# Electrical Contacts 1968

ELECTRICAL CONTACTS - 1968

Proceedings

of the

Engineering Seminar on Electrical Contact Phenomena

The purpose of this Seminar is to provide a forum for the presentation and discussion of fundamental theory and the latest findings amd developments, both theoretical and applied, in the field of electric contact phenomena in the several areas of permanent connections, surface films and contact deterioration, separable and arcing contacts, sliding contacts and commutation, new techniques for evaluation of contacts, and a look at the future of electrical contacts.

Price: Ten dollars

November 11-15, 1968

Illinois Institute of Technology
Chicago, Illinois 60616

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# PREFACE

The 1968 Engineering Seminar on Electric Contact Phenomena, which takes place from November 11 to November 15, includes a day of tutorial pre-sessions and four days of papers and discussions spanning the field of electric contact phenomena.

The Tutorial Pre-Sessions comprise a full day of lectures on the fundamentals of electric contact theory and are planned especially for engineers and scientists new to the field of Electrical Contatcs. In addition to this, the several session chairmen give introductory remarks which tie together the papers in their sessions with Monday's review of fundamentals.

The Seminar Proper includes six sessions of both invited and volunteered papers on November 12-15 in the six major areas:

Permanent Connections
Surface Films and Contact Deterioration
Separable and Arcing Contacts
Sliding Contacts and Commutation
New Techniques for Evaluation of Contacts
and a look at the future of,
Electrical Contacts

Opportunity is provided in each session for questions and discussion of individual papers; and, in addition, a portion of Wednesday afternoon is set aside as a general Discussion Session in which individual questions are asked and problems discussed.

Included in this volume are the papers of those speakers who made their material available in written form. The papers are arranged in the order in which they are presented, except that certain papers received too late to be placed in order appear after the others.

One must recognize that questions, answers, and discussions constitute in substantial measure the value of the Seminar; and that these proceedings, assembled before the Seminar, cannot include them.

Illinois Institute of Technology is grateful to the speakers for their valuable contributions to the Seminar, and for permission to include their writings in this volume.

Ralph E. Armington
Seminar Chairman

Illinois Institute of Technology
Chicago, Illinois
November 11, 1968

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CONSIDERATIONS AND SIMPLIFIED METHODS OF COMPUTATION
FOR STATIC CONTACT CURRENT CARRYING CAPACITY

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Abstract

To comply with customer requirements and help the engineer design electrical contacts, a method has been resolved to compute the actual current carrying capacity of a contact in air for a 5 degree centigrade thermal rise. This paper deals primarily with thermal rise computations and measurements of silver and brass contacts used in low current carrying capacity rotary switches. Some discussion on upper limit ambient operating temperatures is given for various currents and materials.

## Introduction

In the past, contact research has delved into relay contact studies, and sliding contact studies, however, the field of a combination type contact as those used in rotary switches has remained basically untouched.

In the electronics field today the Rotary switch industry is a highly competitive one, with a variety of demands imposed upon a basic style, manufactured

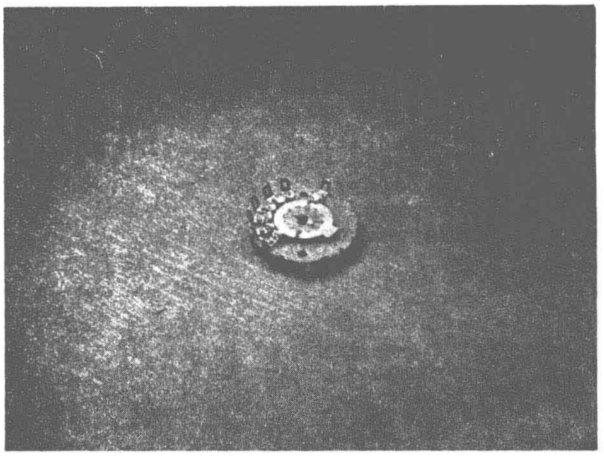


Fig. 1 - **Typical Rotary Switch Wafer**

in many shapes and sizes it is still a rotary switch and must perform both a sliding and breaking making function.

Being in such a competitive field the Rotary switch engineer is limited in his choice of contact materials and methods. Fortunately the least expensive of the precious metals contact materials silver, also the best conductor is within his competitive pocketbook. His alternate choice of material is brass or a choice of a few other copper alloys, with a plate of silver or gold of varying thickness. Generally speaking clad metals are impractical due to production methods geared to high production, large scrap leavings and practically an infinite variety of shapes that the rotor can be stamped into.

