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FINAL REPORT

ESTABLISHMENT OF STANDARDS FOR COMPATIBILITY OF PRINTED CIRCUIT AND COMPONENT LEAD MATERIALS

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ESTABLISHMENT OF STANDARDS FOR COMPATIBILITY OF PRINTED CIRCUIT AND COMPONENT LEAD MATERIAL

by

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FOREWORD

This report was prepared by the Martin-Marietta Corporation, Orlando, Florida under National Aeronautics and Space Administration Contract No. NAS8-11474. The development was administered by the Quality Control Division of the George C. Marshall Space Flight Center, Huntsville, Alabama. The Martin Company wishes to express appreciation for the support, guidance, and cooperation from NASA technical representative Mr. M. J. Berkebile, Chief R-QUAL-AAR, and for his assistance in developing the tests and procedures for screening component lead materials.

In addition to the authors, other Martin personnel who contributed to the project were D. A. Smith, R. W. Wilson and C. D. Watts in the areas of welding, chemical plating and surface studies. Acknowledgement is also given to D. W. Pease and R. D. Summers who took the photomicrographs and performed the statistical analysis of the test data.

PURPOSE

The purpose of this task was to screen the materials presently used by industry in the manufacture of electronic component leads. Two groups of lead materials emerged which were either weldable or solderable. Tests were conducted on these two groups which allowed reduction in their size by isolating those materials exhibiting the most desirable characteristics from the standpoint of the manufacturer and from the standpoint of the user.

The objectives of this task were as follows:

1. Reliability improvement in electronic assemblies.

2. Standardization of materials and development of non-destructive test methods for lead material evaluation.

3. Improved control over manufacturing processes.

4. Inputs necessary to update or involve MSFC documentation depicting the quality and reliability requirements.

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ABSTRACT

This is the final report for "The Establishment of Standards for the Compatibility of Printed Circuit and Component Lead Materials" under Contract Number NAS8-11474 and covers the period 27 June 1964 to 27 October 1965. During this report period major effort was directed toward the following objectives:

1. Literature Search and Industrial Survey

During this phase of the program survey letters and questionaires were sent to the major wire manufacturers and component manufacturers to determine the most commonly used wire and the processes involved during attachment of lead wires to the components. Letters were also sent to weld equipment manufacturers to determine the most commonly used equipment.

Government reports and papers from industry were screened and studied to take advantage of similar work performed elsewhere and to supplement the knowledge gained by the Martin Company on welding and soldering.

2. Rough Screening (Welding)

This phase of the program was concerned with the selection of test methods and reduction in the number of the candidate lead materials. A torsion shear type test was selected for screening, and a reduction was made to the following materials:

1 Stainless Steel

2 Copper, OFHC

3 Dumet

4 Alloy 52/152

5 Nickel

6 Kovar.

3. Rough Screening (Soldering)

Seventy-four candidate materials, platings and surface conditions were screened by flow soldering to a copper land on printed circuit boards. Visual inspection of the solder joints was used to eliminate those materials and/or platings which were inferior.

During this phase a new non-destructive test method, the droplet test, was developed which was improved and used during the fine screening phase.

4. Weldability Phase II

Weld theory and tests were studied during this phase with the effects of variables such as lead orientation, electrode preparation and power supply functions. Photomicrographs were made and studied to determine the effects of these variables. High speed color and infrared movies were made to study the dynamics during the weld cycles and the heat flow characteristics.

A Weldability Index was devised and used to determine those materials which were consistent and offered the highest potential for good physical and electrical connections. This test was subjected to statistical analysis. The test was determined to be within acceptable limits in sample size and percent variations obtained.

The component lead materials selected as most weldable according to usage is as follows:

1 Nickel "A" (Au plated)

2 Stainless Steel Pins (Bare)

3 OFHC Copper (Au plated)

4 Rodar (Au plated)

5 Alloy 152 (Au plated)

6 Dumet (Au plated)

5. Solderability Phase II

After the rough screening of solderable lead materials, tests were run on eight candidate materials and platings. These materials were subjected

to peel, spread and droplet tests which were used to evaluate differences between these materials and platings.

In addition to the above tests special attention was given to:

1 The effects of electro-tin thickness

2 Ultrasonically tinned wire

3 Nickel wire

4 Kovar and Rodar platings other than gold.

A special test for gold plated OFHC copper wire was also constructed. This test proved hot dipped OFHC copper to be superior to the gold plated OFHC copper wire.

Statistical analysis was performed on the fine screening droplet test to show that the differences in solderability rating were considerably more than could be accounted for by experimental error.

Lead materials selected as most desirable for soldering were:

1 OFHC copper - 60/40 hot dipped

2 Dumet - 60/40 hot dipped

3 OFHC copper - electro-tin plated

4 Dumet - electro-tin plated

5 Kovar - gold plated.

I. WELDABILITY PHASE I

A. INDUSTRIAL SURVEY

A survey was made of eleven prominent welding equipment manufacturers (Appendix A) to determine the type of welding equipment commonly used by the electronic industry for resistance welding of component leads. Three companies responded to the survey listing customers using their weld power supplies (Appendix B). The lists provided by Hughes Aircraft Company, Unitek Corporation and Wells Electronics, Incorporated, revealed that 615 research and manufacturing companies are using capacitor discharge weld power supplies.

While AC or repetitive pulse type power supplies are manufactured and sold by such companies as Raytheon, Precision, and General Electric Company, the majority of electronic fabricators use the capacitor discharge type power supplies. The Hughes power supply utilized in electronic module fabrication at Martin-Orlando is typical of this type of power supply which is widely used in industry. For this program, the Hughes Model VTW-30B single range power supply was used with the VTA-60 welding head.

B. LITERATURE SEARCH

A literature search was conducted on component lead welding and evaluation methods. In the earlier days of module fabrication, many different materials had to be welded. Those used by the Martin Company are listed in Table I.

Another survey reported in Table 5-4 of Reference 1 lists the first eight materials noted in Column 1 of the above table, as well as Alloys 42, 90, and 180. Of these, alloys 90, 180, Copperweld, and Kulgrid are used as interconnecting material with Nickel "A" being used for both component leads and interconnection materials.

Typical lead materials chosen by other investigators for evaluation are listed in Table II. Materials presently specified by Military Specifications for electronic component parts are given by Table III. For additional information on the studies performed by investigators A and B, see References 2 and 3, respectively.

TABLE I

Early List of Materials Used in Module Fabrication at Martin-Orlando

Material	Protective Surface	Material	Protective Surface
Nickel	Au*, Sn	Alloy 42	Solder, Sn
Copper	Au, Sn, Solder Ag, or Ni	Alloy 52	Solder, Sn
Kovar	Au*, Sn, Solder	Alloy 90	Solder, Sn
Dumet	Au*, Sn, Solder	Alloy 95	Solder, Sn
Kulgrid-28	Au, Sn	Alloy 99	Solder, Sn, Au
Copperweld	Sn, Solder	Alloy 180	Solder, Sn
Nicron	Sn, Solder	Brass 70 Cu 30 Zn	Solder, Sn, Au, Ag
Oxalloy 028	Sn, Solder		

*Indicates those materials presently being used in module fabrication at Martin-Orlando.

TABLE II

Typical Component Lead Materials Evaluated by Other Investigators

Material	Surface as Specified Investigator A	Investigator B
Nickel "A"	Bare	–
Nickel "200"	–*	Gold**
Kovar	Gold, Solder	Gold, Tin Plate**
Dumet	Gold, Solder, Bare	Gold, Tin, or Solder Coated**
Alloy 42	Solder, Bare	–
Alloy 142	Solder, Bare	–
Alloy 180	Bare	–
Copper (OF)	–	Gold, Tin, or Solder**
Copper (ETP)	–	Gold, Tin, or Solder

*Not investigated
**Preferred component lead materials

TABLE III

Materials Presently Specified by Military Specifications for Electronic Component Parts

Type	Material	MSFC-SPEC-270 (May 20, 1964)	MIL-STD-1276A (Proposed)
A	Alloy 42 (Au Plated)	Component Lead*	-**
D	Dumet (Au Plated)	Component Lead	Wire
K	Kovar (Rodar) (Au Plated)	Component Lead	Wire
N	Nickel Wire and Ribbon	Interconnecting Material Component Lead Feed-Through Material	-
N-1	Nickel (Bare)	-	Wire and Ribbon
N-2	Nickel (Au Plated)	-	Wire and Ribbon
C	Copper (Tin-Lead Coating)	-	Wire

*Not to be used after May 20, 1965
**Use not specified

From this list, materials were selected for the program. Included, were certain materials which had desirable properties but questionable weldability.

