A crimp-type electrical connector especially useful for terminating aluminum wires wherein the ferrule portion is at least internally surfaced with brittle intermetallic compound, preferably formed by high temperature diffusion of a cladding-metal into the base-metal of the connector, which compound upon crimping breaks into small sharp particles which abrade and pierce the surface of the wire conductor to expose clean non-oxidized metal for forming intimate joints in the resulting connection.

6 Claims, 2 Drawing Figures
BRITTLE-SURFACED CONNECTOR

The present invention relates to electrical connectors, and more especially to crimp-type electrical connectors primarily useful in terminating smaller aluminum wires as well as copper wires.

The termination of aluminum wires has always been a significant problem in the electrical arts due to the formation of a relatively non-conductive oxide surface layer on the aluminum which interferes with the formation of an effective aluminum-to-aluminum, aluminum-to-copper, etc. crimp termination. For example, in the use of a typical standard copper crimp connector with a cylindrical ferrule, not only is the original termination somewhat inferior, but the inevitable micro-flaws remaining with the crimp structure result in rapid deterioration upon exposure to the natural environment. This deterioration occurs at such a rapid rate that under standard quality control testing for copper-wire to copper-connector crimp terminations (wherein the latter would result in only a small percentage increase in resistance after testing) the aluminum-wire to copper-connector connection after such testing results in at least a 50% increase in the resistance and more often with essentially open circuit terminations resulting.

There have been many attempts in the prior art to overcome these aforementioned difficulties in terminating aluminum wire. For example in the utility field, the interior of the crimp connector ferrule was often filled with a corrosion-inhibiting jelly and hard nickel particles which serve the purpose of breaking through the oxide layer during the crimp to expose fresh unoxidized aluminum for cold welding with the metal of the connector, and with the jelly serving to exclude subsequent corrosion from the external atmosphere. See for example U.S. Pat. No. 2,815,497. This found some usefulness in the larger utility-type connectors, but is not nearly so useful in the 10 to 40 gauge wire range. Additionally, such connectors are more expensive and difficult to use.

Therefore, it is an object of this invention to develop a crimp-type electrical connector for terminating solid or stranded aluminum wire, which is particularly useful in the smaller wire gauge ranges (e.g. 10 gauge to 40 gauge) all with a longevity and termination quality on the order of that achieved by copper terminations to copper wiring. It is a further object of this invention to achieve the foregoing result with a connector whose physical confirmation and field utilization is substantially identical to standard copper wire connectors and as such can utilize existing connector manufacturing tools and existing application tooling. It is a still further object of the present invention that the foregoing results be achieved by a relatively simple and comparatively inexpensive connector.

According to the present invention, these and other objects and advantages of the present invention will be achieved by the treatment of crimp-type connectors formed from typical base-metal materials such as copper, brass, bronze, steel or the like with a cladding-metal such as aluminum, tin, indium, their equivalent alloys, or the like wherein the cladding-metal has been applied to the base-metal so as to diffuse substantially entirely into the surface of the base-metal to form a thin surface layer of the order of 30 to 300 micro inches thick of a brittle intermetallic compound of said base-metal and said cladding-metal. As will be developed more fully below, this intermetallic compound surface layer may be formed on the surface of flat metal stock from which the connectors are formed, or may be formed on the surface of the otherwise completed connector as one of the last finishing steps in its manufacture.

In this specification and the accompanying drawings we have shown and described preferred embodiments of our invention and have suggested various alternatives and modifications thereof, but it is to be understood that these are not intended to be exhaustive and that many other changes and modifications can be made within the scope of the invention. These suggestions herein are selected and included for purposes of illustration in order that others skilled in the art will more fully understand the invention and the principles thereof and will thus be enabled to modify it and embody it in a variety of forms, each as may be best suited to the conditions of a particular use.

FIG. 1 is an isometric view of a standard crimp-type connector in which the present invention would commonly be utilized.

FIG. 2 is a vertical cross-section of the connector in FIG. 1 with the intermetallic layer illustrated in exaggerated thickness and delineation for purposes of clarity on the internal surface of the barrel and tongue of the connector.