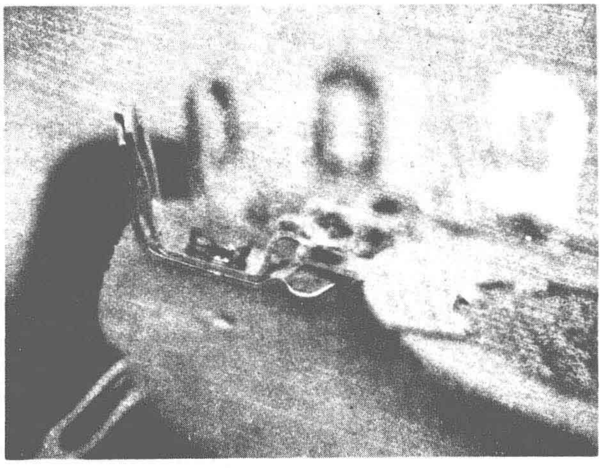


Fig. 2 - **Rotary Switch Contacts**

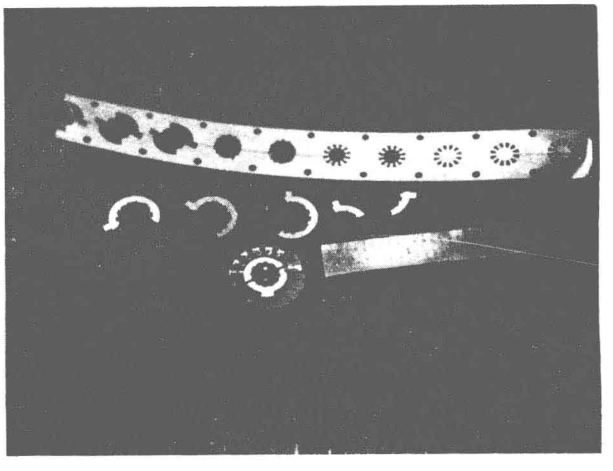


Fig. 3 - **Contact Fabrication Method**

It is for the preceding reasons these studies were undertaken. In essence to learn every possible and practical approach in the use of the least expensive of contact materials that will give the utmost performance. The first point of research in this study, is that of temperature. The question must be answered how high a temperature can the contacts be operated continuously at:

## Useful Temperature of Alloys

Basically there are three types of Silver Alloys:

1. Coin Silver 90 Ag 10 Cu
2. Spring Silver 90 Ag 5 Cu 5 Zn
3. High Temperature Silver

All three of these alloys have these disadvantages as follows, #1 is impractical for spring type contacts. #2 is impractical over 105° C due to a slow anneal. #3 is brittle and can not take severe bending, however, some recent developments in melting is overcoming this problem and the alloy shows future promise. However, it is approximately 30 cents a troy oz. higher.

Of the Brass and Copper Alloys there are again three types used.

4. Cartridge Brass
5. Spring Brass
6. Berrilium Copper

The disadvantages of these alloys are:

(a) To be useful as an efficient conductor with extended life and low contact resistance, these alloys must be plated.
(b) Alloy #4 is not useful as a spring contact, but is useful as a rotor contact.
(c) Alloy #5 loses its spring properties with heat and life.
(d) Alloy #6 is porous and brittle, however it is useful to high temperature, and has a slightly higher cost.

As can be seen by the preceding; Alloys #1, #2, #4, and #5 are the least expensive and most commonly used, therefore, we will deal only with them.

Alloy #2 is useful to 105° C for spring contacts.

Alloy #5 is useful to 125° C however, silver plated brass was found to be generally unsuitable for dry circuit application, reliable contact resistance and endurance at high temperature. And therefore is used only in commercial applications and not military.

The reason for this prior information is that it must be remembered for later usage when dealing with thermal rise.

## Derivation & Calculation of Current Carrying Capacity for 5°C. Thermal Rise

Based on AWG wire standards of 700 circular mils per ampere for copper wire for a 5° C thermal rise we will find an equivalent figure for Silver and Brass.

From the accompanying table #1 comparative figures of the electrical conductivity of more commonly used contact materials and conductors is shown:

TABLE # 1

| Metal or Composition | Chemical Symbol | Conductivity Silver = 100 |
|---|---|---|
| Copper | Cu | 97.61 |
| Gold | Au | 76.61 |
| Iridium | Ir | 13.52 |
| Lead | Pb | 8.42 |
| Mercury | Hg | 1.75 |
| Nickel | Ni | 12.89 |
| Platinum | Pt | 14.43 |
| Silver | Ag | 100.00 |
| Tin | Sn | 14.39 |
| Tungsten | W | 14.00 |
| Zinc | Zn | 29.57 |

From this table conductance of most alloys can be computed as shown, considering the fact that we will require that the conductance of Brass 70 Cu 30 Zn must be known.