Producers of OFHC copper agreed that it has a high degree of weldability because of its inherent freedom from impurities (Reference 4).

During evaluation of Alloy 180 by investigator A, it was found that some of the welds failed because of brittleness. Removal of the outer surface by chemical etching allowed a sound weld. However, because of the relative susceptability of this alloy to sulfur contamination, it was recommended that it not be considered for component lead application.

Methods such as establishment of optimum welding parameters by the use of the iso-strength diagram and weld parameter profile were reviewed. In another method (Reference 5), which utilizes a plot of preweld surface resistance, ten specimens were checked at each of several electrode pres-

sures. The lowest pressure which gave the minimum spread in contact resistance was chosen as the optimum welding pressure. A plot of this type is shown in Figure 1.

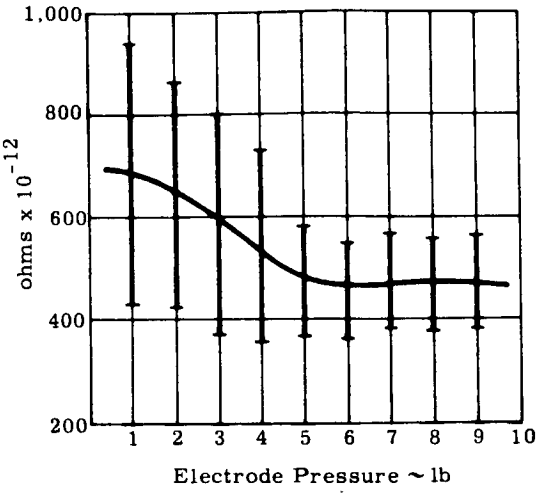


Figure 1. Static Resistance versus Static Load

By the selection of an electrode pressure of 5 pounds, a significantly lower contact resistance spread was noted than for pressures 1, 2, or 4 pounds. One significant weld variable is minimized at a minimum pressure which precludes excessive electrode deformation during welding or a permanent set after welding.

Other evaluation tests, in addition to the conventional torsion-shear testing, were employed by Bell Laboratories. These tests consisted of vibration fatigue, and bending fatigue. In each case, the inherent ductility of the weld joint is utilized during life tests until failure. (Reference 6).

To establish a weldability index, physical properties were used in an emperical formula to provide a general weldability pattern between materials of different compositions. Being emperical, it does not yield valid results in all cases, but may be used as a guide for untried materials and alloys.

Formulae, developed by two investigators are shown below (References 7 and 8):

$$W = \frac{R}{Tm \times Cp \times Hf \times K}$$

where

Tm = melting temperature
Cp = specific heat
Hf = heat of fusion
K = thermal conductivity
R = electrical resistance

and

$$W = \frac{R}{FK_t} \times 100$$

where

W = weldability index
R = resistivity
F = melting point
K_t = thermal conductivity

Weldability ratings (Reference 9) of potential component lead materials were calculated from formula 7; data on two of these materials are shown in Table IV.

TABLE IV

Theoretical Weldability Rating

Material	Resistance	Melt Point	Thermal Conductivity	Weldability
Ni	6.48	1,455°C	0.22	2.15
Cu	1.673	1,083°C	0.94	0.16

In this instance, Ni was calculated to be 13.4 times better than copper.

The literature search for the weldability section included Government Reports and Specifications as well as authoritative articles by various industry specialists. See Appendix C.

C. ROUGH SCREENING

1. Lead Material Selection

Selection of component lead materials for weldability rough screening was accomplished concurrently with the completion of the industrial survey

and literature search section of this program. The materials are shown in Table V. This selection was based upon the highest frequency of use of the particular material by the industry.

All materials were welded in the optimum condition to better evaluate inherent weldability without the influence of adverse protective coatings. Materials requiring oxidation protection were gold plated except for the high conductivity copper lead material which was electro-tin plated to provide controlled electrical resistance at the weld interface. All other materials not requiring oxidation resistance were welded in the bare condition.

2. Selection of Test Methods

A 180 degree vertically opposed electrode set-up was initially made using standard Hughes 1/8 inch diameter RWMA class 2 electrodes. This choice was made to limit variables in the welding system caused by tip deflection which occurs when electrodes are offset.

TABLE V

Base and Plating Materials

Base Material	Plating Material			Plating Comments
	Gold	Tin	Bare	
Copper, OFHC		X		
Copperweld	X			All gold plate shall be* 0.05 to 0.2 mil thick per MIL-G-45024, Type I, Class I.
Alloy 180	X		X	
Alloy 52/152	X			A nickel strike may be deposited before gold plate per MIL-STD-1276.
Alloy 90				
Nickel "A"		X	X	
Dumet	X	X		Tin electroplate for subsequent hot flow shall be 0.1 to 0.2 mil thick.
Kovar	X	X		Tin electroplate not hot flowed shall be 0.3 to 0.5 mil thick.
Kulgrid 28			X	
Tantalum			X	
Brass	X			
Phos Bronze	X			
Stainless Steel			X	*Gold deposit shall contain no borates.

Torsion shear, and both restrained and unrestrained "T" tensile tests were conducted. During the evaluation of strength and sensitivity characteristics of these tests it was noted that orientation of the "T" test specimens in the slotted tensile test fixture was significant. Placement of the major wire against the front of the test fixture (Figure 2a) produced a degree of restraint which gave approximately 10 percent higher strength than obtained when specimens were rotated 180 degrees. The unrestrained "T" test in the slotted fixture (Figure 2b) produced a simple peel effect type failure.

"T" tests made in a hole (Figure 2c) instead of a slotted fixture produced the highest strength values. However, this was caused by a wedging force on the major wire against the side of the hole sufficient to bite into the wire and increase the load carrying ability above that of the weld joint by approximately 30 percent.

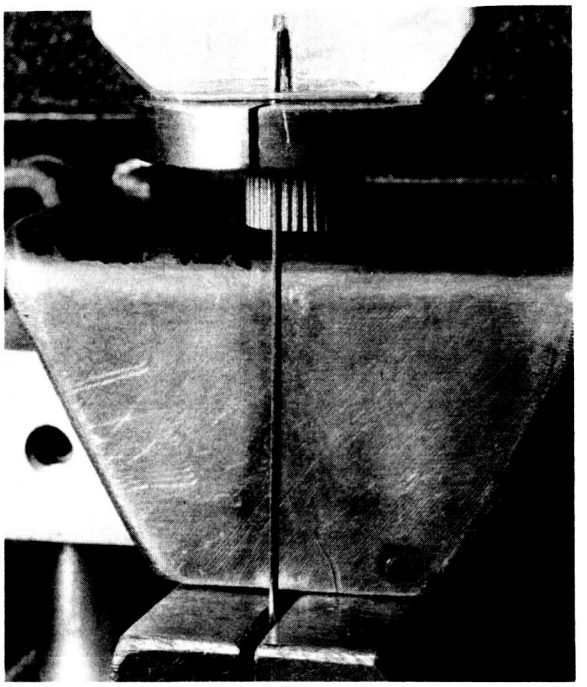
The lowest strength values and highest percent variation were produced by the torsion shear test (Figure 2d). Strength and ductility are evaluated best by the torsion shear test, and variation in weld joint configuration is more readily discerned as noted by the high percent variation in Tables VI and VII. The other tensile test methods do not impose as severe a bending moment at the weld joint and, therefore, were judged as being less discerning.

As a result of the test series the torsion shear test was chosen for component lead evaluation.

