MFR/PRVLBR NOTIFIED 11/24/95
No Comments made
Comments attached
Excisions/Revisions
Firm has not requested further notice

LOG OF MEETING

SUBJECT: Twist-On Wire Connectors for Aluminum Wire, Presentation by Dr. Jesse Aronstein and a General Discussion.

DATE: September 28, 1995 **PLACE:** Room 410 B/C East West Towers

DATE OF LOG ENTRY: October 6, 1995

SOURCE OF LOG ENTRY: William H. King, Jr., ESEE WHK

CPSC PARTICIPANTS:

William H. King, Jr., ESEE
Andrew Stadnik, ES
Linda Edwards, ESEE
Ed Krawiec, ESEE
Anna Luo, ESEE
Mai Ngo, ESEE
Ron Reichel, EXHR

NON-CPSC PARTICIPANTS:

Dr. Jesse Aronstein, Consulting Engineer
Mark Johnson, AMP, Inc.
Bob Baird, Independent Electrical Contractors Assoc.
Courtney Marshall, Alcan Cable
Meg Goss, B & H, law firm representing the Aluminum Assoc.
Dave Haataja, Underwriters Laboratories Inc.
Dan Friedman, American Society of Home Inspectors
Todd Leeuwenburgh, Product Safety Letter
David Shapiro, Geo. Washington Chapter, International Assoc. of Electrical Inspectors
Bruce Navarro, B C Navarro, Legal & Regulatory Affairs
Jerry Kopstein, Underwriters Laboratories Inc.
Lee Dosedlo, Underwriters Laboratories Inc.
Phil Sawyer, Ideal Industries, Inc.
Bill Blaha, Ideal Industries, Inc.

SUMMARY:

At the request of Dr. Jesse Aronstein, Consulting Engineer, a meeting between the CPSC staff and Dr. Aronstein took place for the purpose of discussing his views on the subject of twist-on wire connectors for aluminum wire. Following the meeting with Dr. Aronstein, a general discussion of this topic took place with others in attendance. See attached meeting agenda.

Dr. Aronstein reviewed the history of experience of twist-on wire splicing connectors with aluminum wire. He pointed out the widely disseminated information on pigtailing with twist-on wire

connectors provided in a statement prepared by a UL Ad Hoc Committee dated March, 1973. Dr. Aronstein also shared his view that the metal spring contained within twist-on connectors provides a significant path for electric current as the current passes from wire to wire.

Dr. Aronstein was critical of the Underwriters Laboratories (UL) Standard for Safety, UL 486C, Splicing Wire Connectors, with regard to the requirements for connecting aluminum wires. He presented a comparison of the provisions in the UL standard versus what he considered more real-world field conditions to support his position. He compared the higher test currents and test duty cycles specified in the standard to lower currents and lower duty cycles likely to be encountered in normal service. He cited the laboratory ambient conditions that would be used during testing per the standard compared to the 100% relative humidity conditions and the 80 degrees C change-in-temperature that often takes place in outlet boxes in residences.

Dr. Aronstein further compared the mechanical disturbance requirements of UL 486C, the aluminum conductor specified in the standard, the wire combinations tested, and the quantity of the connectors required to be tested. He compared the specifications in the standard to what he viewed as conditions, materials and values likely to be representative of actual service conditions.

Dr. Aronstein indicated that he would make available for the meeting minutes copies of materials that he presented at the meeting. A copy of his material is attached.

Dr. Aronstein provided his recommendation for a method to more satisfactorily connect aluminum wires with a twist-on connector. He advocated the use of a non-combustible inhibitor, but said that inhibitor alone was not the answer. He further advocated abrading the wire surfaces after the application of a small amount of inhibitor to the wire surfaces. He then recommends pre-twisting the wires together in a tight bundle with the aid of a heavy duty electrician's pliers, and trimming off the ends of the wires so that exposed aluminum will be contained within the insulated twist-on connector. He cited the need for a "live spring connector" that will maintain contact pressure on the conductors during use.

Dr. Aronstein reported that his initial testing of the new twist-on wire connector introduced earlier this year indicates that the connector does not maintain a low resistance, stable contact. Previous work performed by Dr. Aronstein and others on similar types of connectors have demonstrated that unless low resistance conductor-to-conductor contact is achieved and sustained, failures have occurred in a substantial number of aluminum-wired connections in less than a year of test time using currents at or below the circuit rating and with on-off duty cycles of less than 50%. This could lead to poor field experience in the future, and manifest into a fire hazard in the years of anticipated service life.

A representative of the manufacturer of the new twist-on wire connector, Mr. Phil Sawyer, Ideal Industries, Inc., provided comments following the remarks of Dr. Aronstein. Mr. Sawyer indicated that his company trusts and relies on the National Electrical Code and Underwriters Laboratories, Inc. for safety requirements applicable to their product. He said that his company introduced the "Twister" Al/Cu wire connector in February, 1995, believing that it "is completely safe when installed in accordance with directions."

Mr. Sawyer confirmed that, despite initial marketing materials that may have indicated otherwise, it is not the intention of Ideal Industries that the Ideal "Twister" be applied as a retrofit for completely modifying aluminum wiring systems in existing residences. In this regard, Mr. Sawyer indicated that his company's product is not in conflict with the recommendations of the CPSC which advocates rewiring aluminum wiring systems with copper wiring or the use of special compression connectors manufactured by AMP, Inc. The Ideal company represents their product as a method to connect to the pigtail leads of a ceiling paddle fan, a light fixture, or wiring device when the user is not prepared to completely modify the branch circuit aluminum wiring system as recommended by the CPSC.

Mr. Dan Friedman, representing the American Society of Home Inspectors (ASHI), commented that he viewed the Ideal "Twister" product as one of limited applications in homes. For any application, he stressed the need for product evaluation by the manufacturer that duplicates field conditions, including product disturbance and load current.

Mr. Bob Baird, representing the Independent Electrical Contractors Association (IEC), expressed a willingness to provide information to their membership in the form of training materials regarding the recommended methods of connecting branch circuit size aluminum conductors in existing residences.

In response to the requests of Underwriters Laboratories and Ideal Industries, Inc., copies of material from these companies that address CPSC staff concerns regarding twist-on connectors for use with aluminum wire are attached to this meeting log.

Mr. King, CPSC staff, concluded the meeting by indicating that the CPSC staff sincerely appreciates the visit by Dr. Aronstein and the input from particpants in the discussion. He further noted that the CPSC staff will continue to monitor developments and interact with the manufacturer and UL on this subject, and that the staff is not prepared at this time to make recommendations to the Commission regarding revising the aluminum wiring repair message for consumers. The CPSC staff is hopeful that on-going tests by the manufacturer and others will provide technical data which will enable CPSC to respond further. The

CPSC staff is considering a forum to develop recommendations for consideration by Underwriters Laboratories and any manufacturer that may produce a connector intended for use with branch circuit size aluminum conductors in residences.

MEETING AGENDA

TWIST-ON WIRE CONNECTORS FOR ALUMINUM WIRE

SEPTEMBER 28, 1995
CPSC HEADQUARTERS
ROOM 410
9:00 a.m.

MEETING WITH DR. JESSE ARONSTEIN

1. Experience Testing Twist-On Connectors
2. Fretting Corrosion
3. Connector Performance Stability
4. Environmental Conditions in Real World Situations (temperature, humidity, contaminants)
5. Characteristics of Aluminum Conductors Installed in Homes
6. Connector Materials

MEETING WITH ASSEMBLED GROUP FOR GENERAL DISCUSSION

1. Field Experiences
2. Test Data
3. Intended Applications for Twist-On Connectors
4. Long Term Performance Outlook
5. Other Considerations

U/L

May 22, 1995

1. **Wiring Used to Test the Connectors Differs From Wiring Installed in Many Homes -**

UL-486C does require testing with the old technology conductors in certain sizes. See paragraph 7.11. These were determined as the worst case conductors by a task force during the development of the UL-486 Standards.

UL can obtain old technology solid conductors in sizes 10 and 12 AWG if additional testing using these are agreed upon. These will be fresh samples and not removed from existing buildings. Testing with wire pulled from existing buildings is not feasible. It is difficult to obtain and it does not result in uniform and repeatable testing. Results of testing may vary from one building to the next. The abuses and stresses that these conductors have been subjected to also cannot be confirmed, thereby casting another variable into the results of any testing.

The manufacturer has performed the UL testing with the old technology aluminum conductors. They have tested with conductors representative of conductors in use during the 1960s and 1970s. They have made copies of the carton information available detailing material grade and age. (Ideal to furnish copies at meeting).

2. **UL Standard for Twist-on Wire Connectors Lack Environmental Testing-**

UL has addressed this point in past correspondence with the CPSC as well as others. UL believes that UL-486C does discriminate a good connection from a bad connection by subjecting the connector to a high current heat cycling test. This test has been proven to be a very good discriminator without having to additionally subject the connector to environmental testing.

UL has commented in the past that high humidity and high temperature conditioning are extreme. Past work attempting to evaluate connections under these conditions were criticized concerning the test methodology and repeatability.

The oxide inhibiting compound is used to remove the oxide and prevent its further formation by excluding oxygen and moisture from the connection interface. This oxide inhibiting compound seals the connection from the environment.

Additional testing would not appear to prove anything. However we could concede based on Item 1 and try to agree upon a program with the manufacturer's and CPSC's assistance.

3. **Connectors Likely to be Misapplied by Consumers-**

Other products which are also acceptable for connecting aluminum could be also equally misapplied. The CPSC states the tool for crimping the COPALUM connector is not available to consumers. Consequently, this system is not being widely used. Existing reports from the field show that the do-it-yourself consumers are not using the Copalum connection system as recommended in the CPSC literature. They misapply other products. The high cost and lack of availability of the existing recommended product results in their seeking alternatives. Some of these alternatives have been the misuse of copper only rated products. The likelihood of improper installation is very high when consumers are forced to make do with alternatives.

The Ideal Model 65 connector is a complete product. It is foolproof in the sense that the user cannot leave off the antioxidant compound since it is prefilled within the connector.

There is nothing unique or different in connecting aluminum wire for a twist on rated for aluminum as opposed to a twist-on rated for copper wire only. The instructions are clear and do not seem to be more inordinate or unique.

4. **Anti-Oxidant Compound Used in the Connector is Flammable-**

In order for the material to ignite, there must a source of ignition. There is no source of ignition (i.e. no arcing parts).

The MSDS sheet is for storage of the material from excessive heat or direct exposure to open flame. It is not meant to be a statement regarding use.

The alleged propensity to fail when using aluminum conductors has not been borne out. Acceptable completion of the tests contained in UL 486C have demonstrated temperatures are low (less than 50 C rise using higher than actual use currents). The basis of this statement must be from past field reports on old technology products or from past studies criticizing old technology products.

The antioxidant compound seals the connection from oxidation and resulting excessive heat due to poor connection. This particular antioxident is UL listed and is subjected to UL's Follow-Up Program.

5. **Connector Made of Flammable Thermoplastic Material-**

The connector body is molded from material rated 94V-2. Once again there is no internal source of ignition.

6. **Connector Violates Principle of Safe Wire-to-Wire Electrical Splices-**

There is a misstatement referring to the cap. It is the internal spring that connects the conductors, not the cap (plastic shell). The spring itself is NOT the current carrying path. All twist-ons including those rated for copper wire only do not require pre-twisting. When properly installed the conductors interweave with one another. This interweave results in conductor to conductor current flow. The steel spring is not the current path. If this were the case there would be many more failures of twist-on connectors even when using copper wire only.

7. **Aluminum Wires Installed in Homes Are Weak in Resisting Shear Fracture-**

The potential damage to conductors cited are not unique to twist-ons. Such damage can also occur to other types of connections including tool applied crimps. During the evaluation of all twist-on connectors, UL performs installation and mechanical type testing. Breakage or shearing of any stranding is not acceptable. There has been no field problems reported or experienced.

8. Field Failures Involve Twist-On Connectors With Aluminum Wire-

The cited reports of failures appear to be from pre-UL486C products (UL-486C became effective on January2, 1987). Special service connectors are not UL Listed. These are products reportedly used in Canada. In addition the continued new reports of failures must still be old technology products or from misapplied products. The fact that current products are not readily available or extremely expensive leaves one to conclude that users are finding and using alternatives. Is it possible to receive and review these reports?

UL has in the past responded in writing to all of the CPSC comments as well as all other interested parties. Our response weighs concerns from consumers, manufacturers, government agencies, and all interested parties. CPSC's staff dissatisfaction with some of UL's past responses may be due to their one-sided approach which may be slanted due to some past studies. These studies were manipulated to show a certain performance. These studies also could not be duplicated due to the test method used. We should not let these past studies deter the introduction of a new and viable product from the market.

To satisfy the CPSC concerns, UL is willing to participate in additional testing of this product. However any additional testing should be pertinent, reasonable, and reproducible. In addition we should subject a variety of current products to the same test program, including the recommended crimp connection. This will provide a good basis for comparison.

Reports on the number of Copalum products in use would be noteworthy. Does CPSC have any records on the use of Copalum and any failure reports.

9. Mechanical Integrity With No. 10 and 12 AWG Solid Aluminum Conductors-

The CPSC comment seems to be more related to technique by the installer. Other types of products as well as crimp tool applied and copper only twist-ons could also manipulated to come apart when positioned into boxes. We have not received any reports of such cases involving twist-ons. Can CPSC provide them for study?

10. Limited Technical Data to Support Twist-on Connector for Aluminum Wire-

UL has not conducted a chronic study on this product. UL normally does not conduct chronic studies. Chronic studies are performed when a long term problem has surfaced. It is unfair to compare the performance of the past products to this new product.

If chronic studies were performed on all new products, it would take years for new and innovative products to become available.

Have there been any chronic studies conducted on the long term performance of the alternative type products? Can CPSC provide?

May 22, 1995

UL is willing to assist CPSC in reevaluating and revising the position stated in the CPSC publication #516 "Repairing Aluminum Wiring". When new products become available, we must work cooperatively to enlighten users of all alternatives.

(Material Submitted by Ideal Industries, Inc.)