If 70% of the alloy is 97.61% efficient as an ideal conductor the product of these efficiencies is equal to 68.127%.

If 30% of the alloy is 29.57% efficient as an ideal conductor the product of these efficiencies is equal to 8.87%.

Since the whole is equal to the sum of its parts or products of efficiencies added together.

$$\begin{array}{r} 68.127 \\ +\ 8.870 \\ \hline 76.997 \end{array}$$

Thus 70 Cu 30 Zn is 76.997% efficient as Silver as an electrical conductor.

We therefore have the efficiencies of conductance of our desired contact materials.

Ag = 100% efficient
70 Cu 30 Zu = 77% efficient
Cu = 97.61% efficient

Copper must be included also as we will use its conductance efficiency in later calculations.

Since basic figures given in wire tables for a $5^{o}$ C rise are given as 700 circular mils for copper we must assume copper to be 100% efficient so we can find how many circular mils in silver, will give us a $5^{o}$ C rise. This can be found by:

$$\frac{100}{97.61} = 1.02448$$

Therefore we re-establish our efficiency figures:

Ag = 102.45%
Cu = 100.00%
Brass = 78.9%

and by simple ratio and proportion:

Ag = 682 circular mils per ampere
Cu = 700 circular mils per ampere
Brass = 890 circular mils per ampere

The next problem for consideration is how can we adopt a figure of conductance for wire into one that is useful for small point contacts. When analyzing wire a cross sectional area is taken, converted into square inches and multiplied by $1.27 \times 10^6$, the number of circular mils/sq. in. to find the number of circular mils. The wire itself is of a uniform diameter and is carrying the same current over its entire length. The wire is heated uniformly by molecular friction and this heat itself is dissipated over the entire length of the wire, therefore in analyzing the physics of current in a wire, parallels must be evident. In the case of a point contact, we shall investigate these parallels.

Since a point contact makes on a very small area, the number of circular mils of the cross section of the point may be unity and theoretically could not carry the currents that we know it can, therefore the cross sectional approach to the point contact is impractical for basing current carrying calculations upon.

Let us consider the entire contact area from wire terminal to wire terminal as the conductor, but we will consider it not only an electrical conducter but as a thermal conductor as well.

Let us define a circular mil; it is a unit of area .001 in diameter. In wire area's it is given in cross sectional area and easily computed by finding the cross sectional area in square inches, the misnomer lies in the fact that it is really a volume measurement of the cross sectional area times .001.

If we compute the total contact area in cubic inches and multiply by $1.27 \times 10^6$ we will have the true number of circular mils in our total contact. We can then express the total carrying current by the following formula where:

A = total contact area in cubic inches
B = number of circular a square inch ($1.27 \times 10^6$)
C = conductivity of contact material expressed in circular mils per ampere
I = current in amperes

$$I = \frac{A \times B}{C}$$

To prove this formula a given set of contacts made of silver and a similar set made of brass were computed. The total contact area was computed at 2,540 circular mils for both pairs and current computed for silver and brass as follows.

$$\text{Silver } \frac{2540}{682} = 3.73 \text{ ampers for a } 5^{o} \text{ C rise}$$

$$\text{Brass } \frac{2540}{890} = 2.8 \text{ amperes for a } 5^{o} \text{ C rise}$$

These contacts and similar pairs were tested at all switching positions as shown in Figure 1 and the composite curves drawn as shown in Figure 4-5. As can be seen, computed values and measured values are in close correlation.

Further studies and measurements up to $30^{o}$ C rise indicate the safe ambient operating temperature before contact degradation sets in from excessive current, for example, a set of contacts in an environment with an ambient temperature of $100^{o}$ C can only tolerate a current which will yield a $5^{o}$ C rise due to the particular alloy of the contact material (Spring Silver). As discussed earlier this alloy looses its spring properties over $105^{o}$ C.

## Conclusion

In conclusion, the importance of knowing the following can be seen.

1. Metalurgical properties of the contact material
2. Maximum ambient operating temperature
3. Design current of the circuit to be switched

Knowing these parameters it is possible to compute, contact area needed, whether a safe condition exists with a present design or whether some circuit parameter must be changed to give complete circuit reliability. It is possible to compute by using the developed method the total current for the 5° rise and have a starting point for further development of higher rise characteristics by actual measurements of thermal rise developed on the contacts.