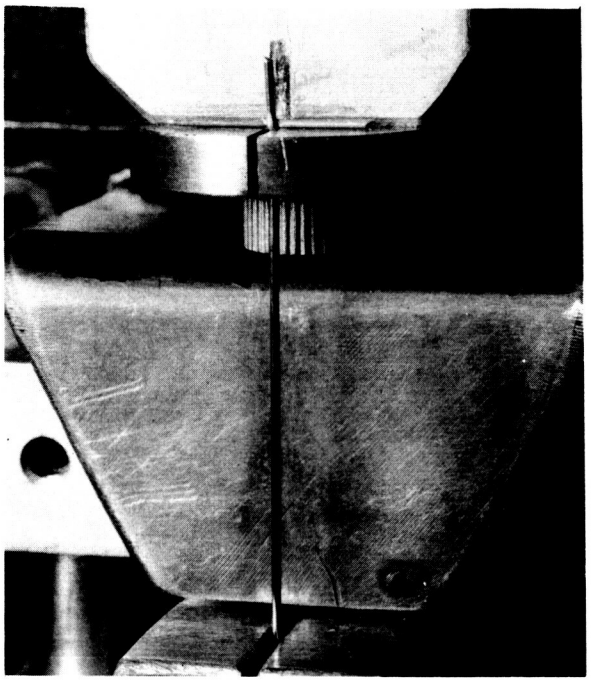
TABLE VI

Comparison of Tensile Test Methods

	Base Metal Tensile	Torsion Shear	Weld Joint	
			Tensile-Shear Unrestrained	Tensile-Shear Restrained
No. of Tests	25	25	25	25
Avg Strength Lbs	33.6	23.4	29.2	32.9
Min Strength Lbs	33.1	21.7	28.5	32
Range, Lbs	0.8	4.2	1.4	1.7
Joint Efficiency	–	70%	87%	98%
Variation, Percent	2.4%	18%	4.8%	5.2%



(a)



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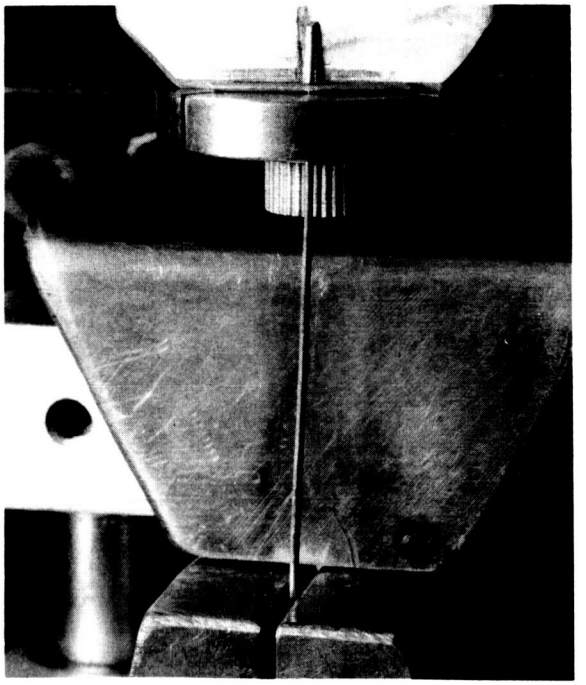
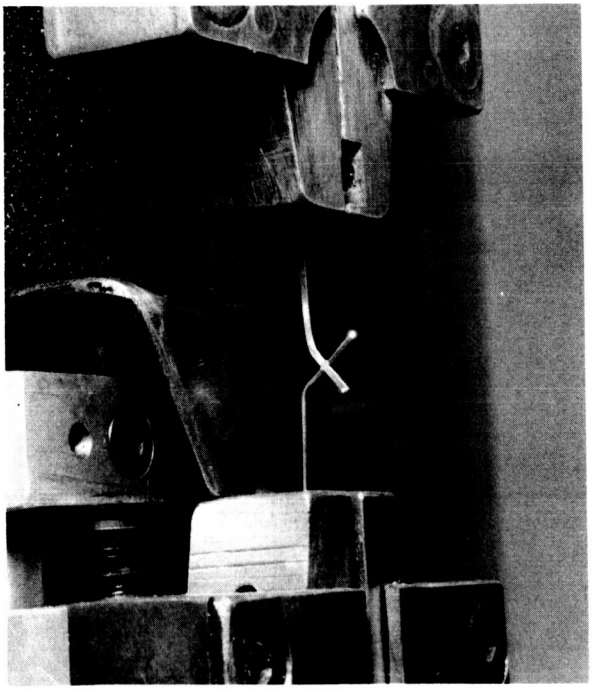


(c)



(d)

Figure 2. Orientation of Test Specimen in Fixture

TABLE VII

Comparison of Restrained Tensile-Shear Tests Welded with Reduced Power Input

	Base Metal Tensile	Weld Joint	
		Restrained-Slot	Unrestrained-Hole
No. of Tests	25	25	25
Avg Strength Lbs	33.6	27.1	33.2
Min Strength Lbs	33.1	24.5	32
Range, Lbs	0.8	7.3	1.6
Joint Efficiency	–	80.5%	98.6%
Variation, Percent	2.4%	27%	5%

Note: Tensile tests made with 0.025 diameter nickel "A" wire welded to 0.025 diameter nickel "A" wire.

3. Weldability Rating System

To furnish a numerical index of relative weldability the following formula was developed:

$$\text{Weldability Rating} = \frac{(\text{Area of Iso-Strength Diagram})}{\text{Percent Variation}} \times \frac{(\text{Minimum Joint Efficiency})}{\text{Percent Variation}}$$

so that:

$$\text{Weldability Rating} = \frac{(\Delta \text{ Joules})\,(\Delta \text{ Pressure})}{\text{Percent Variation}} \times \frac{(\text{Minimum Pull})}{(\text{Average Tensile of Weaker Material})}$$

The area of the iso-strength diagram for the purposes of rough screening was defined as being all settings yielding tensile strengths in excess of 60 percent of the weaker joint material in the low watt-sec region up to 50 percent set down or excessive spitting in the high watt-sec region (Figure 3). Minimum welding pressure in all instances was 4 pounds. Maximum welding pressure was that which produced acceptable welds over a minimum continuous range of two successive watt-sec settings.

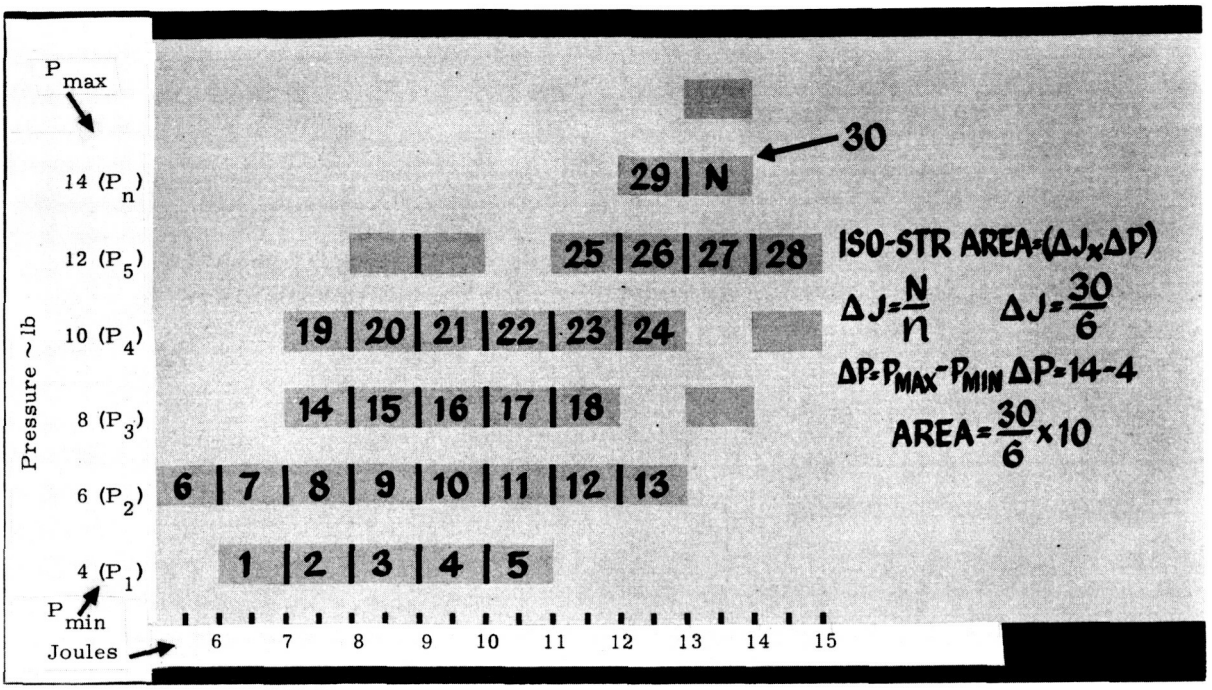


Figure 3. Calculation of Iso-Strength

Delta Joules were obtained by counting the total number of acceptable weld settings and dividing by the number of weld pressure settings which produced a minimum of two or more successive acceptable weld settings.