Referring to the drawings, a common type of a closed barrel crimp connector 1 is utilized to illustrate the preferred embodiment of this invention. The connector 1 is composed of a crimp termination means 2, in the form of a barrel portion of ferrule 2, for receiving the wire 3 therein and a tongue portion 4 having a eyelet 5 for receiving a terminal post therethrough. The thin intermetallic layer 6 has been specifically illustrated in FIG. 2 as being formed on the internal surface of the base metal 7.

The brittle intermetallic conductive layer 6 not only typically serves as a protection for the base metal 7 against oxidation or the like, but is believed to give this novel connector its unique characteristics by reason of the extremely brittle or fragile surface which it forms. This surface 6 during crimping of the barrel 2 onto the wire 3 breaks into small sharp particles which abrade and pierce the surface of the conductor and, particularly in the case of aluminum, thereby expose clean non-oxidized aluminum while simultaneously exposing clean non-oxidized base-metal. During the crimping these exposed and cleaned surfaces of the terminal and conductor rub and work against each other under pressure and form extremely intimate joints or possibly cold welds.

The intermetallic surface 6 can be prepared in a number of ways. In one embodiment, a copper connector 1 was dipped in a molten bath of an aluminum silicon alloy protected by a common aluminum brazing flux. This produced a very hard transfigurable surface resulting in connectors which when crimped to solid aluminum wire showed exceptional life, even under adverse testing conditions. This dipping method is not only dangerous due to spattering and corrosiveness, but also proved very difficult to control; therefore giving non-uniform surfaces of uneven thickness. Consequently a preferred method of forming the intermetallic layer 6 is by plating, roll cladding, or the like of the cladding-metal onto the base-metal in a thickness typically up to about 200 micro inches and thereafter heat treating to
cause the entire cladding-metal to diffuse into the surface of the base-metal (the thickness of which resulting intermetallic compound layer 6 should not exceed about 300 micro inches). Because of the brittle nature of the surface 6 formed, it is advantageous to postpone the heat treatment until after the stamping and forming operation has been finished. In an example of the foregoing, a thin aluminum cladding is rolled onto the surface of a relatively thicker copper sheet, which after stamping and forming into a connector is thereafter heat treated to allow the aluminum and copper to intermingle and form an intermetallic compound. Similarly, a copper connector 1 which has been tin plated is thereafter heated to a high enough temperature to allow diffusion to occur between the tin and copper causing a tin-copper intermetallic compound to form. Similarly, steel may be plated with tin or coated with aluminum and at sufficiently higher temperature will form a hard brittle intermetallic which when clamped on an aluminum wire will break through the aluminum oxide skin and mechanically lock the wire to form a good electrical connection of high mechanical strength.

These latter rolling and plating methods not only give much greater control over the uniformity of thickness of the intermetallic layer 6, but also over the placement of such layer on the surface of the connector 2. For example in the dip method, the entire surface of the connector 2, if totally immersed, would be coated with the intermetallic layer. However, the rolling and rolling methods can be adapted to restrict the intermetallic layer to just one surface of the base metal from which the connector 1 is formed (as is the case illustrated in FIG. 2), or even be restricted to the internal surface of the barrel portion 2 alone.

Consistently superior results have been achieved with the use of a connector made according to the present invention when clamped on solid aluminum wire 3. Somewhat less consistent results are achieved when stranded aluminum wire is used in place of solid aluminum wire. This is understandable, because the super-porosity of the intermetallic connector is due to the interaction during the crimp between the outer surface of the wire 3 and the intermetallic layer 6. In the case of multi-filament stranded aluminum wire only those portions of those strands of the wire 3 in contact with the intermetallic surface 6 are deriving benefit from this superior interaction and the aluminum-to-aluminum surface interaction of the strand surfaces within the wire remain as before and are therefore subject as before to relatively rapid failure due to corrosion from naturally occurring external phenomena resulting from heat cycling, creep and the like.