Fig. 4 - 2540 Circ. Mils Silver Contacts

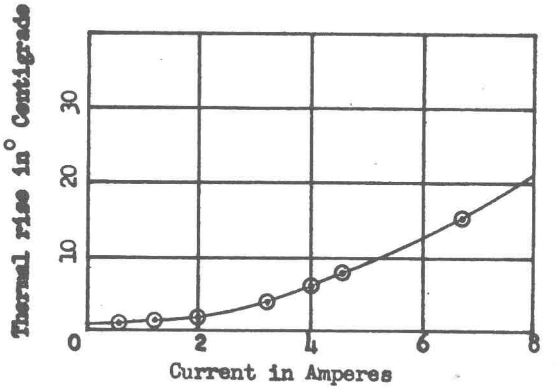
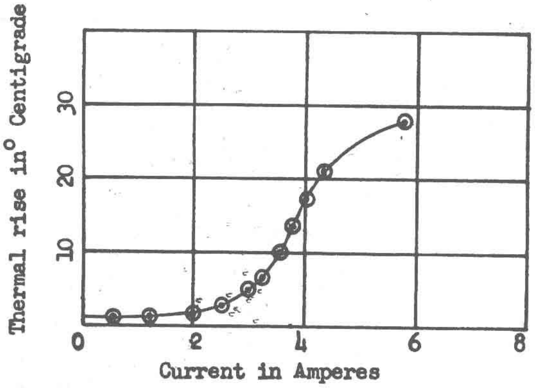



Fig. 5 - 2540 Circ. Mils Brass Contacts




## References

1. Table #1
   Machinery's Handbook
   17th Edition, p. 1890
2. Ref. 700 circular mils/sq. in. found in:
   Radiotron Designers Handbook
   4th Edition, Wire Tables, p. 1416

EFFECT OF SHORT DURATION TEMPERATURE AND PRESSURE PULSE ON BOND STRENGTH OF WIRE INTERCONNECTIONS

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Abstract

This paper reports laboratory studies of bonding polyethylene insulated aluminum telephone cable conductors using the "band-and-join" method initiated by Mr. R. H. Cushman of the Western Electric Company Engineering Research Center at Princeton. The effect of temperature and pressure on bond strength was studied to determine a temperature, deformation (pressure), and time ranges within which reliable bonds can be made using the heated ram method. Results show that some bonding occurs when band and wire interface temperatures exceed 800°F coupled with a minimum deformation of about 40 percent. The length of time these interfaces were held at a given temperature was not significant for pulse durations of up to several seconds. Repeatable reliable bonds are obtained when interface temperatures are at about 1000°F and the wires are deformed about 60 percent. For these studies no special surface preparation or atmosphere to prevent oxidation were used.

Introduction

Due to the potential copper shortage and its high price, aluminum is being developed as a substitute conductor material for copper. This requires development of wire joining methods compatible with both copper and aluminum.

The objective in wire joining development is to use little or no additional material to make and to insulate the joint. The method, of course, must be economically competitive with existing methods and also highly reliable.

Restriction that little or no additional material can be used to make the joint guided the interest towards application of welding. Since copper and aluminum form a brittle alloy when fused, effort was focused on diffusion or thermocompression bonding, cold-welding and related joining methods which have been successfully used to bond or join leads to semiconductors and other materials.

The wire joining method studied and discussed in this paper was initiated by R. H. Cushman of the Western Electric Company.[1] It is referred to as the "band-and-join" method. Figure 1 shows three stages in making a joint: (1) a thin band of material is placed over polyethylene insulated wires to be joined; (2) heat and pressure are applied to bond the wires to the band through the insulation which flows out of the way; and (3) the joint is insulated by applying additional material.

The bonding method reported is of exploratory nature. It does not represent the technique to be used in the field. There are potential simplifications or improvements of the method which can include elimination of the external band.