Delta pressure was obtained by subtracting the minimum pressure from the maximum pressure, both of which produce two or more acceptable weld settings. Percent variation was obtained by subtracting the minimum pull strength from the maximum strength (of a series of 25 specimens pulled at the apparent optimum weld setting) divided by the average of the 25 pulls. Minimum joint efficiency was calculated by dividing the average of the five lowest strength specimens (of the optimum 25 series) by the average parent metal strength of the weaker joint material.

4. Summary of Rough Screening

All materials surveyed were grouped into three categories: weldable, marginal, and unweldable. Weldability rating results, basic parameters for rating, and welding parameters are shown in Tables VIII, IX and X.

Eight pound pressure settings predominated in the summary of weld parameters. However, those materials with optimum pressure settings of 10 pounds could have been run at 8 pounds pressure without significant degradation of average strength values or percent variation.

TABLE VIII

Summary of Weldability Rating Rough Screening Results

	Resistance* Microhm-cm	Plating Material			Minimum Pull in Lbs
		Gold	Tin	Bare	
Weldable					
Stainless Steel†	70	–	–	3.7	16.1
Copper, OFHC	1.67	–	3.2	–	9.0
Dumet	10.8	2.8	1.5	–	15.1
Tantalum	12.5	–	–	2.2	15.3
Alloy 52/152	43.	2.2	–	–	15.1
Nickel	10.	–	1.9	1.8	15.0
Kovar	50.	1.4	1.2	–	14.2
Copperweld	4.5	1.3	–	–	8.5
Marginal					
Kulgrid-28	2.25	–	–	1.0	10.1
Alloy 90	15	0.5	–	–	10.4
Unweldable					
Alloy 180	30	1.4×1.0^{-2}	–	–	3.4
Brass‡	–	–	–	–	–
Phos Bronze‡	10	–	–	–	–

*Published data.
†0.031 diameter, all other materials 0.020 diameter
‡Unable to establish an iso-strength diagram for evaluation due to weld cracks and fractures.

Of the materials screened, a normal separation is apparent from the weldability rating number. Weldable materials had ratings equal to or greater than R 1.2; marginal materials had ratings of R 0.5 to R 1.0; and unweldable materials less than an R 0.1 rating. The weldable materials may be welded over a considerable pressure range while the marginal and unweldable materials cannot. Weldable materials were welded over a delta pressure range of 10 pounds or more while the marginal to unweldables were restricted to a delta pressure range of 6 pounds or less.

TABLE IX

Basic Parameters for Weldability Rating Materials Joined to Ni "A" Ribbon (Rough Screening)

Serial Number	Material	Δ Joules in Watt-Sec	Δ Pressure in Pounds	Variation in Percent	Minimum Pull in Pounds	Average Tensile of Weaker Material	Weldability Rating
109	S. S. Pins	5.25	14	15.6	16.1	20.54	3.7
114	Tantalum	3.29	12	14.1	15.3	20.54	2.2
107	Nickel "A"	4.17	10	17.8	15.0	19.8	1.8
108	Kulgrid 28	5.67	4	15.4	10.1	15.1	1.0
Gold Plated							
104	Dumet	3.83	10	11	16.4	20.54	2.8
112	Alloy 152	3.88	14	18.6	15.1	20.54	2.2
105	Kovar	2.86	12	17.9	15.4	20.54	1.4
111	Copperweld	4.00	10	20	8.5	13.1	1.3
113	Alloy 90	3.00	6	22.6	10.4	16.9	0.5
110	Alloy 180	2.33	4	116	3.4	18.9	0.014
Tin Plated							
106	Cu OFHC	4.67	10	10.4	9	12.44	3.2
117	Nickel "A"	3.43	12	16.9	15	19.6	1.9
118	Dumet	4.00	12	23.5	15.1	20.54	1.5
119	Kovar	2.63	14	21.1	14.2	20.54	1.2

TABLE X

Weld Parameters for Rough Screening of Component Lead Materials

Condition	Material	Pressure in Lbs	Joules in Watt-Sec	Serial Number
Bare	S. S. Pins	8	11	109
	Tantalum	10	9	114
	Nickel "A"	8	12	107
	Kulgrid 28	5	17	108
Gold Plated	Dumet	8	9	104
	Alloy 152	8	7	112
	Kovar	6	6	105
	Copperweld	8	19	111
	Alloy 90	8	15	113
	Alloy 180	7	12	110
Tin Plated	Cu OFHC	8	16	106
	Nickel "A"	10	13	117
	Dumet	8	10	118
	Kovar	10	7	119

Note: All electrode setups 180 degrees vertically opposed

It should be noted that the weldability ratings calculated in this phase of the program were established on material procured directly from the wire manufacturer, material which had not been subjected to the effects of component fabrication. It is anticipated that processing by component manufacturers could alter the welding characteristics sufficiently to produce some change in weldability rating. Also other factors such as offset electrode setups typical of industry application, lead material orientation between the electrodes, uniformity and repeatability of current magnitude and duration from the welding power source, and the criteria used to define and limit "acceptable settings" have an important bearing upon the weldability numbers.

All welding for the rough screening of component lead materials was performed on a commercial capacitor discharge power supply, Hughes, Model VTW-60, which has all current carrying components gold plated; large AWG-1 welding leads were used. It is recognized that the design of the power supply is an important factor in achieving a sound weld joint

and that weldability of the materials under evaluation can be improved by improving power supplies. This phase of the study was performed to establish weldability of component lead materials welded by typical equipment in use by the industry at present. See Appendix D for additional equipment that was used.

In concluding the Phase I rough screening part of this program the following lead material selections were made for Phase II fine screening. The selection is based upon the indicated weldability rating and industry utilization.

1 Stainless steel

2 Copper, OFHC

3 Dumet

4 Alloy 52/152

5 Nickel

6 Kovar.

II. WELDABILITY PHASE II

A. FINE SCREENING WELD THEORY AND TESTS

1. Welding Control and Monitoring Circuits

The instrumentation needed for recording load strain curves and to monitor various weld characteristics was assembled and calibrated at the beginning of the Phase II fine screening. Samples of curves obtained by this instrumentation are shown in Figures 4, 5, and 6. These figures were made from the actual curves and are true representations of the recorded data.

Figure 4 is a reproduction of the load-strain characteristics of unborated Dumet wire precleaned by the OP-98 process. The wire was 0.02 inch in diameter and was pulled at a constant speed of 0.5 inch per minute. The sample showed an elongation of 0.28 inch with a gage length of 1 inch. Ultimate failure occurred at a force of 24 pounds. The jitter at the beginning of the trace was caused by movement of the tensile jaws while inserting the wire sample.