Responses to CPSC Staff Concerns

1. Wiring used to test the connectors differs from wiring installed in many homes.

The Twister AL/CU was developed and tested using a variety of different aluminum and copper conductor materials. All testing was conducted on unused (fresh sample) conductors.

Specific examples of aluminum conductors used include:

Coleman Cable and Wire	-12 AWG Solid. Carton stamped Jan 3, 1969. 10 AWG Solid. June 18,1968.
Senator	10 AWG Solid. March 14, 1972. 12 AWG Solid. June 21, 1974.
Senator	10 AWG Solid. August 5,1975.
Southwire	10 & 12 AWG Solid. July 20,1990. 10 AWG Stranded. August 10,1992. 12 AWG Stranded. October 28, 1993.

Our testing of the Twister AL/CU demonstrated no discernible differences in performance related to either the brand or age of aluminum conductors used.

2. UL Standard for Twist on Connectors Lacks Environmental Testing.

The Twister AL/CU is intended only for use in applications which conform to the National Electric Code. The Twister AL/CU is UL listed for dry locations only.

Our connector testing programs include such elements as temperature rise, long term high temperature aging, mechanical strength, long term over-current performance and insulation dielectric strength.

We have not done extensive testing for conditions where the connector is not permitted or intended. For example, we have not done salt spray, corrosive environment or high-humidity testing. Such tests could be performed, of course.

We believe the Twister AL/CU testing we have conducted is appropriate and comprehensive.

3. Connectors likely to be misapplied by Consumers.

It is widely recognized that connection failures can result from improper application.

Our experience with failed connections is that virtually all result from failure to follow instructions or from a gross misapplication of product.

We do not agree that the Twister AL/CU instructions are inordinate or unique. We believe all our connector application instructions are clear and complete. The Twister AL/CU instructions are consistent with other connector products and time proven to be fully satisfactory.

We continue to review instructions for clarity and conciseness to maximize ease of understanding and use by our customers.

4. Anti-Oxidant compound used in the connector is flammable.

Our antioxidant is rated for higher temperature use than most wire conductor insulations.

The antioxidant is not intended for direct exposure to open flame. It will ignite when exposed to an open flame.

The polybutene suspension media used in our antioxidant has a flash point of 310 F, a fire point in excess of 330 F and may spontaneously autoignite at temperatures in excess of 500 F. It will decompose at temperatures above 518 F.

Noalox has been widely used as a safe and effective oxide inhibitor for 27 years.

5. Connector made of flammable Thermoplastic material.

The connector shell material is made from a proprietary flame retardant polypropylene which is UL yellow card listed and flame rated at 94V-2.

The material is thermoplastic and will melt when heated. Our testing confirms that the material will not support a flame. The material is self extinguishing.

This same electrical grade of polypropylene is used in many of our connectors.

Polypropylene has proven a safe and reliable material for over 20 years.

6. Connector violates principle of safe wire to wire electrical splice.

Pretwisting of conductors is not required because proper application of the connector provides a controlled twist. The tapered threads of twist on connectors apply high pressure to draw the conductors in while twisting them and forcing them together. This process assures a high pressure joint of low electrical resistance.

The purpose of the connector spring is to provide a controlled mechanical threadlike grip and is not intended to provide additional current paths. Our laboratory tests repeatedly confirm that springs conduct negligible electric current. As further evidence, IDEAL has sold billions of All Plastic connectors which contain no metallic spring inserts and provide very low resistance, highly satisfactory connections.

Twist on connectors provide superior connections than do steel and copper crimp connectors such as those offered for sale by IDEAL and other manufacturers.

7. Aluminum wires installed in homes are weak in resisting shear fracture.

Aluminum conductors are more susceptible to shear fracture than are copper conductors.

Because of aluminum strength limitations, IDEAL instructs users to "Cut and restrip wires 1/2 of an inch." when installing the Twister AL/CU connector.

Properly applied twist on connectors should show 1 and 1/2 twists to 2 twists of the wires outside the connector to assure a reliable connection.

The combination of the tapered Twister AL/CU entry and the lubricity of the antioxidant provide strain relief and a means of smooth, controlled application.

8. Field failures involve twist on connectors with aluminum wire.

We are well aware of the problems experienced with aluminum wire during the 1970's.

We did participate and fully support the more stringent requirements for aluminum wire connections (UL 486C) developed in the early 1980's.

IDEAL INDUSTRIES has not received any customer complaints regarding aluminum wire connections. We have not received any notice of failures or problems with IDEAL twist on connectors related to aluminum wire.

We would appreciate any specific or verifiable field failures or complaints related to IDEAL INDUSTRIES products.

9. Mechanical integrity with No 10 and No. 12 AWG solid wire conductors.

It appears that improper technique is the main reason for the concern. However, we may not fully understand the exact nature of this concern as it is described.

We would appreciate a more detailed explanation if related to IDEAL INDUSTRIES products.

10. Limited technical data to support twist on connector for aluminum wire.

We have been producing connectors for 60 years.

Many of our products, particularly lugs, are designed and listed for use with aluminum- to-aluminum and aluminum-to-copper connections. These materials can be connected in a very safe and reliable manner.

Millions of IDEAL twist on connectors were applied to aluminum wire before the effect of UL Standard 486C in 1987. We doubt that all these connectors were replaced and, in the absence of any specific complaints or notice, we conclude that these standard connectors are performing in a fully satisfactory manner.

Unfortunately, we also believe that many of our standard connectors and those of other manufacturers are still being improperly used on aluminum wires directly in conflict with UL Standard 486C.

The Twister AL/CU connector was developed and extensively tested to address this unfortunate situation, to offer a technical solution to needs to retrofit copper wire to 10 and 12 AWG aluminum wiring and to do so to tests defined by UL 486C.

Marketplace response has quickly confirmed the need for the Twister AL/CU and has been very gratifying.

IDEAL INDUSTRIES,INC. believes the Twister AL/CU is completely safe when applied in accordance with all applicable codes and our written instructions.

We will be happy to conduct additional testing or to participate in any scientifically controlled testing to address any long term safety concerns expressed by CPSC.

J. ARONSTEIN

CONSULTING ENGINEER

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William H. King, Jr., Manager
Div. of Electrical Engineering
U.S. Consumer Product Safety Commission
4330 East West Highway Rm. 611 North
Bethesda, MD 20814

October 10, 1995

Subject: Meeting 9/28/95, Twist-on splices, aluminum to copper wire.

Dear Mr. King:

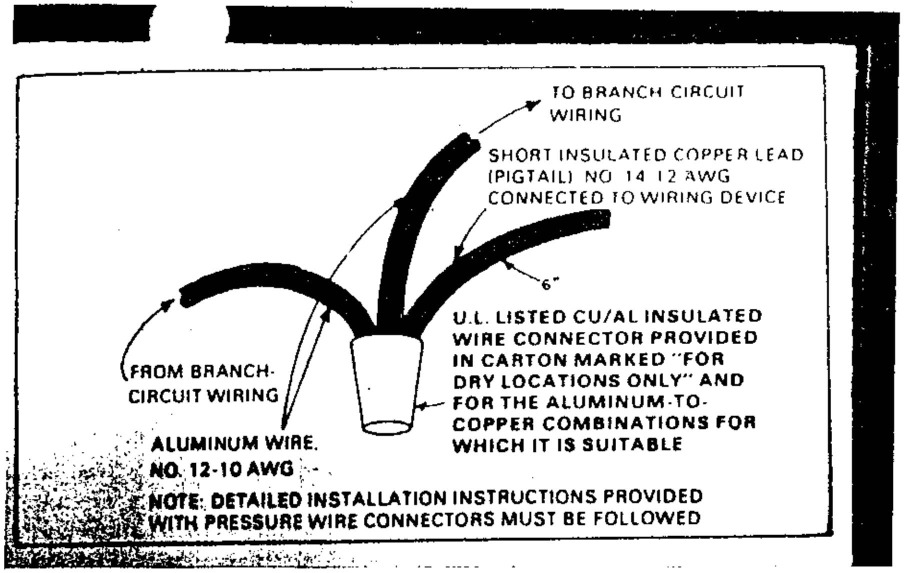
Enclosed per your request is a color copy of the slides used in my presentation at the subject meeting . Descriptive captions have been added to convey the significance that the slides had in the context of the meeting. An index by subject is as follows:

Please contact me if there are any questions.

Yours truly,

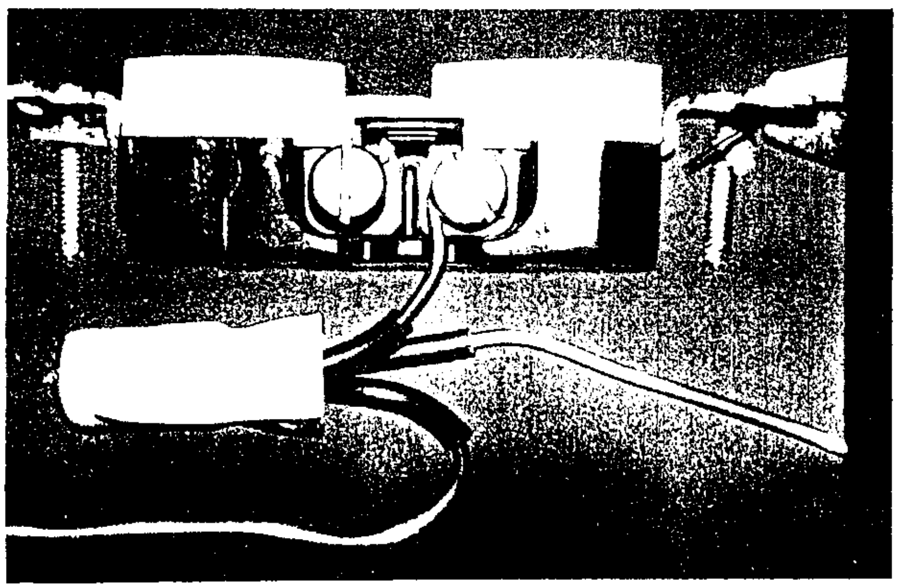
Jesse Aronstein

Jesse Aronstein, Ph.D., P.E.

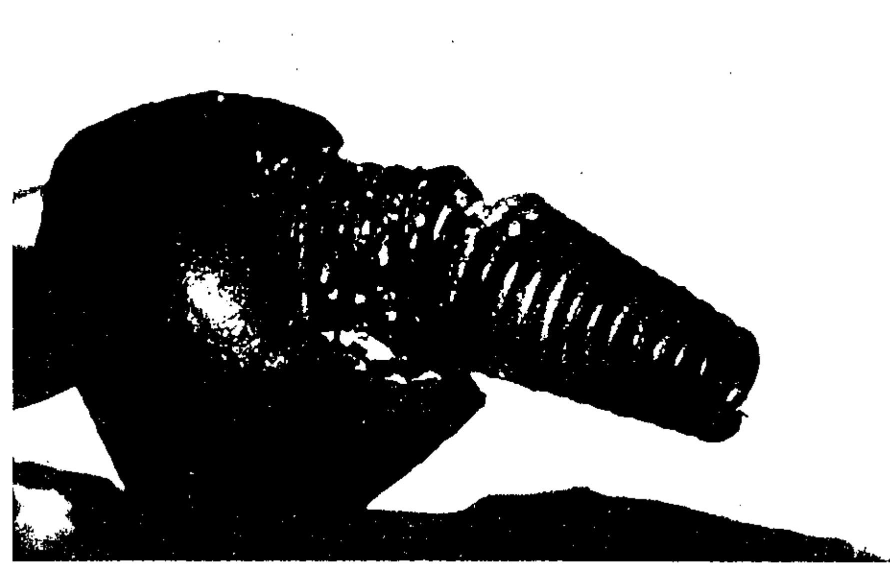


1. COMMONLY USED INSTRUCTION FOR PIGTAILING using twist-on connector. This instruction has been widely published and distributed by UL, by trade journals and instruction books, and in the National Elecrical Code Handbook. Since about 1985, until now, no twist-on connectors were listed by UL for this purpose.

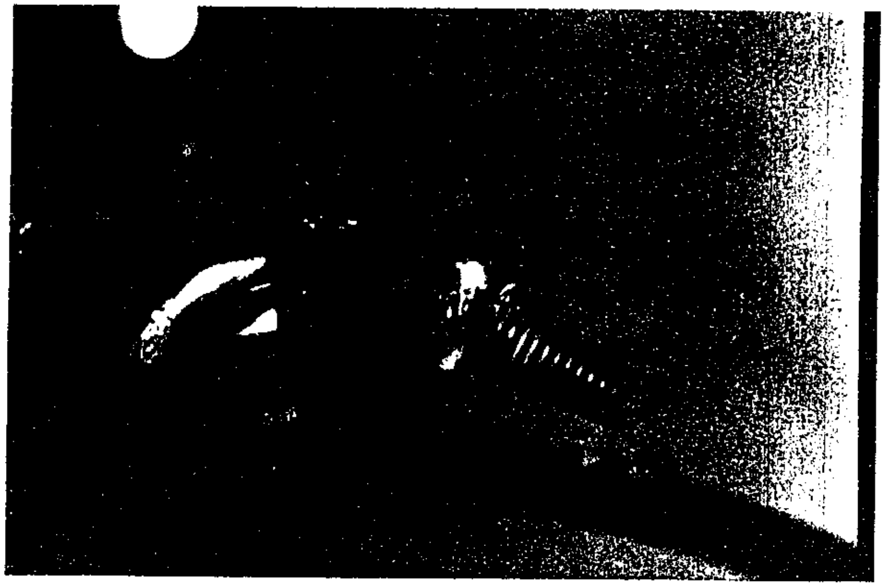
2. PRIOR TO 1985 most twist-on connectors on the market were listed by UL as suitable for the purpose. The actual performance in this application varied widely, however, depending on construction and installation method.