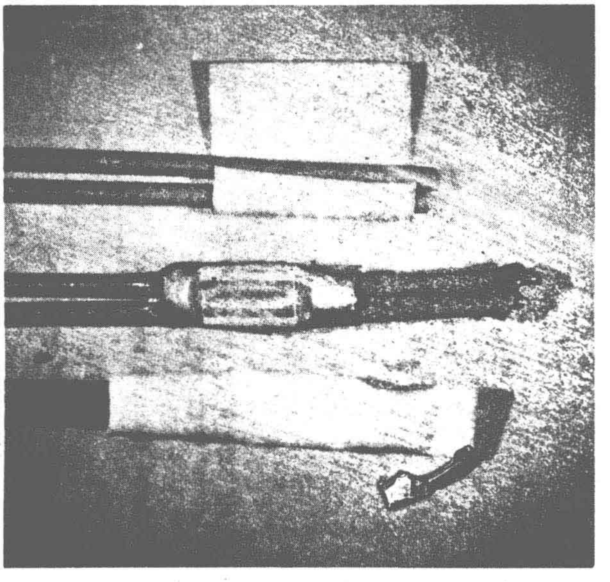

Figure 1. Bonded joint. Showing tin plated copper band partially wrapped around polyethylene insulated wires; bounded uninsulated joint; and, an insulated joint.

Test Procedure and Apparatus

This paper presents test results of a study to determine the effects of:

1) Temperature,
2) Pressure (Deformation), and
3) Time

on bond strength. These variables are recognized as the most important in making a bond after selection of band material, its plating and materials to be bounded. It is important to establish temperature, pressure and time ranges within which reliable joints can be made to aid in the design of tools and required controls.

The data presented is for polyethylene insulated aluminum telephone cable conductors, since aluminum is more difficult to bond than copper using the "band-and-join" method as determined by preliminary investigations. It was also found that a low melting point coating or plating on the band improves bonding of aluminum. Unplated bands did not bond to aluminum under the conditions tested for time duration of up to 6 seconds.

Tin plated copper band was found to be satisfactory and has been used mostly throughout the tests. Zinc was found unacceptable. Indium is excellent but the bonds are weaker due to its lower strength.

For this study a heated ram with a 1/4-inch flat was used to apply force and heat to the work (joint). Figure 2 is a schematic of the laboratory tool used for these evaluations. The ram

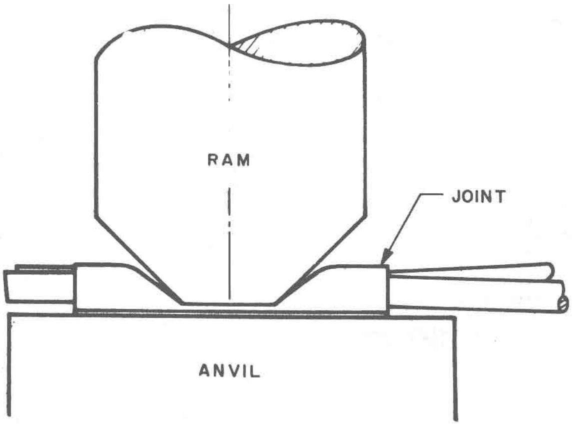


Figure 2. Schematic of heated ram bonding tool.

temperature is controlled to a preset steady-state value and the force the ram exerts on the work is adjustable. The time the ram is in contact with the work is controlled by a timer.

Temperatures of the joint are measured at both the joint-and-ram and the joint-and-anvil interfaces.

Figure 3 shows typical temperature-pressure pulse at the joint anvil interface for a steady-state ram temperature of 1200°F for two 17-gauge polyethylene insulated aluminum conductors (EC grade, H-11).

Due to finite heat capacity of the ram, the size of the heat sink the ram sees has considerable effect on the temperature the joint interfaces reach. To reduce this effect an insulating anvil of asbestos base material was used.

Bonds are evaluated by their mechanical strength. This evaluation method is widely used for other types of welded joints. Resistance measurement of the bonded joint does not yield data by which individual joints can be classified according to their quality, because of the very large contact areas and thus very small contact

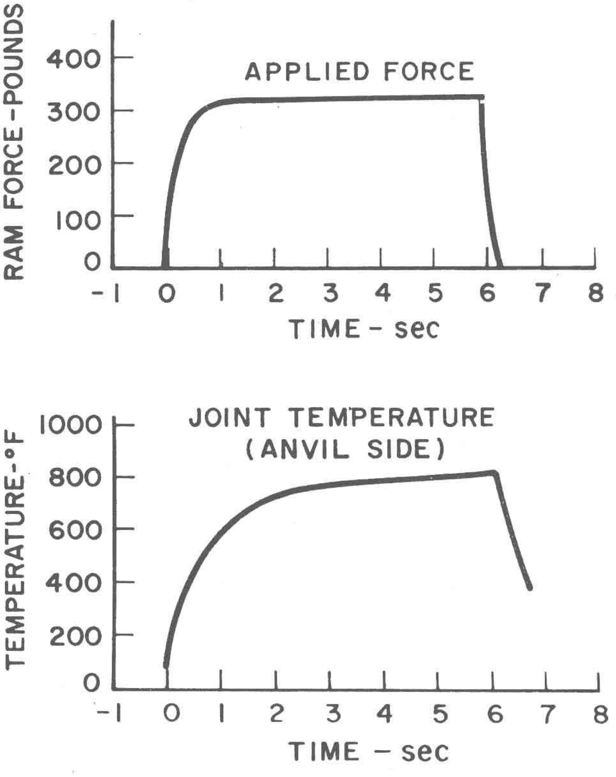


Figure 3. Typical temperature and force pulses seen by the joint.