However, by carefully controlled crimping methods ensuring a high degree of crimping, but not so much as to lose the wire by undue extrusion from the crimping area, the reliability of the inventive connectors is increased even in the case of stranded aluminum wires. Terminations from the inventive connectors are in any event greatly superior to prior art crimp-type terminations to stranded aluminum wire.

It should be emphasized that for the intermetallic surface 6 to be effective, essentially all of the cladding-metal should be diffused into the base-metal, and vice versa, so that little or no unmodified cladding-metal remains on the surface.

In a series of experiments, a number of copper connectors of the type illustrated in FIG. 1 were plated with tin in an ordinary stannate plating bath, or with tin plated over a flash plated copper, or plated with a bright tin which contains an organic brightener that gives the plated tin a shiny appearance; or alternatively with an indium plating. The plating thicknesses ranged between 50 and 300 micro inches at a diffusion temperature of 800°F or 1000°F for diffusion times ranging from 30 seconds, through 5, 10 and up to 20 minutes. As a standard of comparison three connectors with copper-copper standard tin (100 micro inches), bright tin (50 micro inches), and indium (100 micro inches) plating, respectively, were subjected to normal environmental quality control testing along with the aforementioned tin or indium intermetallic compound surface-invented connectors, as follows: air quenched thermal shock (plus 150°F to -55°F, 15 cycles), current overload (15 minutes on and 15 minutes off at 40 amperes for 12 gauge wire or 52 amperes for 10 gauge wire), humidity (96% at 90°F for 100 hours), and salt spray (5% sodium chloride for 48 hours at room temperature).

By comparison, in some cases the standard aluminum terminations, after testing, showed open circuits while in the best cases they showed such deterioration of resistance that their resistance was 50% higher than their initial values. In contrast, the connectors prepared according to the present invention were, after testing, 10 to 15% higher than their initial values. The foregoing environmental testing was made on otherwise identical copper base-metal connectors crimped to solid aluminum wire by the same crimping tool.

From these foregoing experiments, it was determined that for tin (as the cladding-metal) on a copper connector (as the base-metal) the preferred thickness of the plating applied for subsequent diffusion should range between 30 and 200 micro inches. Upon diffusion this would result in a maximum significant depth of diffusion of about 300 micro inches. Any amount less than this foregoing range would not give a sufficient surface treatment to achieve a meaningful effect while any more than this range would result in excessive brittleness and cracking of the surface prior to crimping, all resulting in undesired unreliability. The preferred temperature for effecting this diffusion of the plating tin into the copper is from 600°F to 1200°F with a diffusion time of from 5 to 30 minutes.

Naturally steel would require considerably higher temperatures and similarly dipping into molten baths will require similarly higher temperatures (1000°F to 1400°F in the case of tin). The temperature ranges are generally determined by having to be high enough in order for the diffusion to be swift enough to be economically feasible but below the melting temperature of the intermetallic compounds and of the base-metal.

We claim:

1. An electrical connector having a crimp-termination means for receiving an electrical wire and forming a connection therewith upon crimping the same, comprising said means being formed of a conductive base-metal whose surface for engaging said wire is at least in substantial part an integral, continuous, thin, fragile, conductive, intermetallic compound layer less than about 300 micro inches thick, said layer being composed solely of metals.
2. A connector according to claim 1 wherein said intermetallic compound layer is at least partially formed of said base-metal.

3. A connector according to claim 2 wherein said base-metal is copper.

4. An electrical connector having a crimp-termination means for receiving an electrical wire and forming a connection therewith upon crimping thereto, comprising said means being formed of a base-metal chosen from the group consisting of copper, brass, bronze, or steel and with at least the substantial portion of the interconnection surface of said means for engaging said wire being a thin, continuous, integral layer of a brittle intermetallic compound between 30 and 300 micro inches thick and formed of the base-metal and of a cladding-metal selected from the group consisting of aluminum, tin, indium, and their equivalent alloys, said layer being composed solely of metals.

5. A connector according to claim 4 wherein said base-metal is copper and interconnection surface is an intermetallic compound formed of said copper and an aluminum-silicon alloy.

6. A connector according to claim 4 wherein said base-metal is copper and interconnection surface is an intermetallic compound formed of said copper and tin.

* * * *