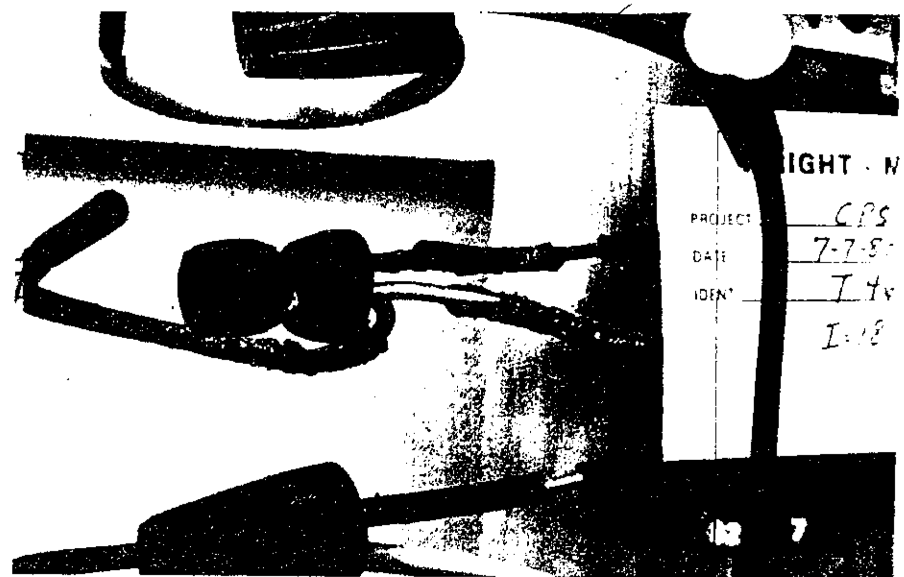
3. THE PIGTAILING APPLICATION works this way. A short copper wire is spliced to the aluminum circuit wire. The copper wire is connected to the device terminal. The pigtail splices carry full circuit current to downstream loads. With the best connector and method of installation, this could be a safe technique.



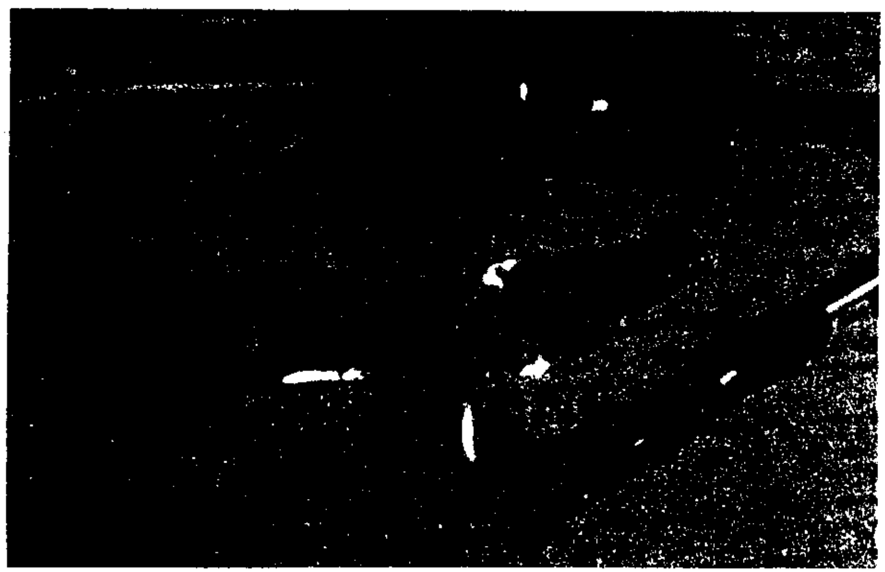
4. BURNOUTS LIKE THIS OCCURRED WHEN VARIOUS UL-LISTED TWIST-ON CONNECTORS WERE TESTED for the pigtailing application, installed as per the manufacturers' instructions. Poor test results for twist-on splices with aluminum wire were reported by UL, Battelle, CPSC, and various wire and device manufacturers.



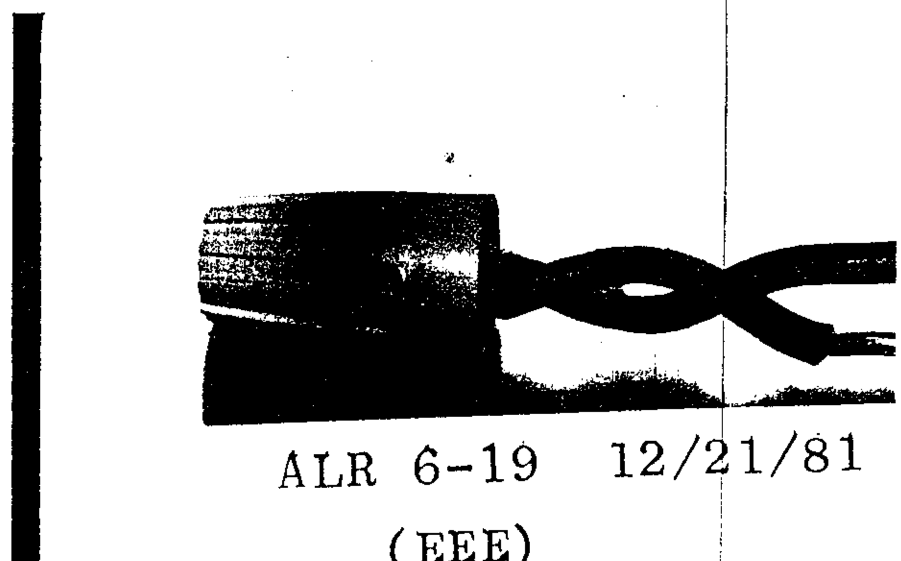
5. THE FIRE HAZARD POSED BY THESE SPLICES WHEN THEY FAIL IS EASILY SEEN WHEN THE "BURNOUTS" ARE OBSERVED WHILE PASSING CURRENT. At about 17 Amps, less than the 20 Amp rating of the (#10 aluminum wire) circuit, the connector spring is red hot. The votage drop is about 2 volts, so downstream loads operate normally.



6. ADDITIONAL RED-HOT TWIST-ON CONNECTOR SPLICES FROM THE CPSC TESTS are shown here. The key point is that a significant percentage of the CPSC test splices, over a period of several years, failed in this hazardous manner, the spring becoming red hot. The connector shells ignited (smoldering combustion).



7. THESE TESTS WERE ALL CONDUCTED WITHIN RATED SERVICE CONDITIONS. Applied current never exceeded 90% of circuit rating (based on aluminum wire size used). The twist-on connectors used were UL listed for the application, and were installed per the manufacturers' instructions.

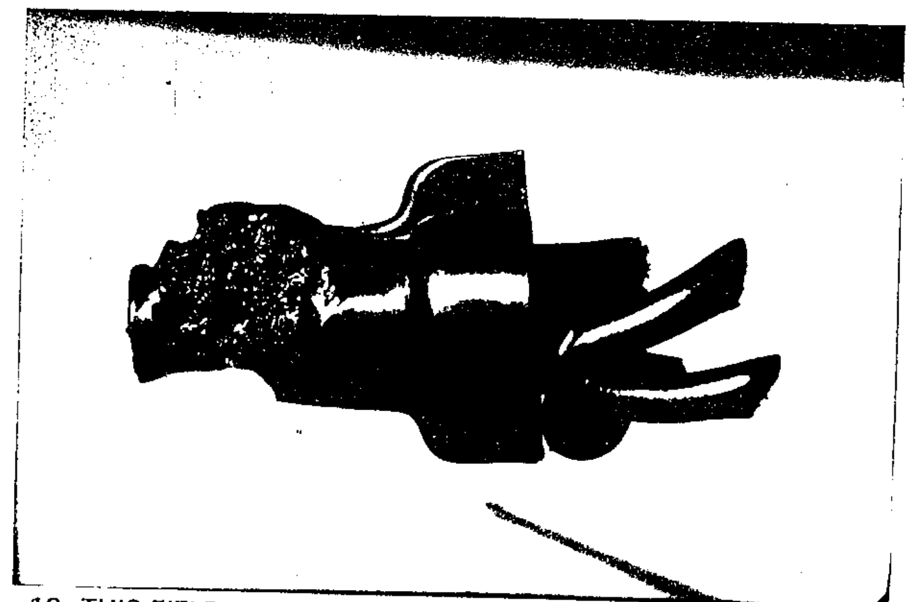


8. SIMPLER SPLICES ALSO FAILED. Here is a basic splice with two aluminum wires. Overheating is evident in the discoloration band around the shell. This is a characteristic heating pattern for failing aluminum wire twist-on splices. With time, further degradation occurs, and fire hazard develops with current loading.

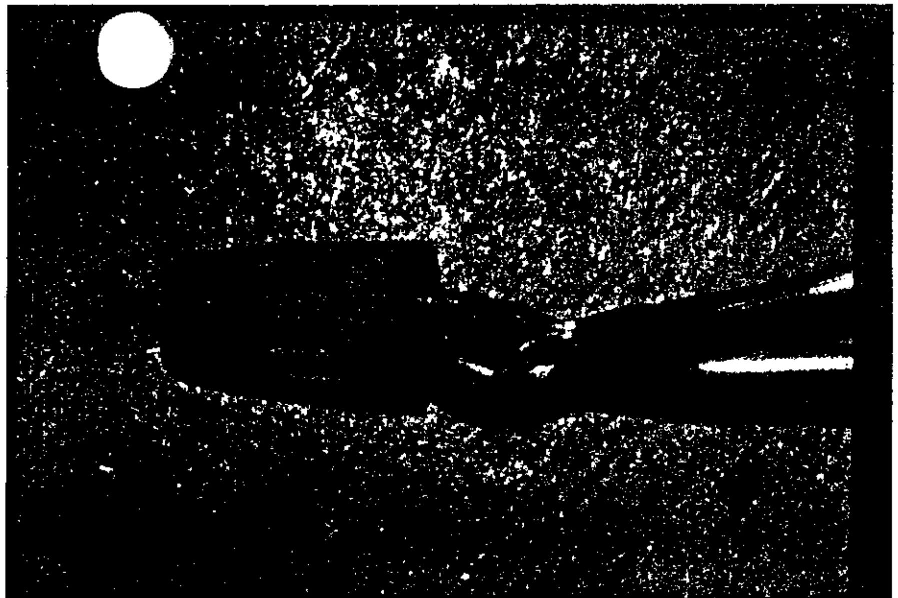
9. THE CHARACTERISTIC BURN PATTERN IS AN IMPORTANT CLUE toward understanding the failure mechanism of the aluminum-wired twist-on connector splices.

10. FIELD FAILURES ARE ALSO SEEN. These were from an aluminum-wired senior housing complex in the DC area. A large number of these twist-on connector splices were found with various degree of heat damage in an on-site inspection in which CPSC participated. (photo courtesy of Tom Donahue)

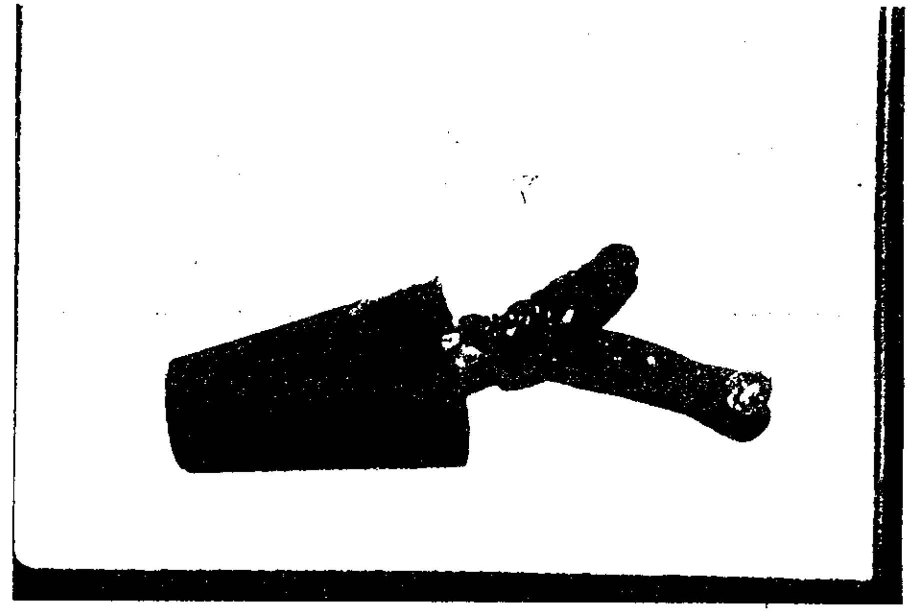
11. THE EARLIEST VISIBLE SIGN OF OVERHEATING is often softening and melting of the wire insulation, as in this field failure.



12. THIS FIELD FAILURE SHORTED TO GROUND when the thermoplastic insulating shell softened due to overheating in the connector spring area. Short circuits, due to insulation deterioration on the connector or wire, add to the fire hazard posed by the failure of aluminum-wired twist-on connections.



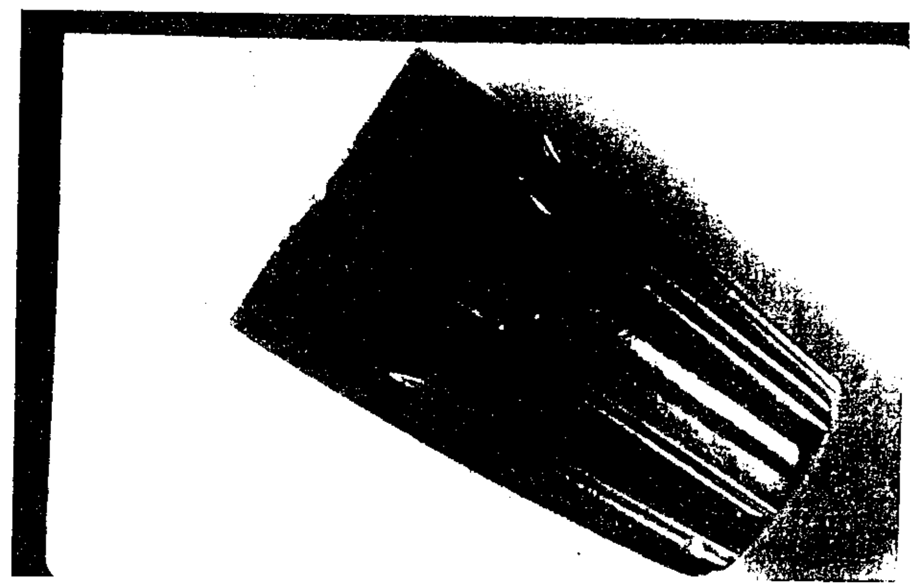
13. THIS FIELD FAILURE IS FROM CANADA, where they had a substantial number of aluminum-to-copper twist-on splice failures in electric baseboard heater installations.