resistances which cannot be distinguished from each other by present resistance measurement techniques.

For evaluation the band was partially wrapped around the wires so as to form a "U". After bonding, the hinged side of the "U" was cut to permit peel testing of the anvil and the ram sides of the joint. Figure 4 shows configuration of a bonded

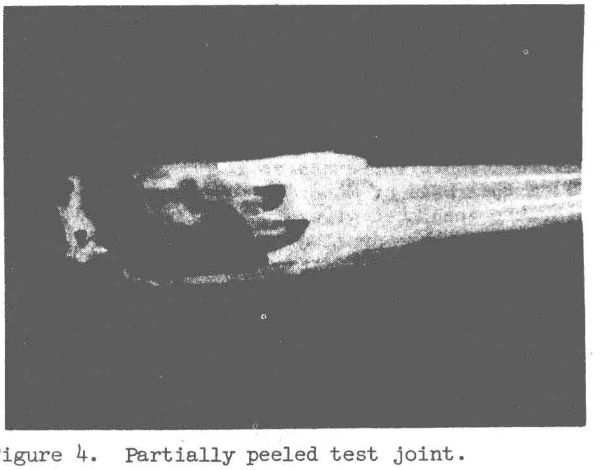

Figure 4. Partially peeled test joint.

joint used in this study. Note the upper half of the band which has been partially peeled from the wires. The test used is referred to as the 180°

peel test. It was chosen for ease of testing.

The data presented in this paper are for two 17-gauge (EC grade, H-11) aluminum polyethylene insulated conductors, banded with 0.003-inch thick copper band having 0.0001-inch tin electroplate, unless otherwise indicated.

The bonding mechanism is believed to be a mixture of several phenomena. They are

a) Diffusion
b) Wetting of clean exposed surfaces,
c) Alloying of the bond interfaces, and
d) Action of interatomic forces between atoms brought within atomic distances of each other.

For this process to be economically feasible, the desirable bonding times should not exceed two or three seconds. Therefore, the process studied depends on large deformations, high temperatures and presence of molten metal in the bond interfaces to aid wetting of exposed clean surfaces. The latter point is very important for aluminum which forms tough, insulating oxide films on its surface extremely fast when exposed to oxidizing atmosphere.

## Results

Figure 5 is a photograph of a bond interface after peel test. Note the tinned areas on both sides of the wire axis. The area over the wire axis has no or very little tinning. This points to the importance of heavy working of wire surface to expose clean metal and thus allow wetting by the molten tin. When using unplated copper bands bonding did not occur. This is probably due to presence of gaseous films adhering to the metal surfaces and gases trapped between these surfaces thus causing oxidation upon exposure of clean metal surfaces.

Figures 6 and 7 show copper-to-copper and and tinned copper-to-copper bonds. Note the increased strength as shown by tearing of metal of the tinned-copper bond.

Due to the short bonding times, the temperatures of joint interfaces were in a transient state and the metal flow was significant with time due to change of conductor physical properties with increasing temperature. The temperature and time effects in the transient state are difficult to separate and later on when bond strength is presented as a function of pressure, time and temperature one must remember that the effects are not separated.

The three variables studied - time, temperature and pressure - have strong influence on bond strength.