The line on the curve from points A to B shows the jitter present due to the closing of the fixture jaws. From points B to C the first stress-strain is evident. The flat portion from C to D shows the setdown of the fixture jaws as they bite into the copper sheath on the Dumet wire. The portion of the curve from D to E represents the straightening of the wire which may not be straight in the jaws. The portion of the curve from E to F is the final pull before the yield point F is reached. It is this portion of the curve which may be used to measure the modules of the test specimen. The line from F to G is the elongation of the wire beyond the elastic limit, and point G is the ultimate failure point, which gives the ultimate strength of the wire or weld joint. The jitter at the end of the curve is due to the backlash of the mechanical linkage in the tensile test fixture.

Figure 5 shows the same information as given in Figure 4 except that Figure 5 is a reproduction of a load-strain curve for Dumet to nickel ribbon. The points shown are the same as given in Figure 4. The setdown of the jaws (C to D) is not as pronounced as in Figure 4 since one end of the specimen is nickel. The greater curve in the portion from D to E is due to

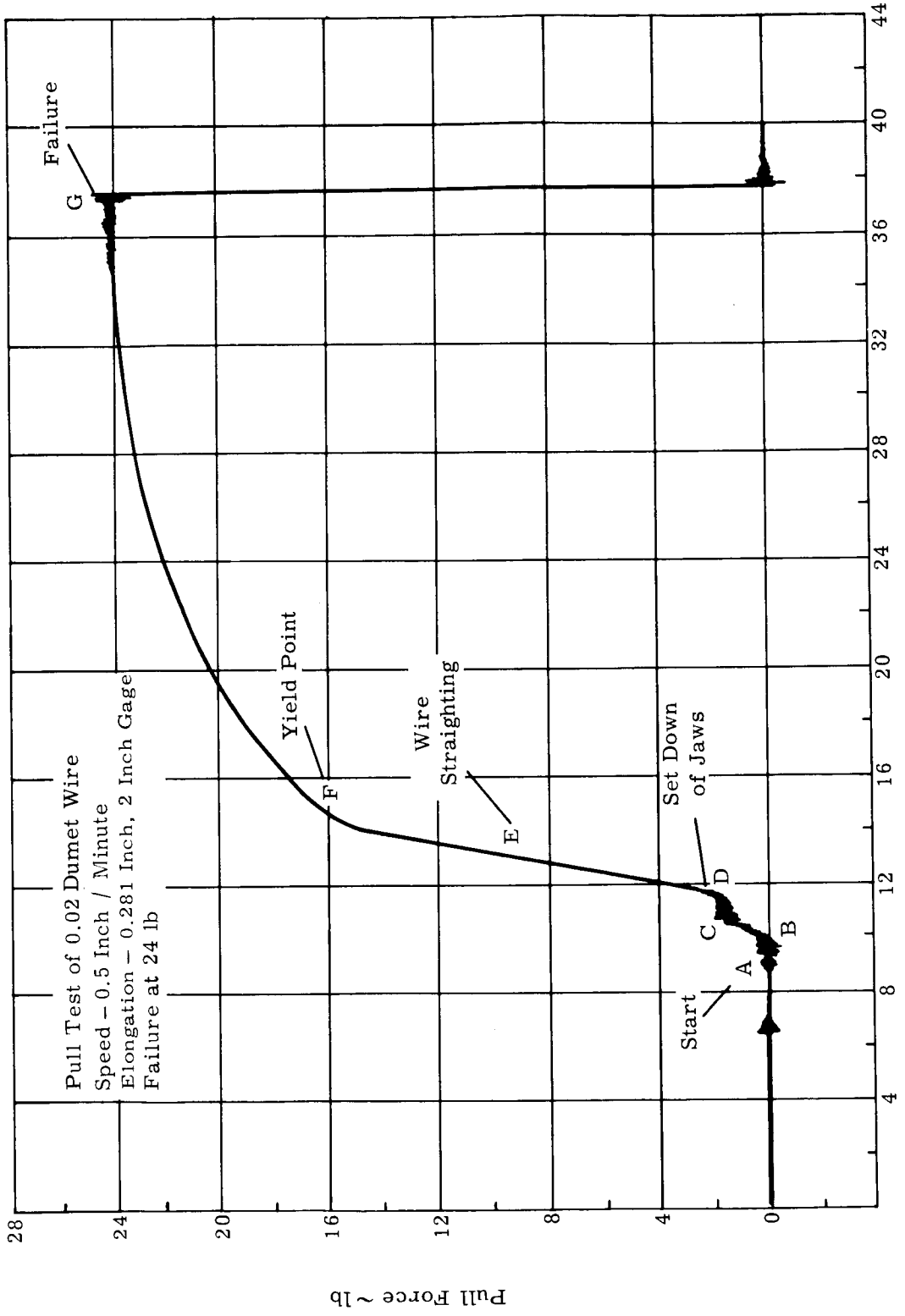


Figure 4. Pull Test of 0.02 Dumet Wire

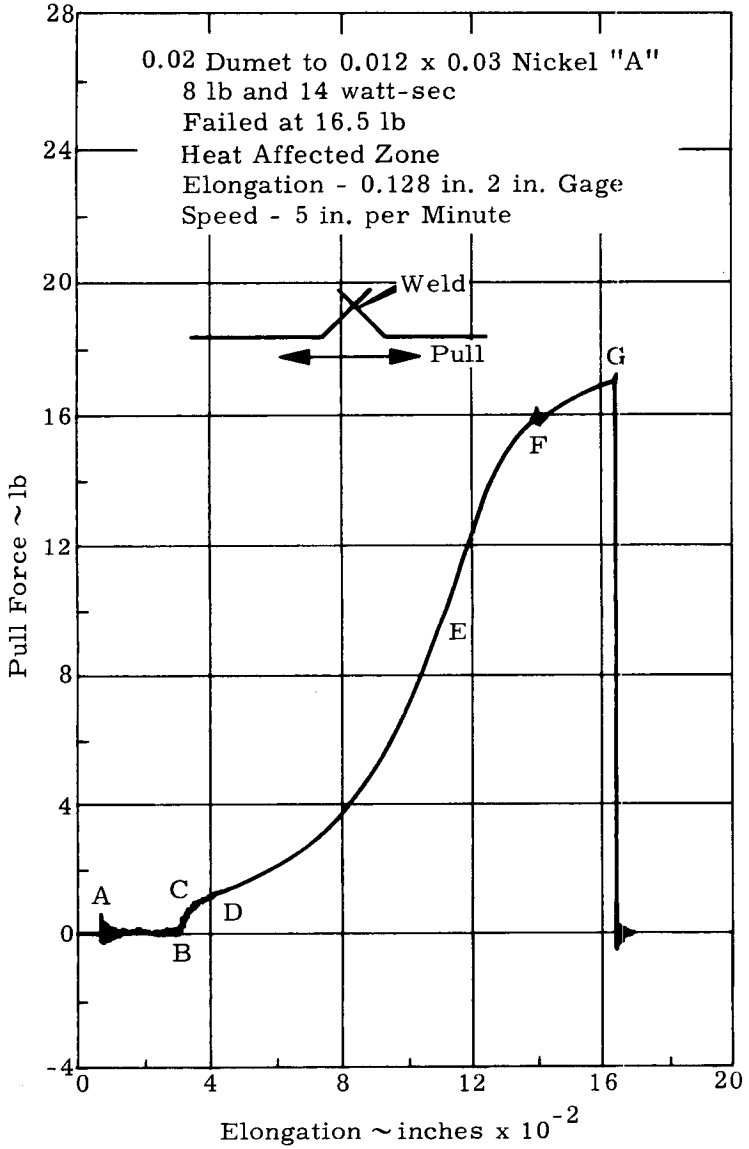


Figure 5. Pull Test of Dumet to Nickel Ribbon

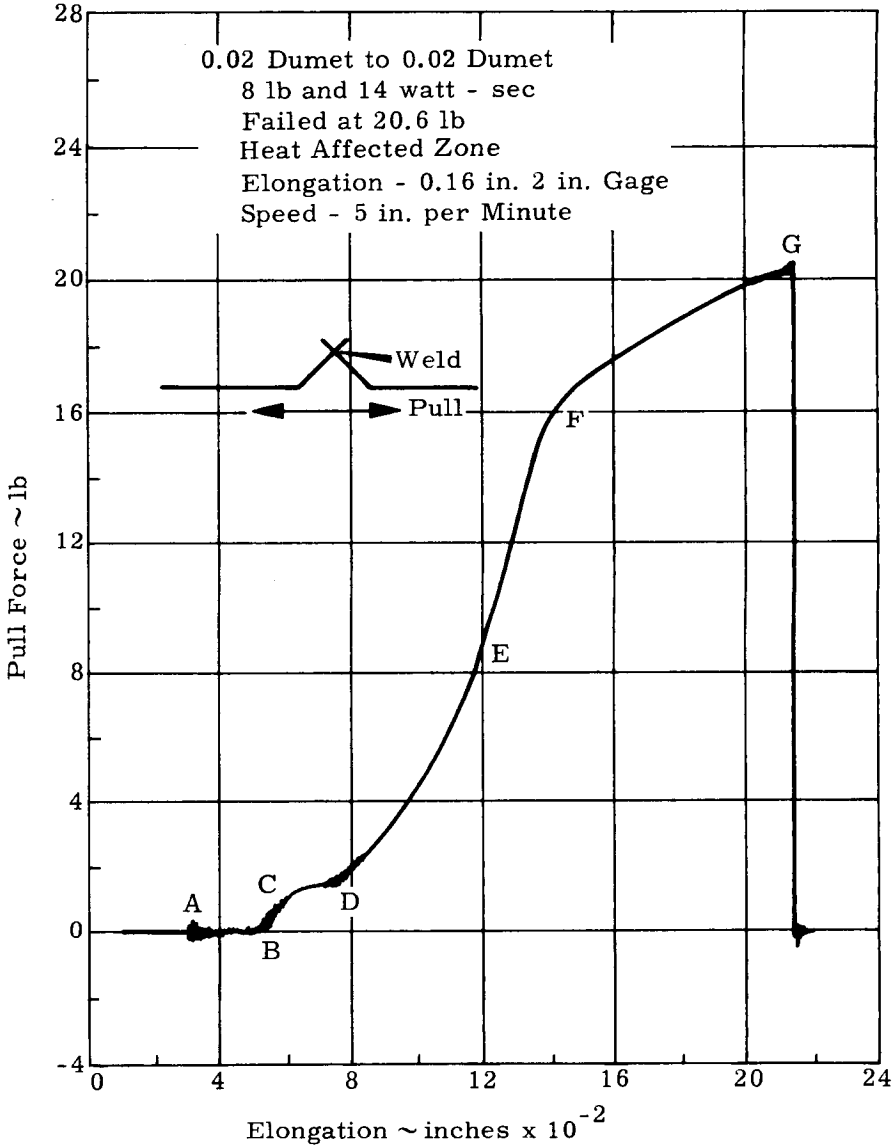


Figure 6. Pull Test of Dumet to Dumet

the offset in the specimen, and it is this offset that must be straight before the curve becomes linear as shown in the portion above point E. Point G is the failure point and as can be seen the joint failed at 16.5 pounds after an elongation of 0.128 inch. The joint failed adjacent to the weld nugget in the heat affected zone. The jitter at point F is due to the backlash caused when the yield point of the weld occurred at the same time the yield point of the wire was reached.

Figure 6 is another load-strain curve reproduction of a welded joint. This curve was made on Dumet to Dumet under the same conditions as was Figure 5. This joint showed an increased strength of 20 percent over the Dumet to nickel weld and an increase in elongation as well. Notice the setdown of the jaws as given by the curve from point C to D. This joint failed at 20.6 pounds and also in the heat affected zone adjacent to the weld.

A comparison of the three curves shows that the first yield point in all cases was that of the Dumet wire and occurred at exactly the same point, which was approximately 15.8 pounds. The slope of the curves between points E and F is a measure of the modulus of elasticity. As can be seen from the curves the modulus is highest for the unwelded Dumet and lowest for the Dumet to nickel weld.