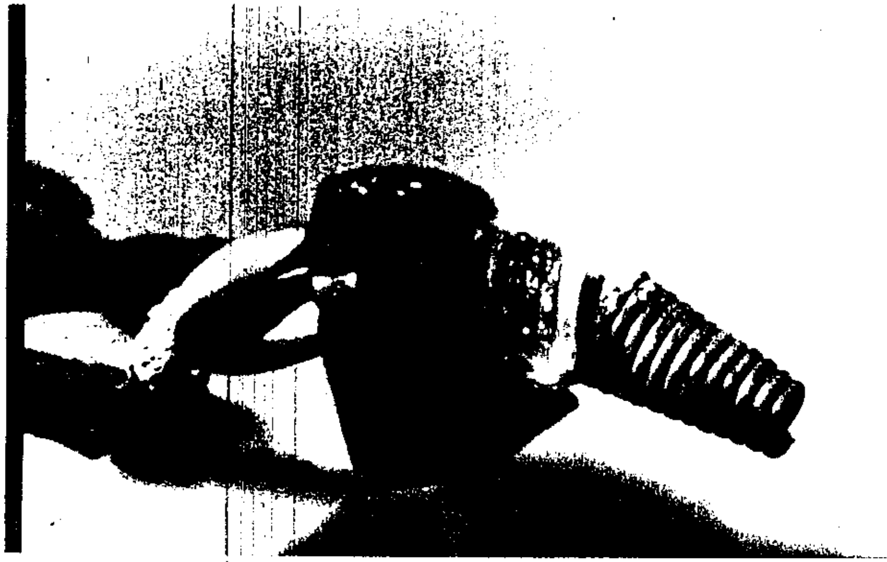
14. THIS FIELD FAILURE WAS IN SERVICE 9 YEARS. Failure of the aluminum-wired twist-on splices occurs in a relatively short time for a component of the permanent built-in wiring system of a home.

15. NOTE THE BURN-BACK OF THE WIRE INSULATION and the characteristic discoloration pattern on the connector shell of this field failure.

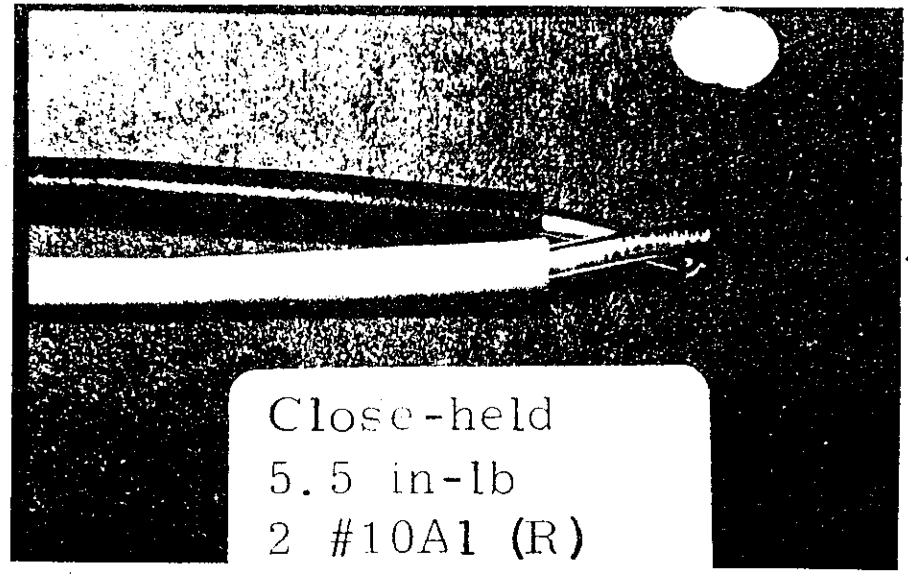
(photo courtesy of Eleanor Posey)



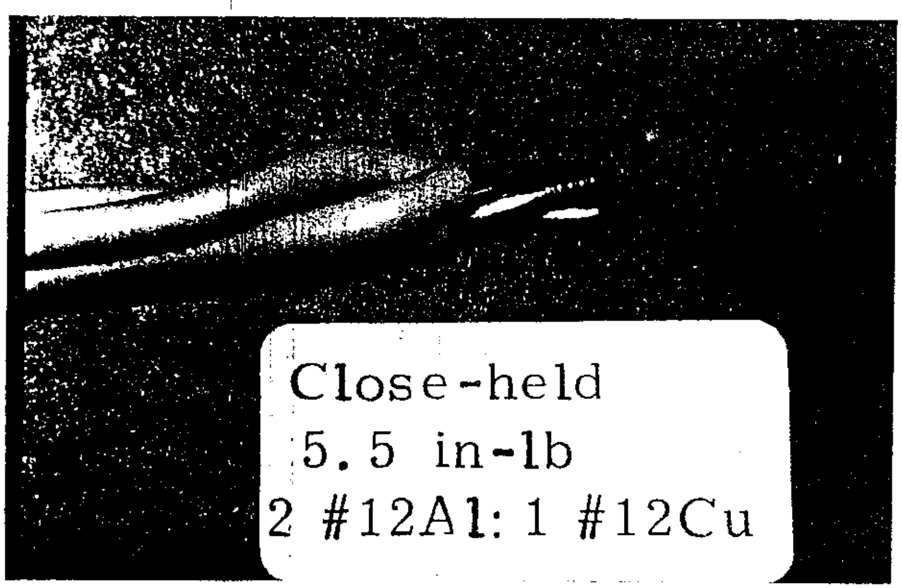
16. THIS LAST FIELD FAILURE AGAIN SHOWS THE TYPICAL OVERHEATING BAND. A number of field failures have been shown to emphasize that they are not rare. Both UL and CPSC investigated field performance and uncovered a substantial number of failures, with the worst-case failures resulting in structural fire and fatalities.



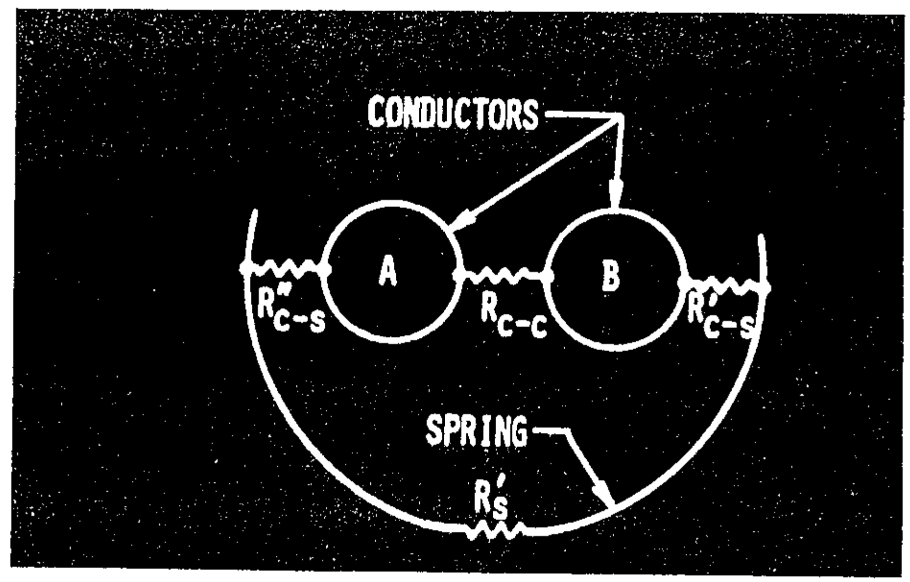
17. THE CHARACTERISTIC HEATING IN A BAND around the connector shows us where the heat is being generated. In all of those failures shown, from both lab and homes, the heat is generated by current flowing in the connector spring. Here, all of the current is passing from wire-to-wire through sections of steel spring.



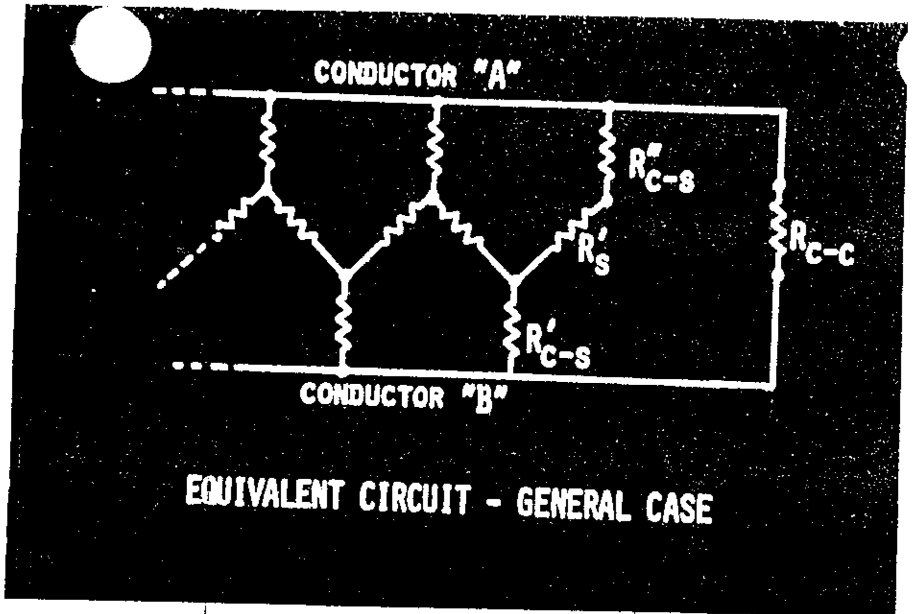
18. CURRENT FLOW IN THE STEEL SPRING occurs due to a fundamental deficiency of this type of connection when made with aluminum wire. There is inadequate metallic contact directly established from wire-to-wire. The insulating oxide on the aluminum is not sufficiently broken up. (Photo: connector removed after splicing.)



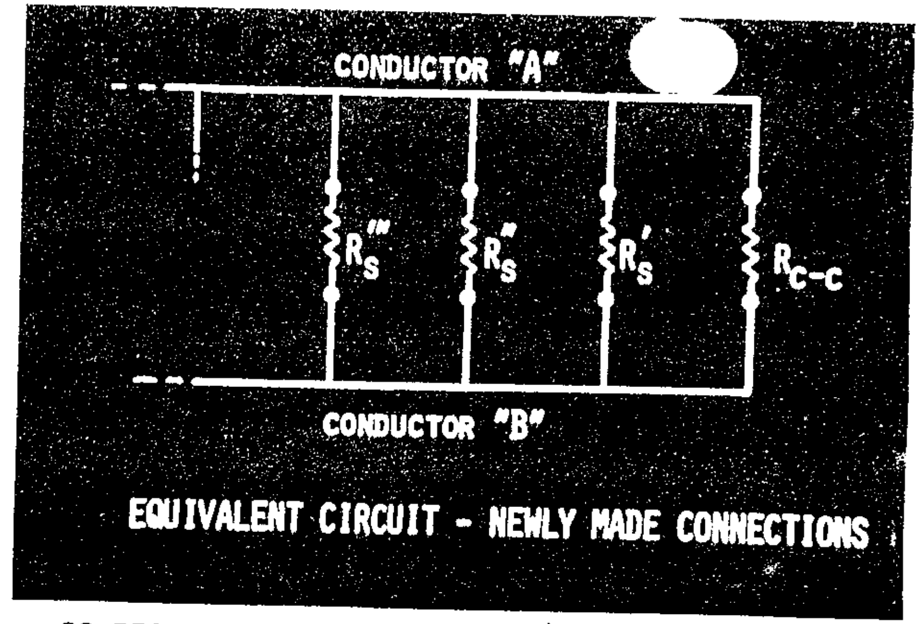
19. THE AMOUNT OF TWISTING TOGETHER OF THE WIRES VARIES SUBSTANTIALLY WITH THE HARDNESS, SIZE(S), AND NUMBER OF WIRES INSTALLED. Inadequate mechanical disturbance results in poor electrical contact at the wire-to-wire interface. THIS IS A FUNDAMENTAL DEFICIENCY OF TWIST-ON CONNECTIONS WITH ALUMINUM WIRE



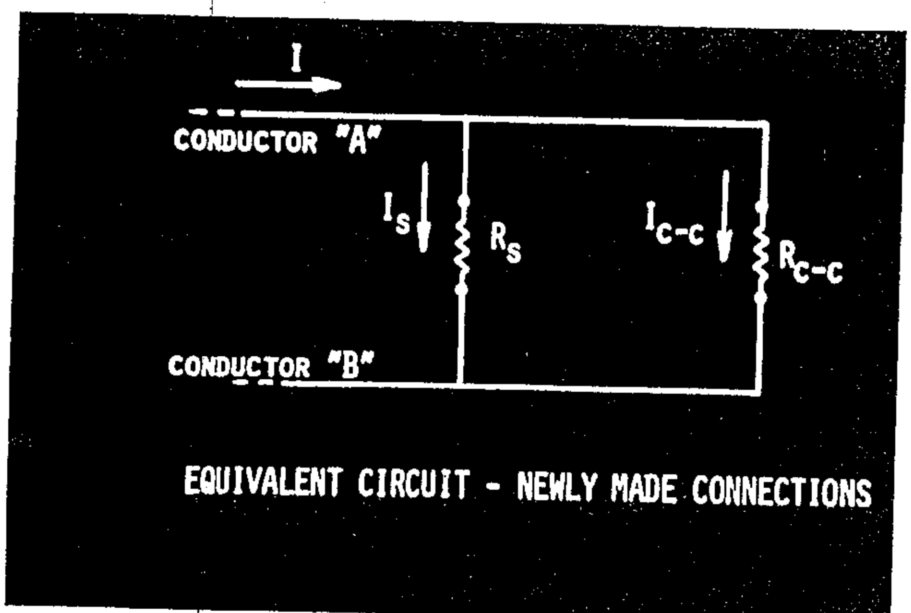
20. HERE ARE THE CURRENT PATHS IN THIS TYPE OF CONNECTION. Each of the paths from wire to wire has some associated resistance. The direct wire to wire path has only contact resistance, while paths through the spring sections have contact resistance as well as bulk resistance of the steel spring wire.