Figure 8 shows bond strength versus time relationship for constant steady-state ram

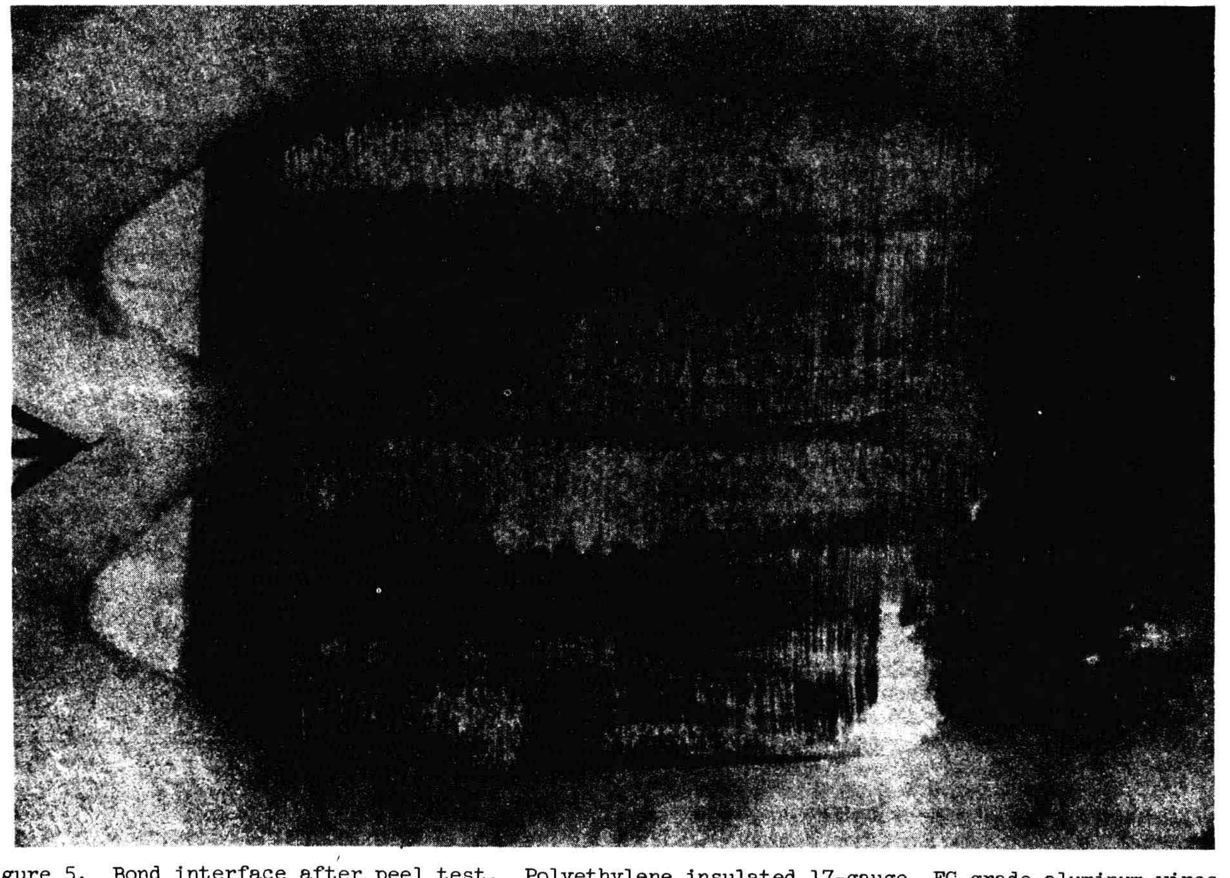

Figure 5. Bond interface after peel test. Polyethylene insulated 17-gauge, EC-grade aluminum wires bonded to tin plated copper band.

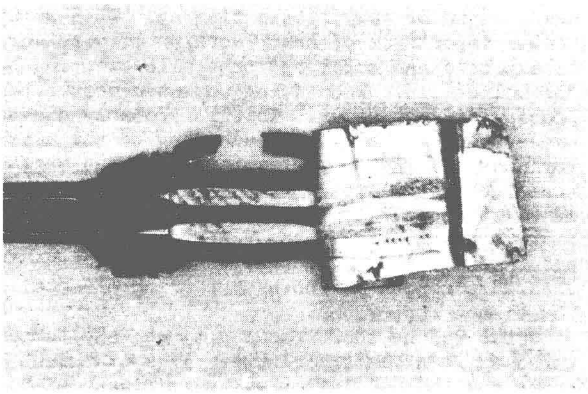

Figure 6. Polyethylene insulated copper wires bonded to copper band.