2. Effects of Weld Cable Size

The effect of interconnecting cable size, which forms the conductive path between the power supply and the welding head, was investigated. Twenty-five tensile test specimens were welded, using first No. 4 AWG cables and then No. 1 AWG cables 10 inches long. The material welded was copper wire (soft) OFHC 0.020 inch diameter plated nickel 50-100 millimeter gold, 50-70 millimeter to nickel "A" ribbon bare. Electrode setup was 180 degrees vertically opposed. Weld settings were 8 pounds and 18 watt/seconds. The tabulation of the results is shown in Table XI.

TABLE XI

Interconnecting Cable Size Test Results

	Maximum Tensile (lb)	Minimum Tensile (lb)	Average Tensile (lb)	Percent Variation
No. 1 AWG Cables	10.9	9.8	10.23	1.1/10.23 = 10.75%
No. 4 AWG Cables	10.5	9	10.04	1.5/10.04 = 14.94%

The larger cables, which offer a lower resistance path to welding current, show a slight advantage. However, the distribution of the tensile strengths shows less difference than the percent variation would seem to indicate. The conclusion, as in the case of other details of the welding system which can introduce small variables, is that the larger cables should be used.

3. Effect of Power Supply Current Variation Versus Strength of Welded Joint

Variations in current output from the power sources were recorded during a series of 15 successive manual firings made at a constant setting with the weld head shorted. The results are shown in Figure 7.

To determine the relationship between weld strength and weld current variation a test series of 25 tensile specimens were made of OFHC copper wire 0.020 inch diameter gold plated and nickel "A" ribbon 0.012 by 0.030 inch bare at an optimum weld setting of 8 pounds and 18 watt/seconds at 180 degrees vertically opposed setup. Correlation of the recorded current magnitude and matching specimen tensile strength did not show any set pattern or relationship between the current variation and the tensile strength of 14.9 percent as shown in Table XII.

TABLE XII

Weld Strength Versus Weld Current Variation

Parameter	Maximum	Minimum	Average	Percent Variation
Current (amps)	1,805	1,759	1,776	2.6
Tensile (lb)	10.5	9.0	10.07	14.9

The increase in percent of current variation from 1.85 percent to 2.6 percent between the two test series is probably accounted for by the variables introduced into the welding system by the lead materials between the electrodes.

4. Evaluation of Electrode Dressing Procedures

Electrode tip preparation methods were investigated for the effect on surface finish of the electrode faces. Also investigated concurrently was the effect of surface finish on weld strength and continuity.