21. HERE IS THE MOST GENERAL EQUIVALENT CIRCUIT FOR THE TWIST-ON CONNECTOR



22. BECAUSE THE SPRING SCRAPES AND DIGS INTO THE WIRES, the spring-to-wire contact resistance in the newly-made connections is extremely low. The equivalent circuit is then simplified to this form.



23. Combining the bulk resistances of the sections of the spring that are in parallel in the current path further simplifies the equivalent circuit for newly-made connections.

$$\frac{I_S}{I} = \frac{R}{R_S}$$

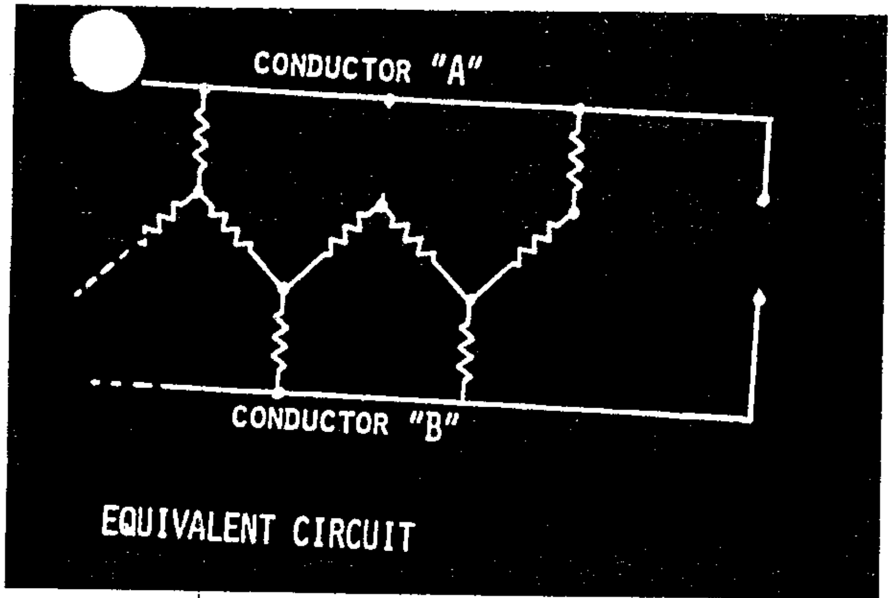
= 0.60 (ALUMINUM, GROUP D)

= 0.69 (ALUMINUM, GROUP F)

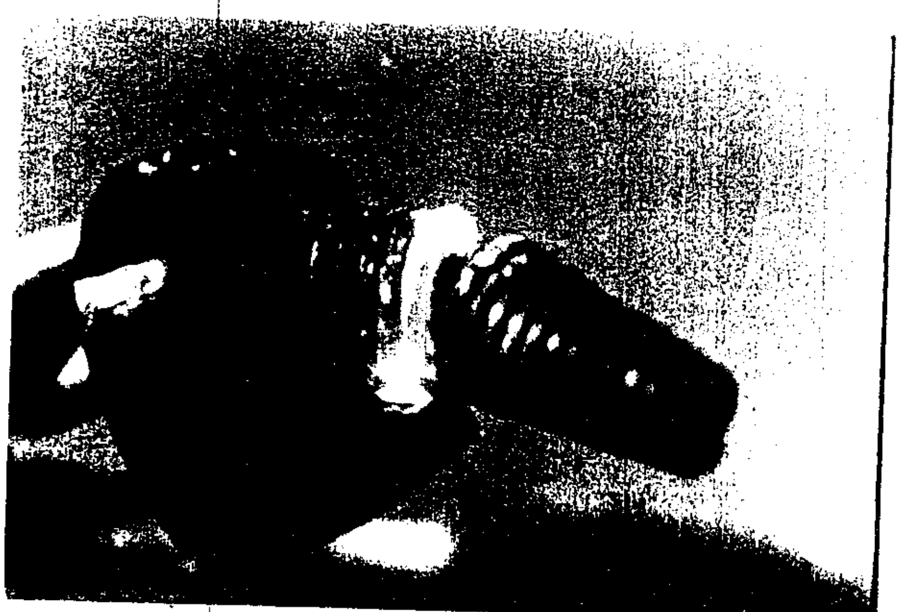
= 0.06 (COPPER, GROUP E)

CURRENT FLOW IN NEWLY MADE CONNECTIONS

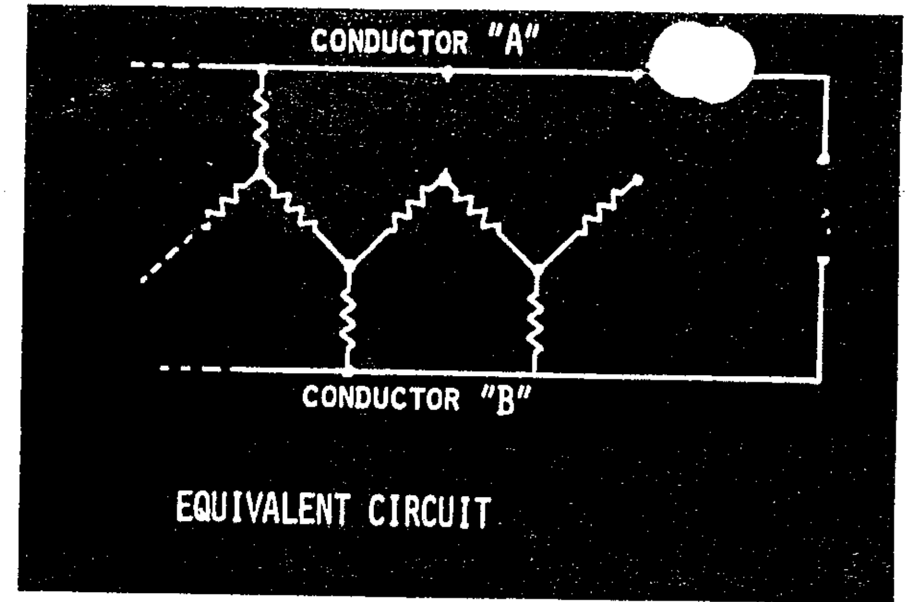
24. MEASUREMENTS ON NEWLY MADE ALUMINUM-WRED TWIST-ON SPLICES SHOW THAT MOST OF THE CURRENT FLOWS THROUGH SECTIONS OF THE STEEL SPRING. More than 60% typically for an aluminum connection but less than 10% in an all-copper connection. There is a basic difference in behavior with aluminum wire.



25. AS THE ALUMINUM-WIRED TWIST-ON SPLICES AGE, the wire-to-wire contact increases in resistance and may finally open altogether. The many wire-to-spring contacts also deteriorate (increase resistance) and some may also open completely, as shown in this equivalent circuit.



27. THAT IS EXACTLY WHAT HAS HAPPENED HERE. All of the current is passing from wire-to-wire through only a few segments of the spring, and those parts of the spring become red hot.



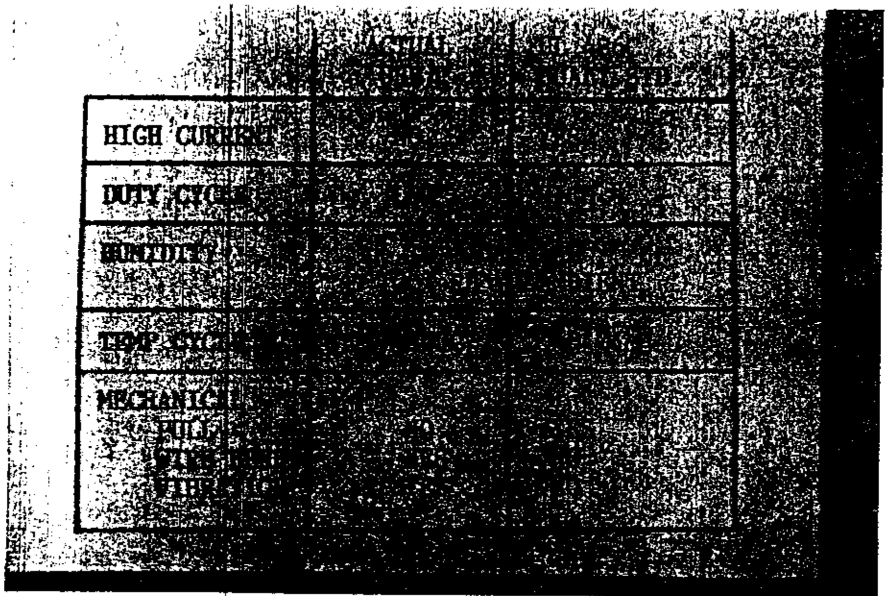
26. THE DETERIORATION PROCESS is observed experimentally as a slow but progressive increase in connection resistance, as the various current paths within the splice degrade. There are less parallel paths active through the spring, and the result can be a red-hot spring when current flows.

THE CPSC RECOMMENDATION AGAINST THE USE OF TWIST-ON CONNECTORS FOR ALUMINUM WIRE is soundly based. There is no reason to believe that the connector, recently UL listed for aluminum-copper combinations, overcomes the fundamental deficiencies of this type of connection for applications with aluminum wire.

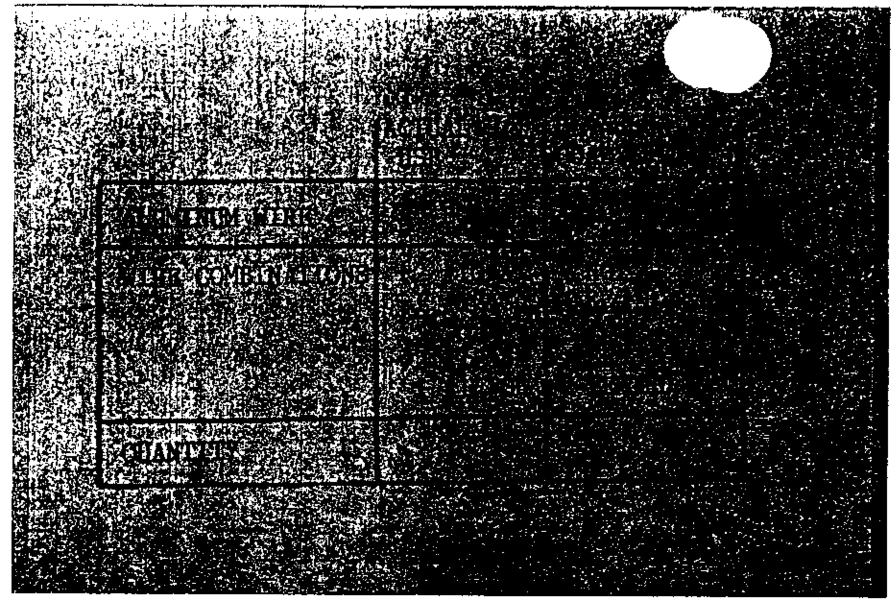
THE CONNECTOR HAS A ZINC PLATED STEEL SPRING, A COMBINATION KNOWN TO BE BAD IN CONTACT WITH ALUMINUM. CONTAINING A FREE-BURNING OXIDE INHIBITOR GREASE, AND HAVING A FREE-BURNING THERMO-PLASTIC SHELL, THE CONNECTOR CAN IGNITE READILY IF FAILURES OF THE TYPES SHOWN HERE OCCUR.

THE ONLY JUSTIFICATION GIVEN FOR MARKETING THIS CONNECTOR AS SUITABLE FOR ALUMINUM WIRING IS THAT IT HAS PASSED THE TEST REQUIREMENTS OF UL486C.

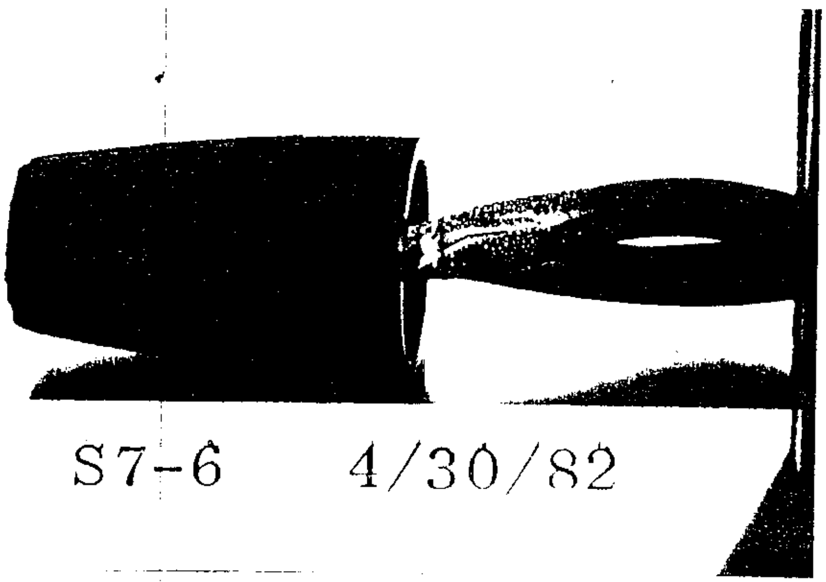
THAT THE TESTS OF UL486C ARE INSUFFICIENT CAN BE UNDERSTOOD BY CONSIDERING THE FOLLOWING TABLE.