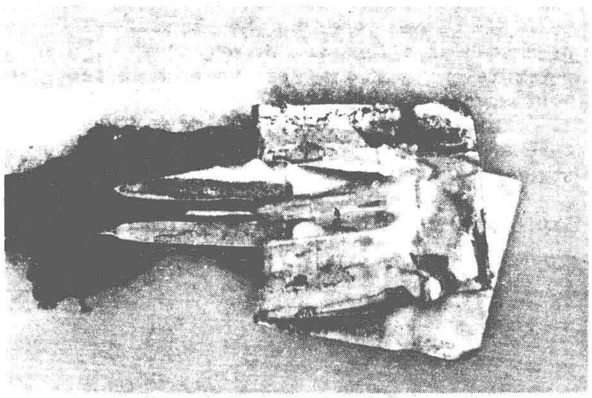

Figure 7. Polyethylene insulated copper wires bonded to tin plated copper band.

temperature and constant ram force. Note the difference in bond strength between anvil and ram joint interfaces. The peel strength of ram interface is higher since the interface temperature on the average was about 50° to 100°F higher than the anvil interface temperature shown in Figure 3. The peel strength increases with time over the 6-second period studied.

Figure 9 is a comparison of bond strength of joints made with tin and indium electroplated bands. The indium bonds are weaker for bonding times in excess of 1 second. At one second and below one second indium bonds exhibited higher strength than tin plated bonds. This is due to the ability of indium to wet aluminum at lower temperatures than tin. The relatively small increase in bond strength for indium over the time range studied and for tin from 4 to 6 seconds suggests that there has been little diffusion or alloying between copper, aluminum and the tin or indium plating. The bond strength reflects the strength of tin or indium.

The band-wire interface temperature levels reached during bonding are significantly more important than the bonding times. Figure 10 illustrates the effect of ram temperature on bond strength for 3-second bonding times and 340 pound ram force. Note that there is an optimum temperature level above which there is no increase in bond strength as shown by the data for ram side

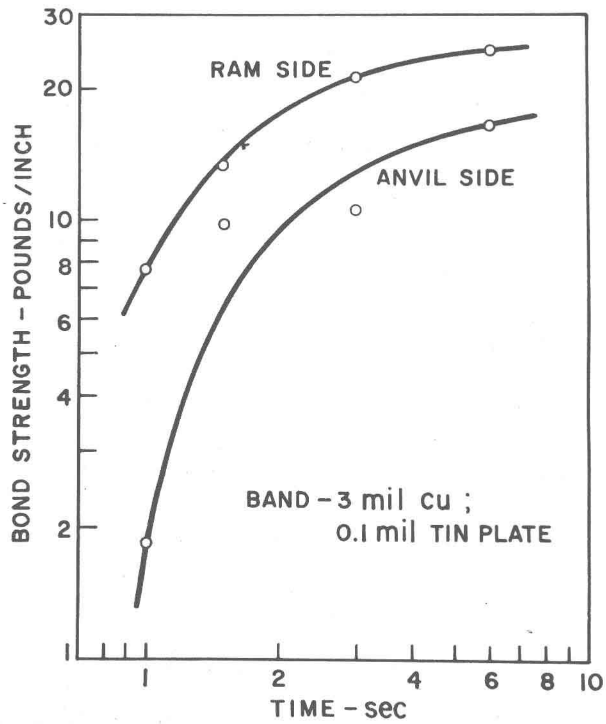


Figure 8. Effect of bonding time on bond strength. (Ram temperature 1200°F, ram force 340 pounds.)

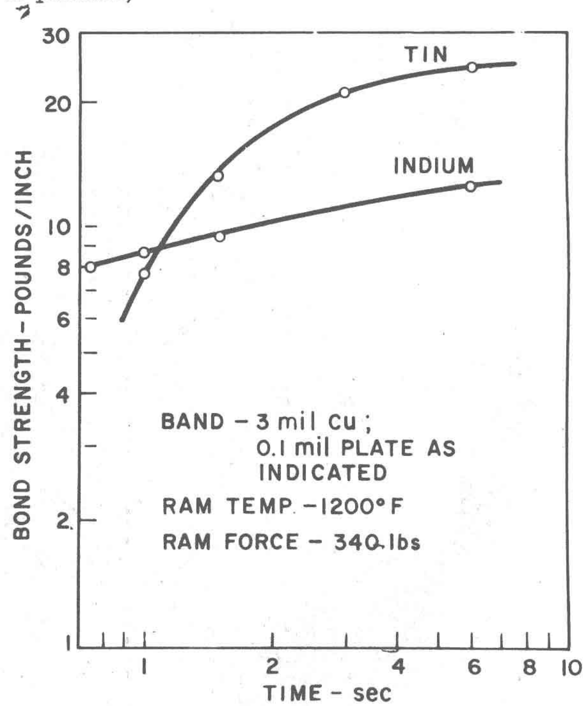


Figure 9. Effect of plating material. (Tin vs. indium).

of the joint interfaces. Other tests and published work show that higher temperatures could result in bond degradation due to formation of