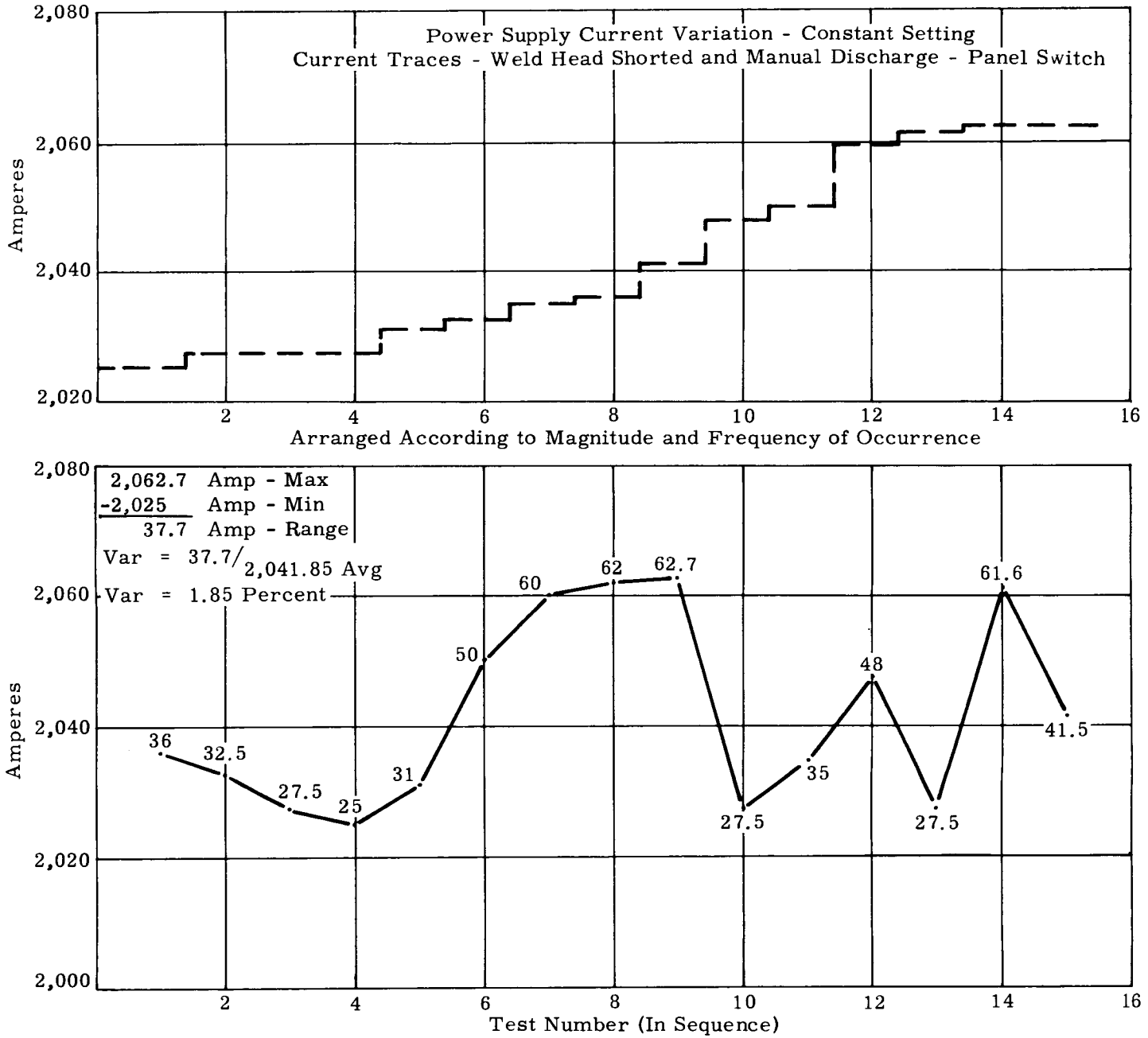


Figure 7. Power Source Current Variation

OFHC soft copper, plated with 50 to 100 microinches of nickel and 50 to 70 microinches of gold was used in the first evaluation. Tests were performed with the electrodes prepared by the standard Hughes 600 grit electrode burnishing discs and the fine abrasive stainless steel strip contact cleaners fabricated by P, K. Neuses, Inc., of Arlington Heights, Illinois. The electrodes were tested in the 180 degree opposed position and in the 60 degree included angle, 9 o' clock position.

There was no significant difference in weld strength between the tip preparations in the 180 degree opposed position. However, there was a significant difference when the lead material orientation was changed and the tips cleaned with the stainless steel cleaners in the 9 o-clock position. The variations in weld strengths were small when the burnishing discs were used on the electrodes regardless of lead orientation. Test results are summarized and shown in Figure 8 as a data profile for comparison.

The stainless steel cleaning strips were drawn through the electrode tips longitudinally under the full setup pressure. When examined under 40X magnification the electrode face showed some score marks, and the stainless steel cleaner strip displayed a loading of the surface with material from the electrodes. This loading of the cleaning strip surface caused by the relatively high per square inch electrode pressure produced the slightly scored electrode faces.

The Hughes 600 grit cleaning pads gave the best cleaning results. Pads were carefully drawn longitudinally between the electrode faces at low pressure and a clean unused abrasive area was presented on each pass. To finish the face a light rotary motion under low pressure was used.

Frequency of cleaning was another factor appraised. With the materials and settings used in this test series, changing the frequency of cleaning from after each single weld to once every five welds did not have any deterimental effect. However, greater frequency of cleaning - such as after each weld - should be used when arcing, spitting, or splatter occurs that could foul the electrode faces. Tin plating or lead tin coating of load materials is an additional cause of rapid electrode face contamination.

A second series of tests was run again on OFHC copper as a representative ductile material; however, in this series, an isostrength diagram was made to establish optimum weld parameters in the 9 o-clock position. There was no significant difference between weld strengths regardless of tip preparation or lead orientation. Results are shown in Figure 9.

A third series was run on gold plated rodar, representative of the harder component lead materials. Results are shown in Figures 10 and 11. It was