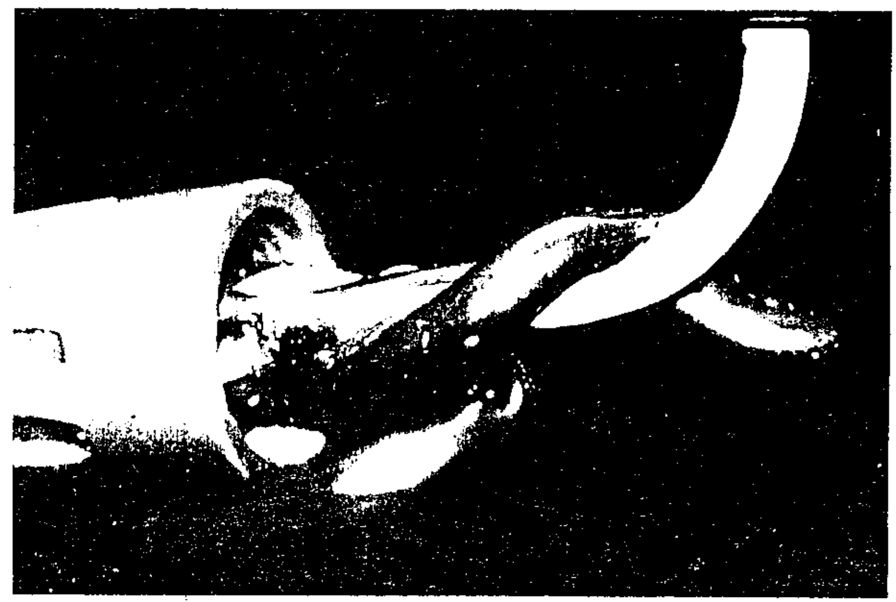
28. THIS TABLE COMPARES FACTORS OF ACTUAL USE WITH THE UL486C TEST CONDITIONS. It is evident that the UL listing is based principally on a high current cycling test, which does not really stress the connection in the ways that it is stressed in an actual residential application.



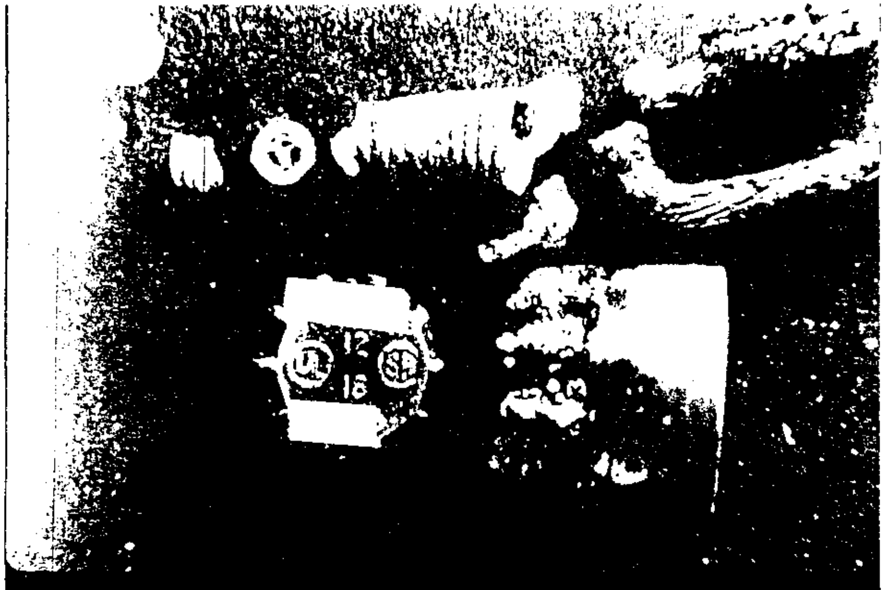
29. ADDITIONALLY, THE UL486C STANDARD DOES NOT USE THE OLDER WIRE FOR ITS TESTS, does not require testing of the combinations most likely to be used, and tests a statistically inadequate sample size.



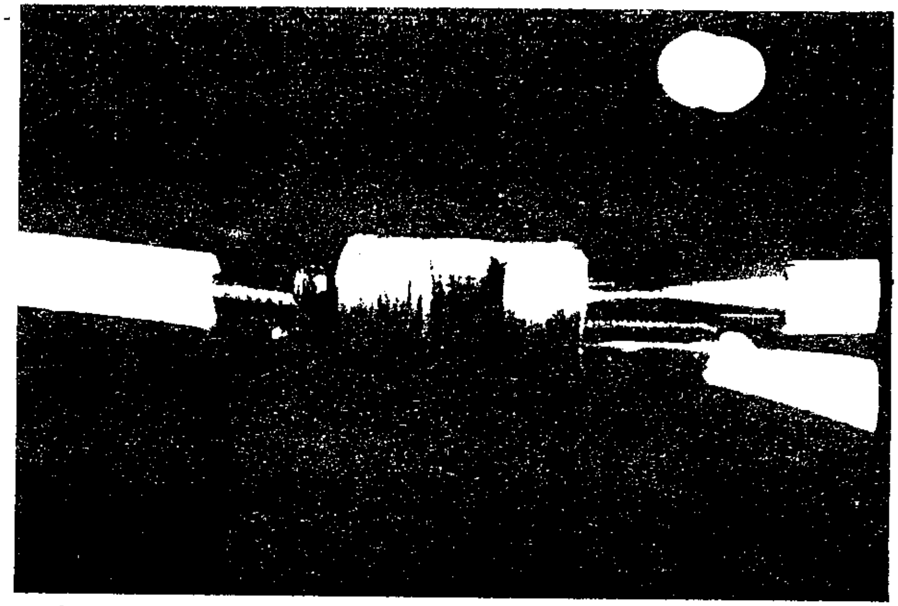
30. THAT TESTING OF THE TYPE APPLIED BY UL486C IS INADEQUATE HAS PREVIOUSLY BEEN DEMONSTRATED by the canadian "Special Service" twist-on connector. These were qualified by tests essentially the same as UL486C, but performed poorly in lon-term tests within rated conditions. This one is starting to overheat.



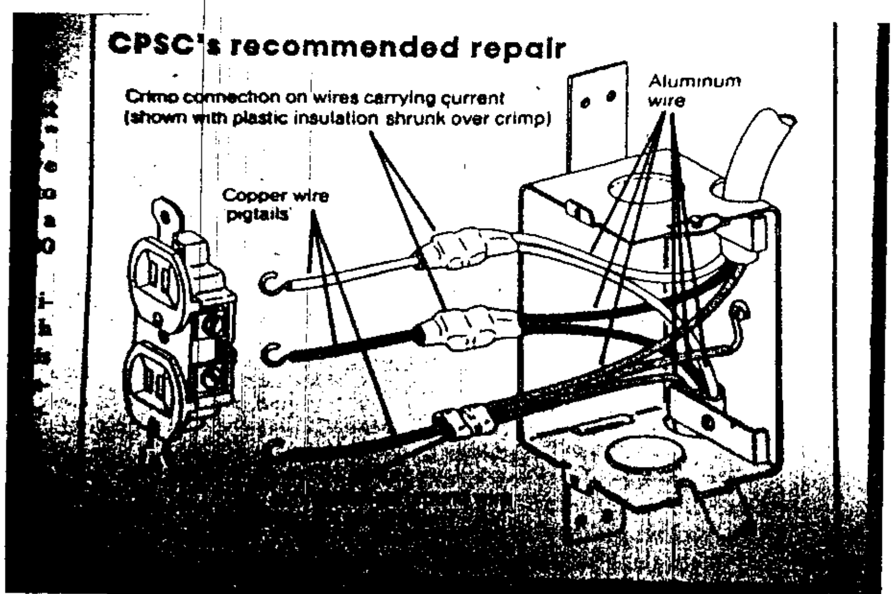
31. THIS SPECIAL SERVICE CONNECTOR SPLICE HAS OVERHEATED TO THE POINT OF SOFTENING THE WIRE INSULATION.



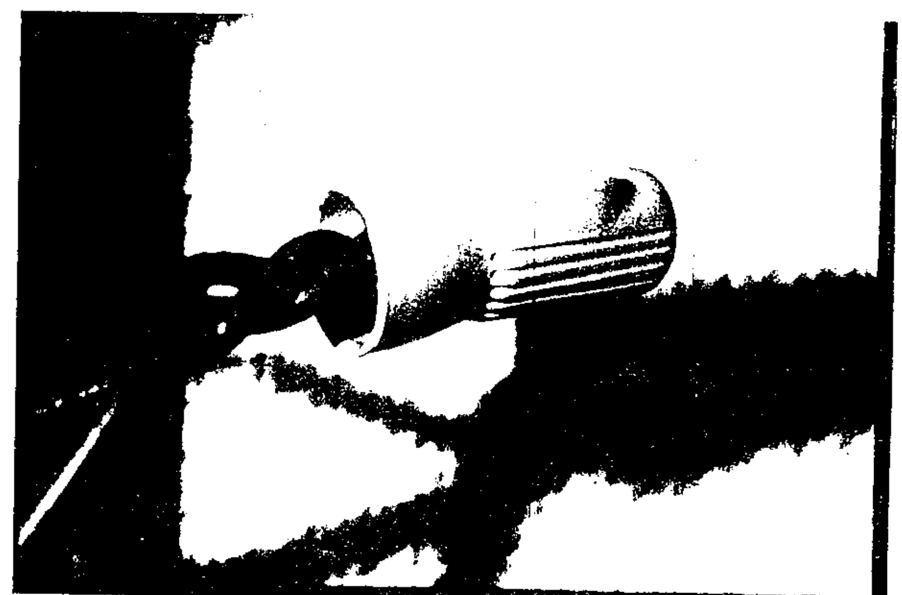
32. THIS SPECIAL SERVICE TWIST-ON SPLICE, BETWEEN ALUMINUM WIRE AND STRANDED COPPER WIRE, BURNED UP.



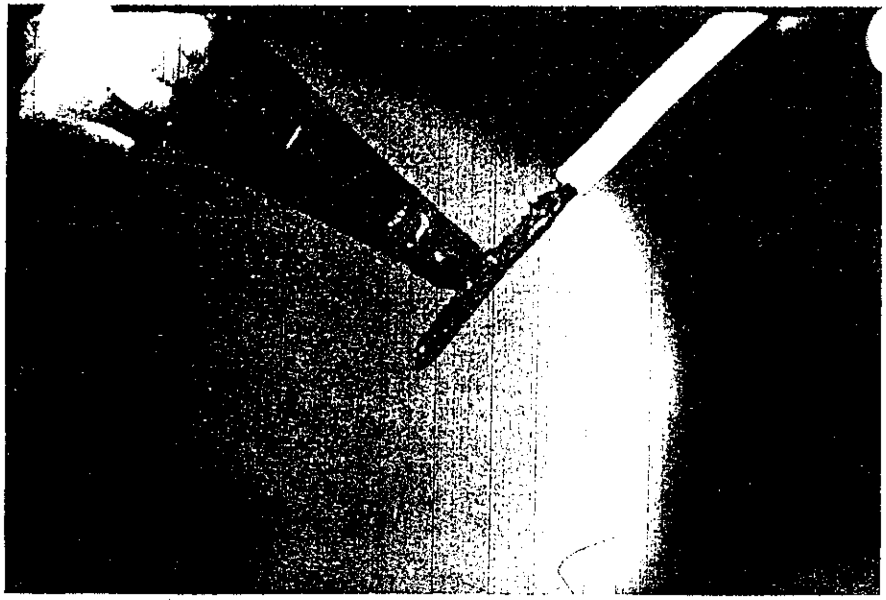
33. THIS CONNECTOR, THE AMP COPALUM, IS THE ONE RECOMMENDED BY CPSC FOR THE PIGTAILING APPLICATION. The connector is applied using special tooling and is only available with installation by specially-trained electricians.



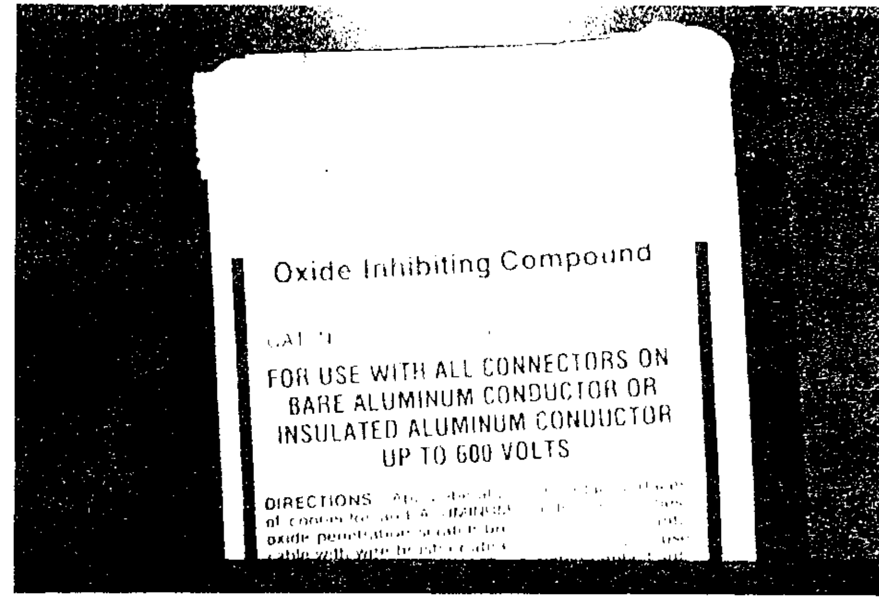
34. HERE IS AN ILLUSTRATION OF THE PIGTAILING METHOD USING THE COPALUM CONNECTOR.



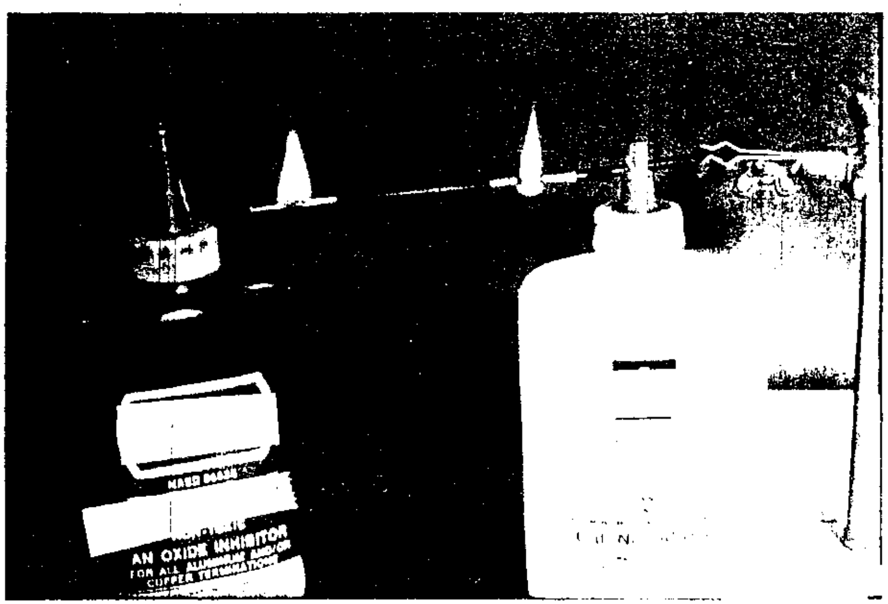
35. UNFORTUNATELY, HOWEVER, THE COPALUM REPAIR IS NOT READILY AVAILABLE IN SOME AREAS OF THE COUNTRY, and is impractical if there is only need to connect a single fixture or appliance. Some twist-on connectors may work well as an alternative, providing that they are installed in a special manner.



