous weld metal in the presence of an inert gas.

28. A method according to claim 27 wherein the copper body is provided with irregular surfaces in the area of bonding prior to the application of the silver metal facing.

29. A method according to claim 27 wherein the weld metal is an aluminum silicon alloy.

30. A method according to claim 27 wherein the silver faced-copper body and the aluminum body are positioned in substantially flat surface opposed relation preparatory to the welding operation.

31. A method of making an aluminum-steel joint, comprising the steps of providing a steel member with a facing of silver metal in the area to be bonded, placing the silver faced-steel member in welding relation to the aluminum member, and arc welding the silver facing on the steel member to the aluminum member in an inert gas atmosphere by forming fillets therebetween of aluminous weld metal.

32. A method according to claim 31 wherein the weld metal is an aluminum silicon alloy.

33. A method according to claim 32 wherein said silver metal facing is an alloy comprising 50% silver, 15.5% copper, 15.5% zinc, 16% cadmium and 3% nickel.

34. A method of making a joint between an aluminum body and relatively thin copper bodies which is characterized by low electrical resistance, comprising the steps of providing the edges of said copper bodies with a silver metal facing which is continuous in nature, assembling the copper bodies on either side of the aluminum body and arc welding the silver metal facing to the aluminum body with aluminous weld metal in the presence of an inert gas.

35. A method of making a joint between an aluminum bus bar and a copper flex of an electric smelting furnace, comprising the steps of providing a copper clip member, cleaning said member and providing a silver metal facing thereon in the bonding area thereof, cleaning said bus bar in the area of bonding, positioning said clip in fusion bonding relation with said bus bar, arc welding the silver metal facing to the bus bar with aluminous weld metal fillets in the presence of an inert gas and affixing one end of the copper flex to said bonded clip member.

36. A method according to claim 35 wherein the clip member is provided with irregular surfaces in the area of the bond prior to silver metal facing.

37. A method of making an electrical connection between aluminum bus bars and copper flexes of electric smelting furnaces, comprising the steps of welding an

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aluminum clip member to the bus bar, providing a thin layer of copper for each side of a portion of said clip removed from the weld zone, providing a silver metal facing on the edges of said copper layers, assembling said layers in weld relation with the clip and arc welding the silver metal facings to the clip with aluminous weld metal fillets in the presence of an inert gas, providing a bifurcated end on the copper flex, and assembling the flex with said clip such that one portion of the bifurcated end contacts the copper layer on one side of said clip while the other portion of said bifurcated flex end contacts the copper layer on the other side of said clip.

38. A method of making an electrical connection between aluminum bus bars and copper flexes of electric smelting furnaces, comprising the steps of providing a copper lug to be bonded to the bus bar, providing said lug with a silver metal facing in the bonding area, welding one end of the copper flex to said lug, positioning said lug in welding relationship to a flex guard member, arc welding the silver metal facing to the flex guard with aluminous weld fillets in the presence of an inert gas, and thereafter welding the flex guard to said bus bar.

39. An aluminum-copper joint between the aluminum bus bar and copper flex of an electric smelting furnace which is characterized by possessing low electrical resistance and high mechanical properties, comprising a copper clip member in integral bonded relationship to the bus bar, the bond comprising a facing of buffer metal on said clip at the bonding surface thereof and at least one aluminous weld metal fillet connecting said facing to said bus bar, said buffer metal facing being in alloy bond relationship with said clip and said weld metal fillets, said copper flex being affixed to said copper clip.

40. An aluminum-copper joint according to claim 39 wherein said facing is silver metal.

41. An aluminum-copper joint according to claim 40 wherein the surface of said clip provided with the silver metal facing is notched.

42. An aluminum-copper joint according to claim 41 wherein said copper clip and said aluminum bus bar are in flat surface opposed relationship.

43. An aluminum-copper joint according to claim 40 wherein the weld metal is an aluminum silicon alloy.

44. An aluminum-copper joint between the aluminum bus bar and copper flex of an electric smelting furnace which is characterized by possessing low electrical resistance and high mechanical properties, comprising a copper clip member in integral bonded, flat surface opposed, relationship to the bus bar, the bond comprising a facing of silver metal on said clip at the bonding surface thereof, said surface being uneven, and at least one aluminous weld metal fillet connecting said facing to said bus bar, said aluminous weld metal being an aluminum alloy comprising 5% silicon and balance aluminum, said copper flex being affixed to said copper clip.

45. A method of making a joint between an aluminum bus bar and a copper member, comprising the steps of providing said copper member, providing a portion of the surface of said member with a facing of buffer metal thereon, positioning said member in fusion bonding relationship with said bus bar, arc welding the buffer metal facing to the bus bar with aluminous weld metal in the presence of an inert gas.

46. A method according to claim 45 wherein the buffer metal is silver metal and wherein said copper member is provided with an uneven surface in the area covered by said buffer metal prior to the application thereof.

47. A method according to claim 46 wherein the surface of said copper member covered by said buffer metal is notched prior to application of said buffer metal.

48. A method of making a joint between an aluminum bus bar and a copper flex of an electric smelting furnace, comprising the steps of providing a copper clip member, providing an uneven surface on said clip adjacent one end thereof, providing said surface with a silver metal facing,

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positioning said clip in fusion bonding relationship with said bus bar, said end of the clip being in flat surface opposed relationship with the bus bar, arc welding the silver metal facing to the bus bar with aluminous weld metal fillets, said weld metal being an aluminum alloy comprising 5% silicon and balance aluminum, and affixing one end of the copper flex to said clip.

49. A method of making a joint between an aluminum member and a member of a metal dissimilar to aluminum which is normally incapable of being fusion bonded to aluminum to produce a joint possessing a low electrical resistance and high mechanical properties, comprising the steps of providing the dissimilar metal member with a facing of buffer metal thereon in the area to be bonded and inert gas arc welding the buffer metal facing to the aluminum member by forming aluminous metal weld therebetween.

50. A method according to claim 49 wherein said buffer metal is silver metal.

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