36. THE SPECIAL INSTALLATION METHOD DESCRIBED HERE IS BASED ON INDUSTRY .) RECOMMENDED PRACTICE CONSIDERED TO BE NECESSARY FOR PROPER CONNECTION TO ALUMINUM. The wires are stripped overlength, and a coating of oxide inhibitor is applied.

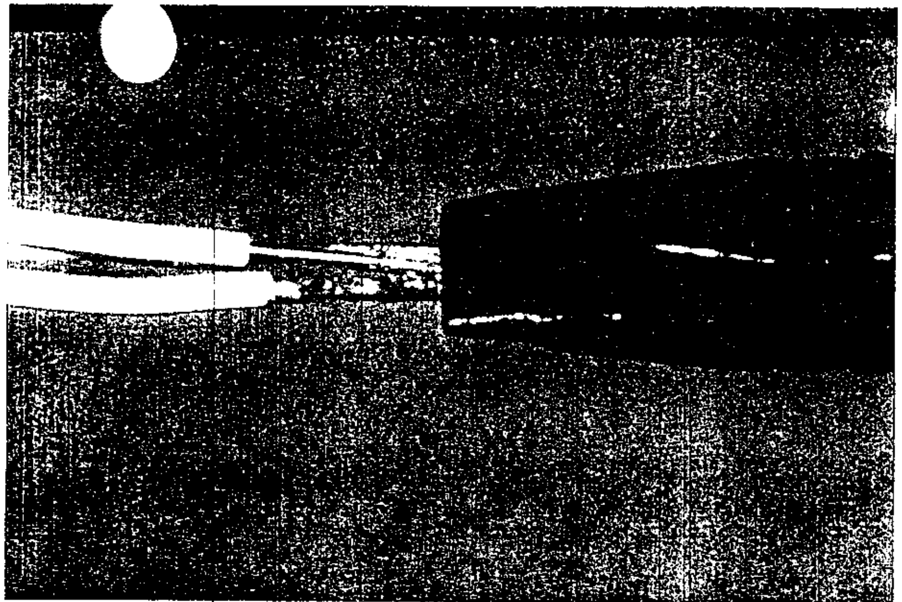


37. THE INHIBITOR USED SHOULD BE ONE THAT DOES NOT IGNITE AND FLAME READILY. Such compounds are commercially available. , shown here, is one of them.

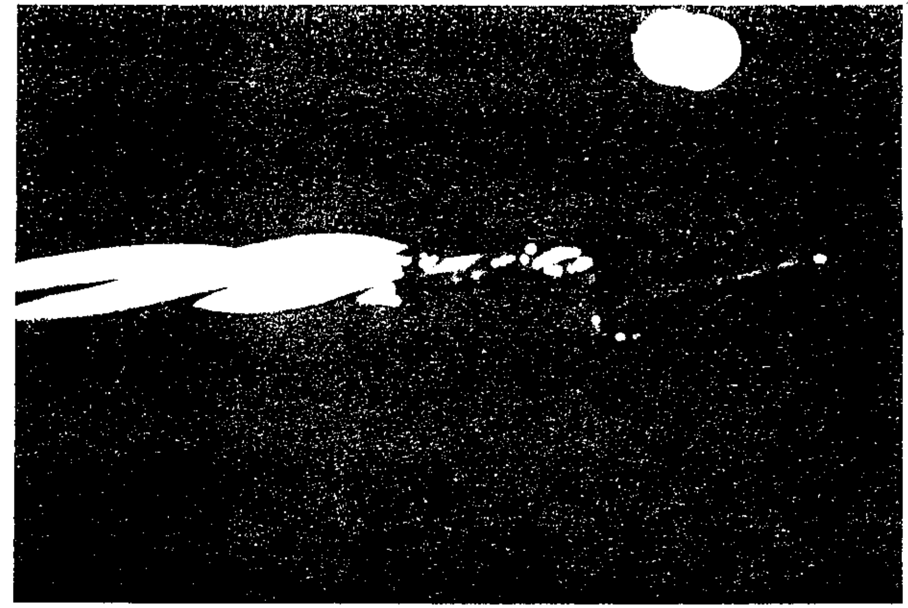


38. OTHER BRANDS. INCLUDING THE ONE MADE BY AND USED IN THEIR CONNECTOR, IGNITE READILY AND BURN VIGOROUSLY.

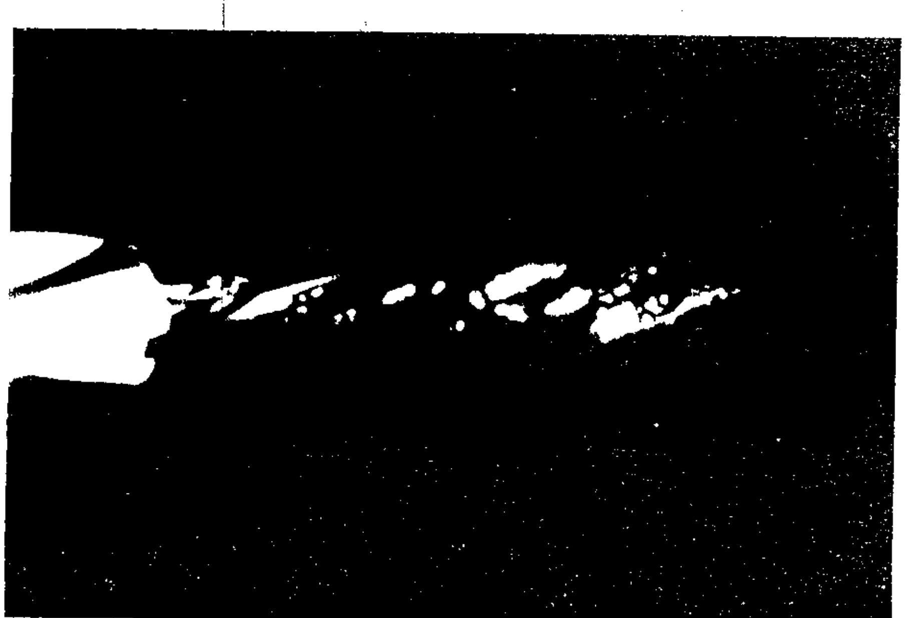
39. THE ALUMINUM WIRE IS ABRADED UNDER THE COATING OF OXIDE INHIBITOR, using, for instance, #220 grit automotive wet-dry finishing sandpaper. This is an important step. Abrasion disrupts and removes much of the insulating oxide, and the inhibitor film prevents fresh oxide formation on the bare aluminum.



40. THE WIRES TO BE SPLICED ARE HELD TOGETHER AND GRIPPED IN THE JAWS OF A PAIR OF PLIERS.

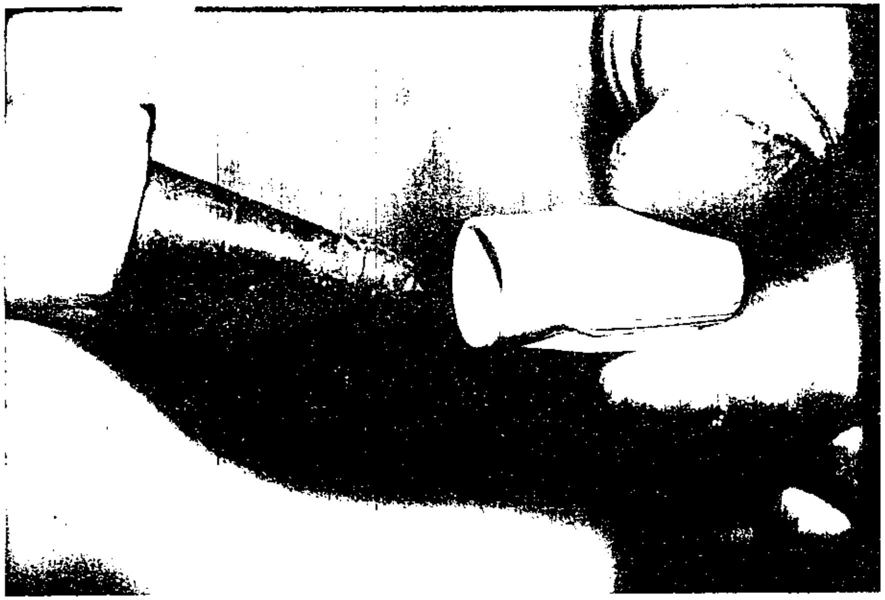


41. THE WIRES ARE TWISTED TOGETHER TIGHTLY, USING THE PLIERS. THIS IS CALLED "PRETWISTING".

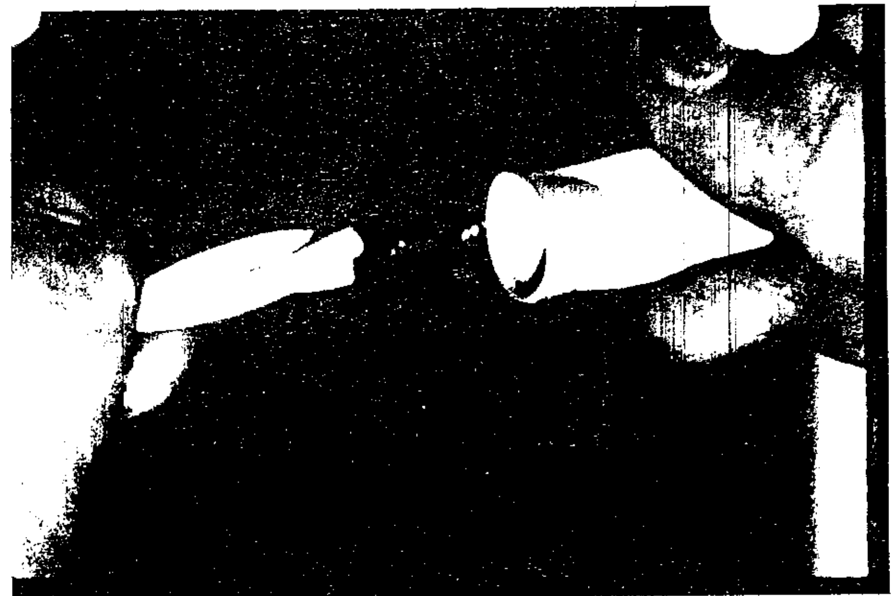


42. HERE IS THE PRETWISTED WIRE SPLICE.
There is substantially better mechanical and electrical wire-to-wire contact in this pre-twisted splice than can be achieved by simply screwing the connector onto the straight wires.

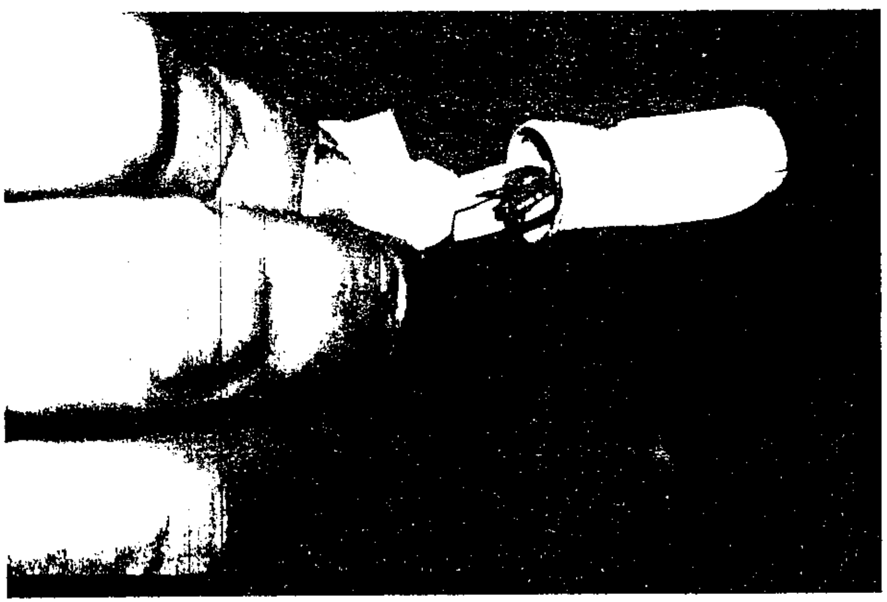
43. THE EXCESS LENGTH OF THE TWISTED WIRE SPLICE IS THEN CUT BACK TO THE LENGTH SPECIFIED FOR THE CONNECTOR THAT IS TO BE USED.



44. THE CONNECTOR SPRING IS FILLED WITH INHIBITOR. The connector that has been found to work well for aluminum and aluminum-copper splices has several features that make it intrinsically safer than the , including a non-flaming shell, a metal shell around the spring, and heavier spring wire.

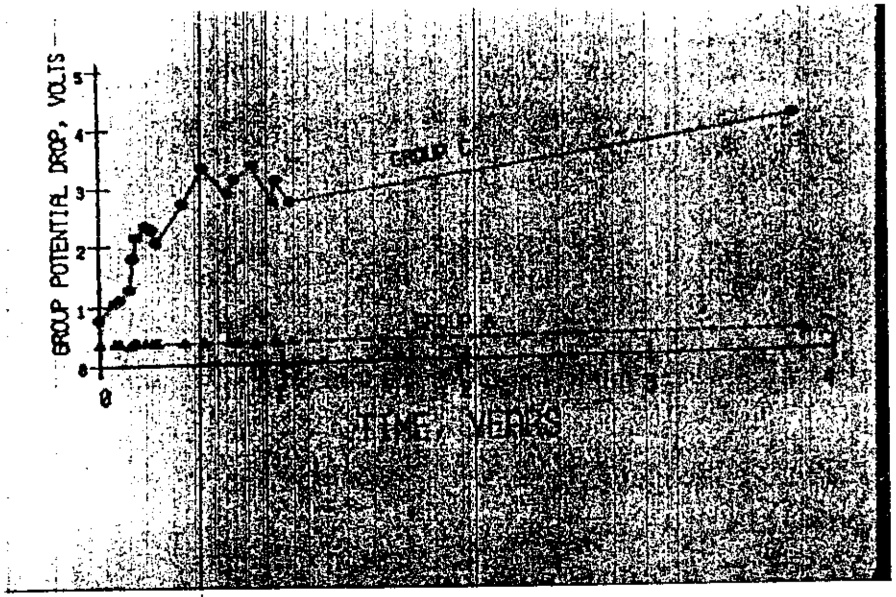


45. THE CONNECTOR IS APPLIED TO THE PRE-TWISTED WIRE SPLICE.

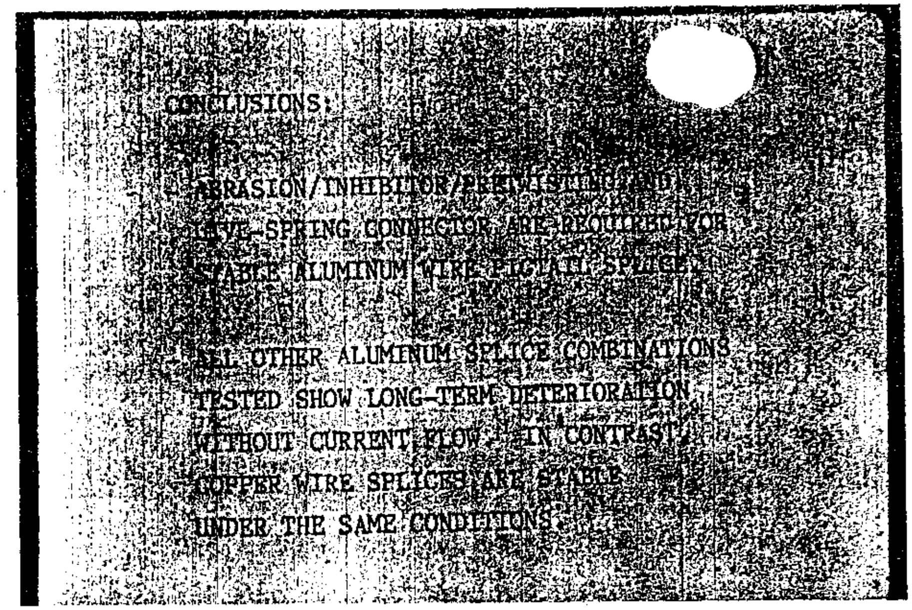


46. THE CONNECTOR IS SCREWED ON TIGHTLY. This may result in the extrusion of some inhibitor compound out of the connector. This excess inhibitor should be removed.

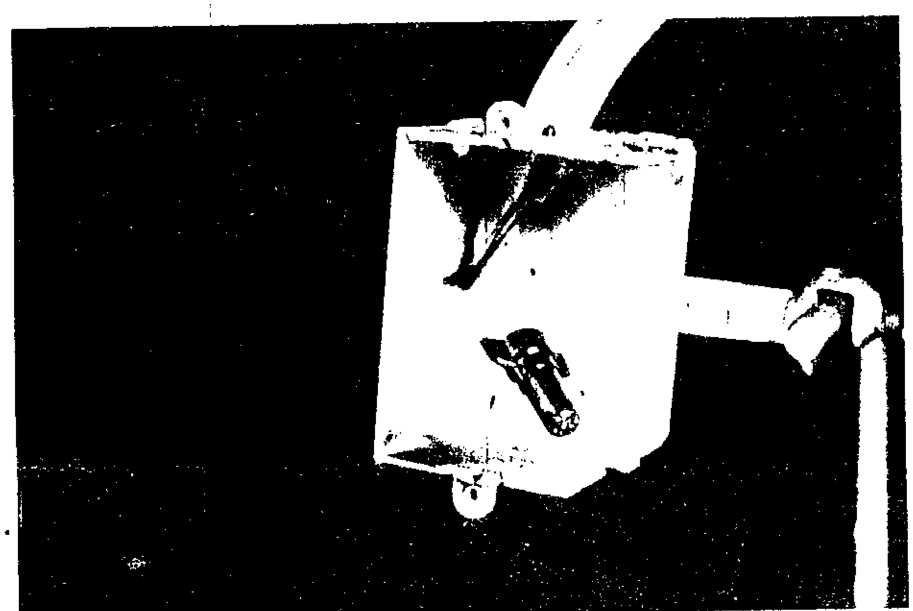
47. HERE IS THE FINISHED SPLICE. This same type of twist-on connector is available in other sizes as required for various wire combinations. Other brands and types may be OK. The key factors are: "live spring" design, non-flaming shell, heavy spring



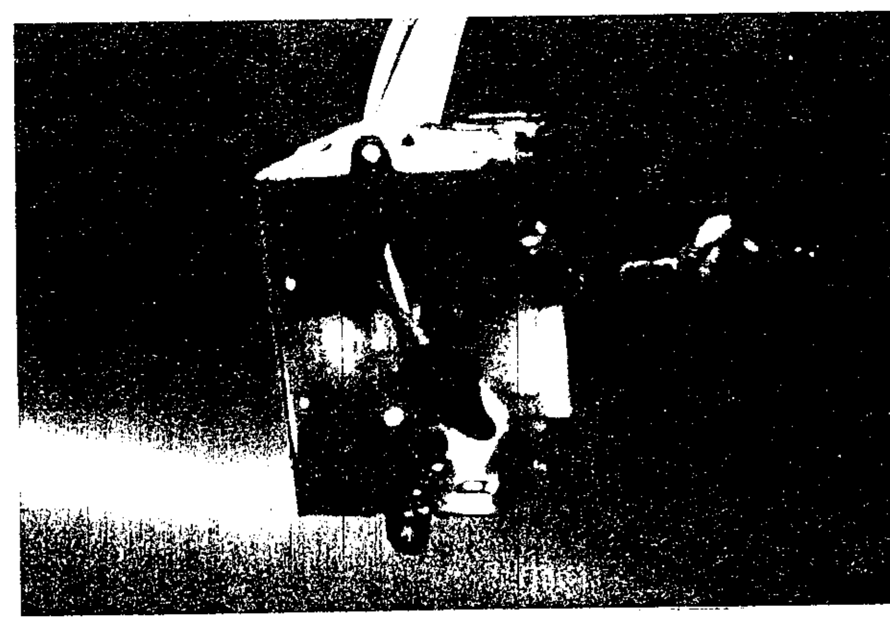
48. THE INSTALLATION TECHNIQUE IS PIVOTAL. In long-term tests, only the groups made with the installation procedure described have remained stable without any increase in resistance (Group A). Serious long-term deterioration is seen (Group C) when the same connector is conventionally installed.



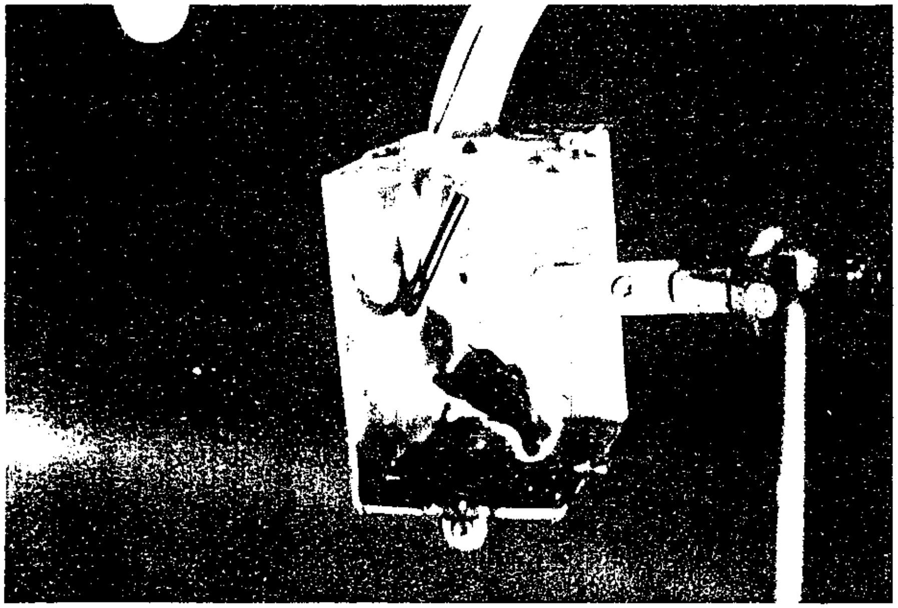
49. THE RESULTS OF MANY YEARS OF LONG-TERM TESTS on aluminum and aluminum-copper splices show conclusively that the abrasion/inhibitor/pretwist installation method shown overcomes the basic failing of the twist-on connector by establishing sound wire-to-wire contact.



50. INSTALLED PER THE MANUFACTURER'S INSTRUCTIONS, MANY IN RETROFIT APPLICATIONS, hazardous failures will occur in considerable numbers over the years. The free-burning connector shell is then a cause for concern. A substantial fire can grow from ignition of a connector shell, as shown in this demonstration.

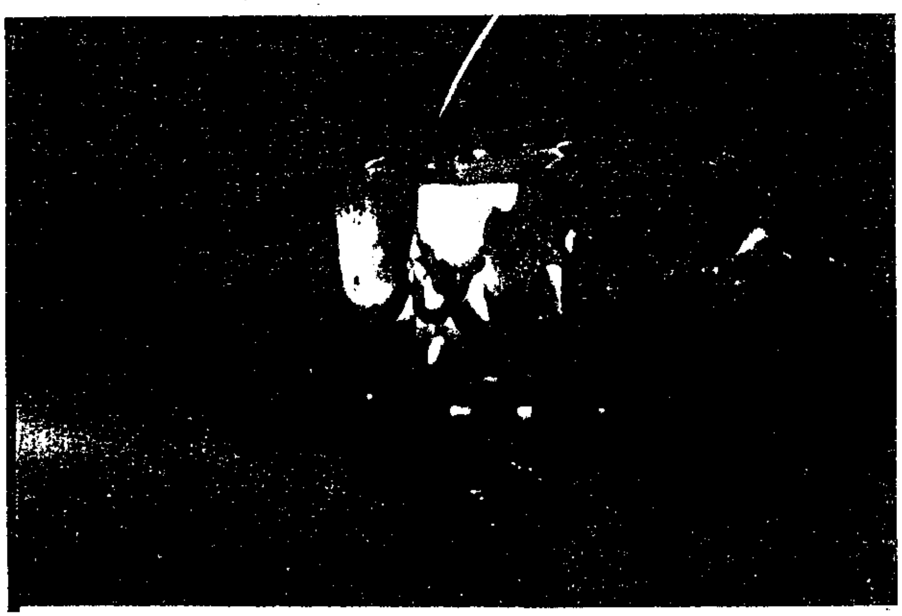


51. THE ONLY MATERIALS HERE ARE THOSE INTENDED TO BE IN THE BOX: the wires, a connector, and the end of the cable sheath. A failing aluminum twist-on splice can ignite its own shell. In this demonstration the connector shell was ignited by a match. A burning glob of plastic drips to the floor of the metal box.

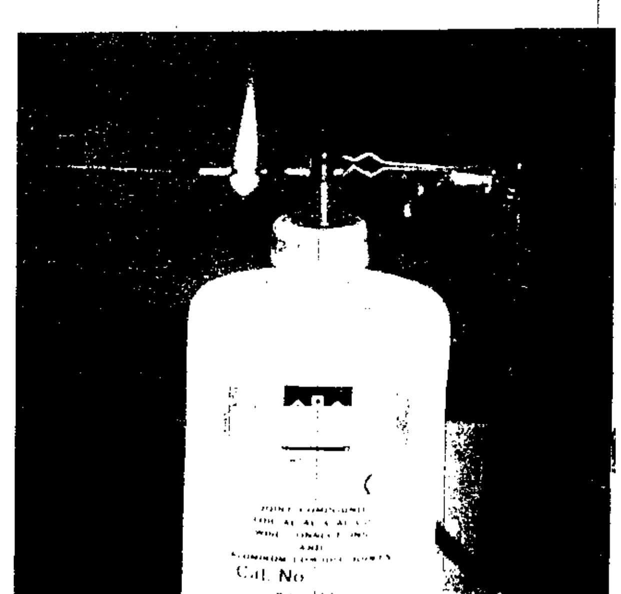


52. THE FLAME DOES NOT EXTINGUISH. Interaction between the shell and the dripped plastic keeps it going. In an actual installation the side and front of the box would be enclosed, but there are generally enough openings and gaps to provide sufficient air for combustion.

53. THE TEMPERATURE OF THE WIRE INSULATION HAS INCREASED TO THE POINT WHERE IT TOO WILL BURN, AND THE FIRE GROWS.



54. AT THIS POINT THE CONNECTOR IS COMPLETELY BURNED BUT THE FIRE CONTINUES ON THE WIRE INSULATION AND CABLE JACKET END. In the wall of an actual home, the fire may spread or not, depending on details. Clearly, however, the inside of the ... for free burning material



55. THE CONNECTOR HAS MORE FREE-BURNING MATERIAL THAN THE CONNECTOR SHOWN IN THE PREVIOUS DEMOSTRATION, BECAUSE IT IS FILLED WITH HIGHLY-COMBUSTIBLE INHIBITER. Now, imagine an outlet box with two or three of

CONCLUSIONS

1. The connector will fail in significant numbers in residential long-term service in the aluminum wire pigtailing application.

2. The failure mode invoves overheating where, at normal operating current, the steel spring becomes red hot.

3. Both the shell and the oxide inhibitor inside the connector ignite readily and burn freely, increasing the fire hazard substantially when failures occur.