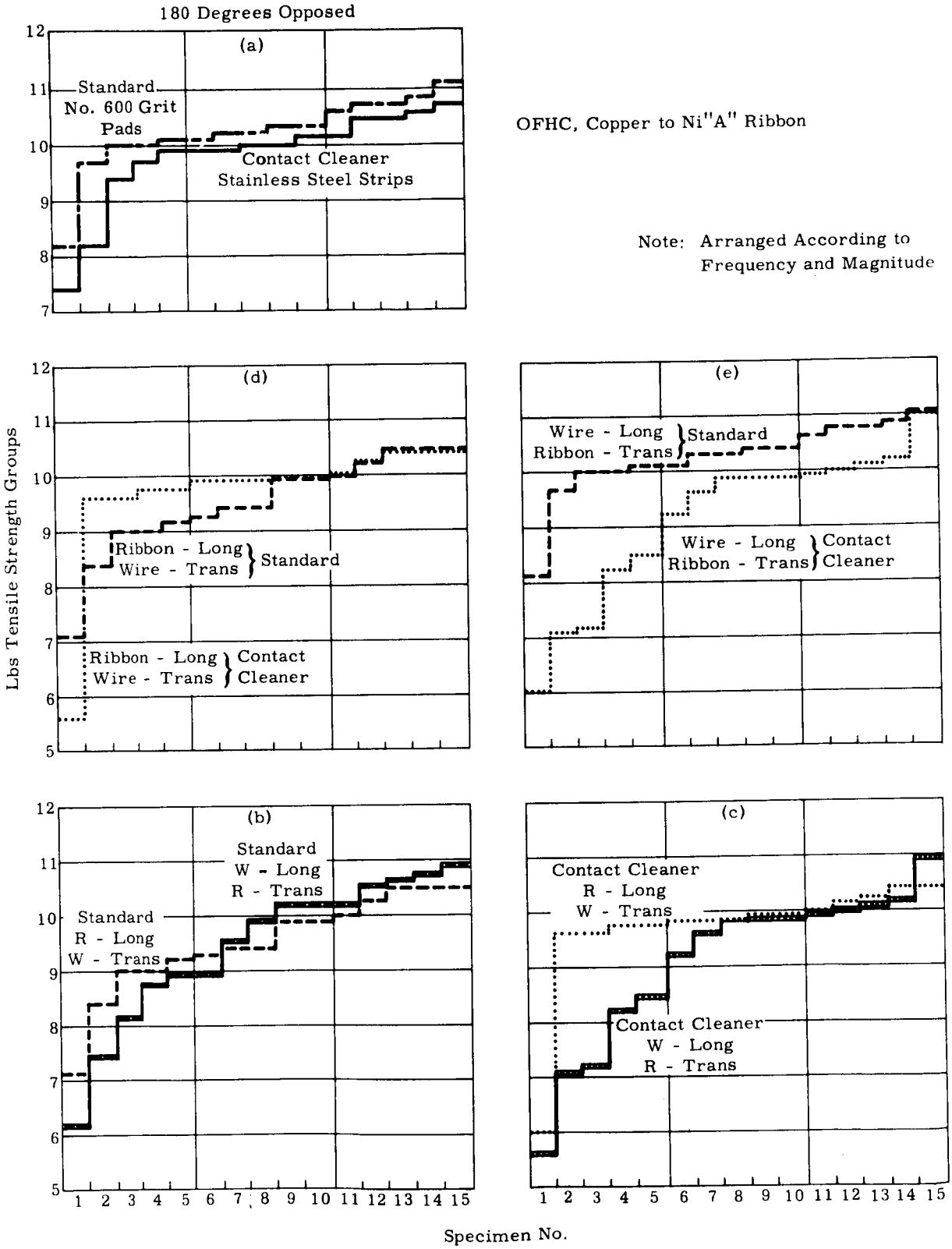


Figure 8. Data Profile Analysis OFHC to Ni "A" Ribbon

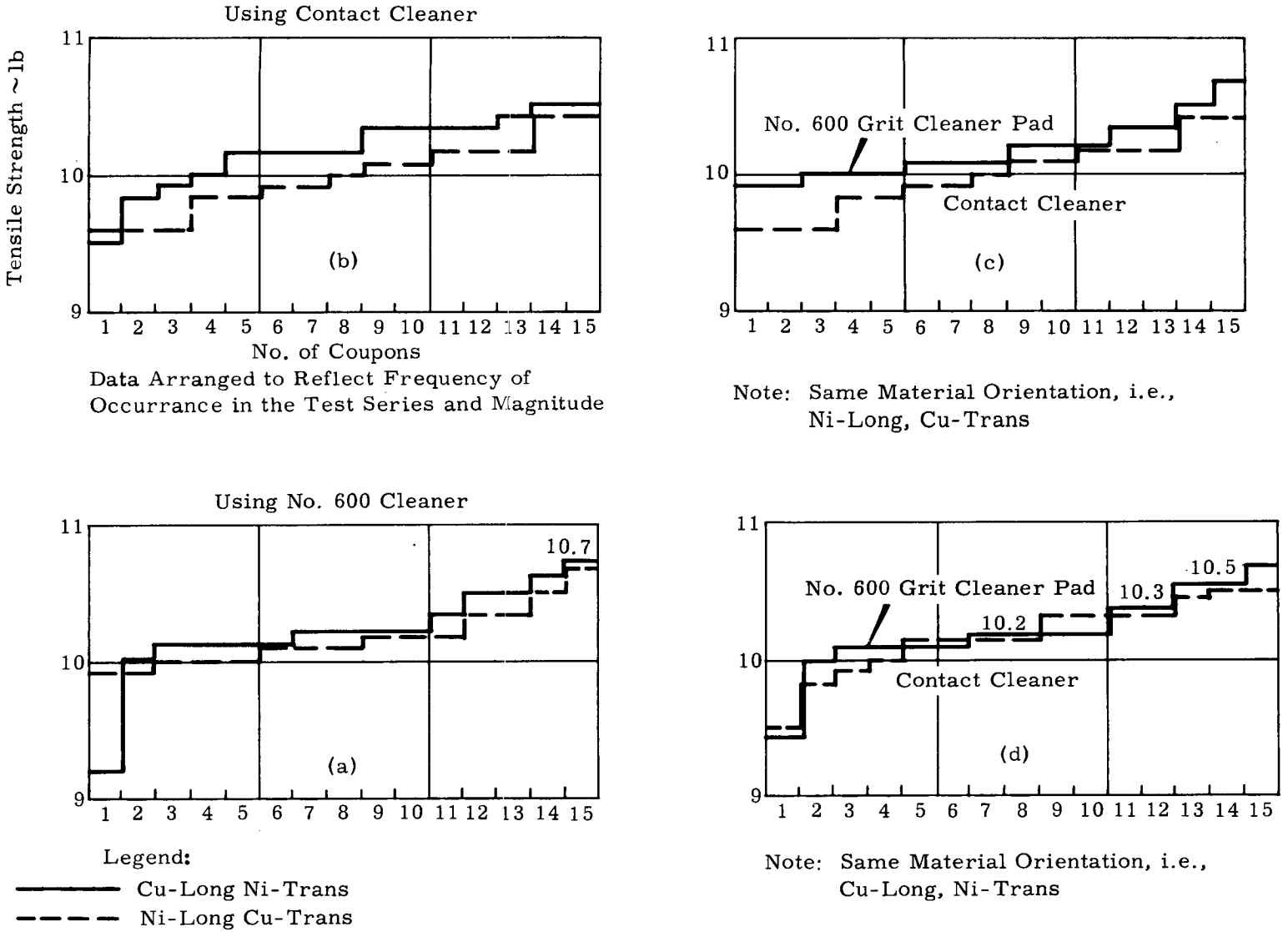
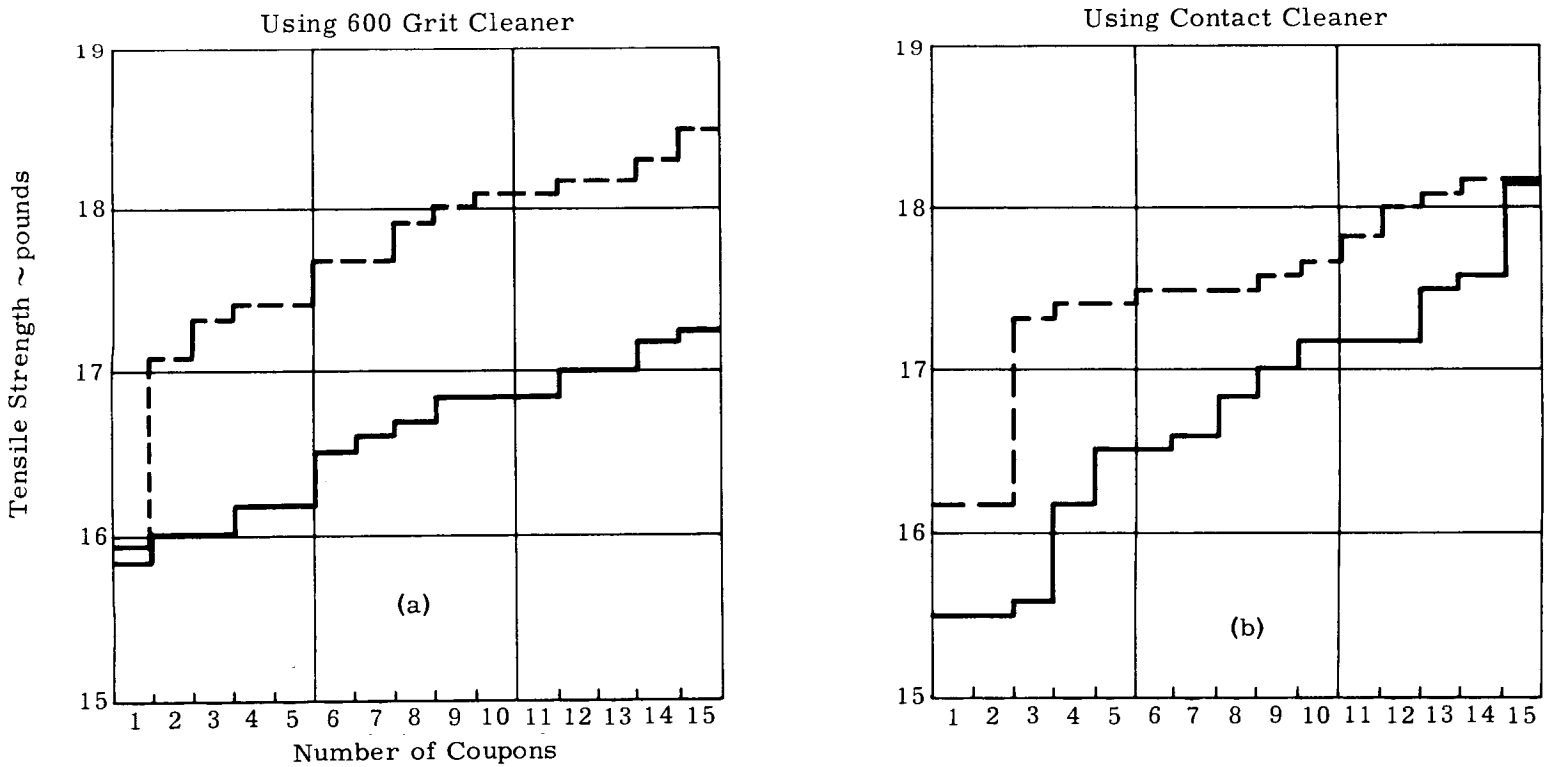


Figure 9. Data Profile Analysis Copper to Nickel Ribbon



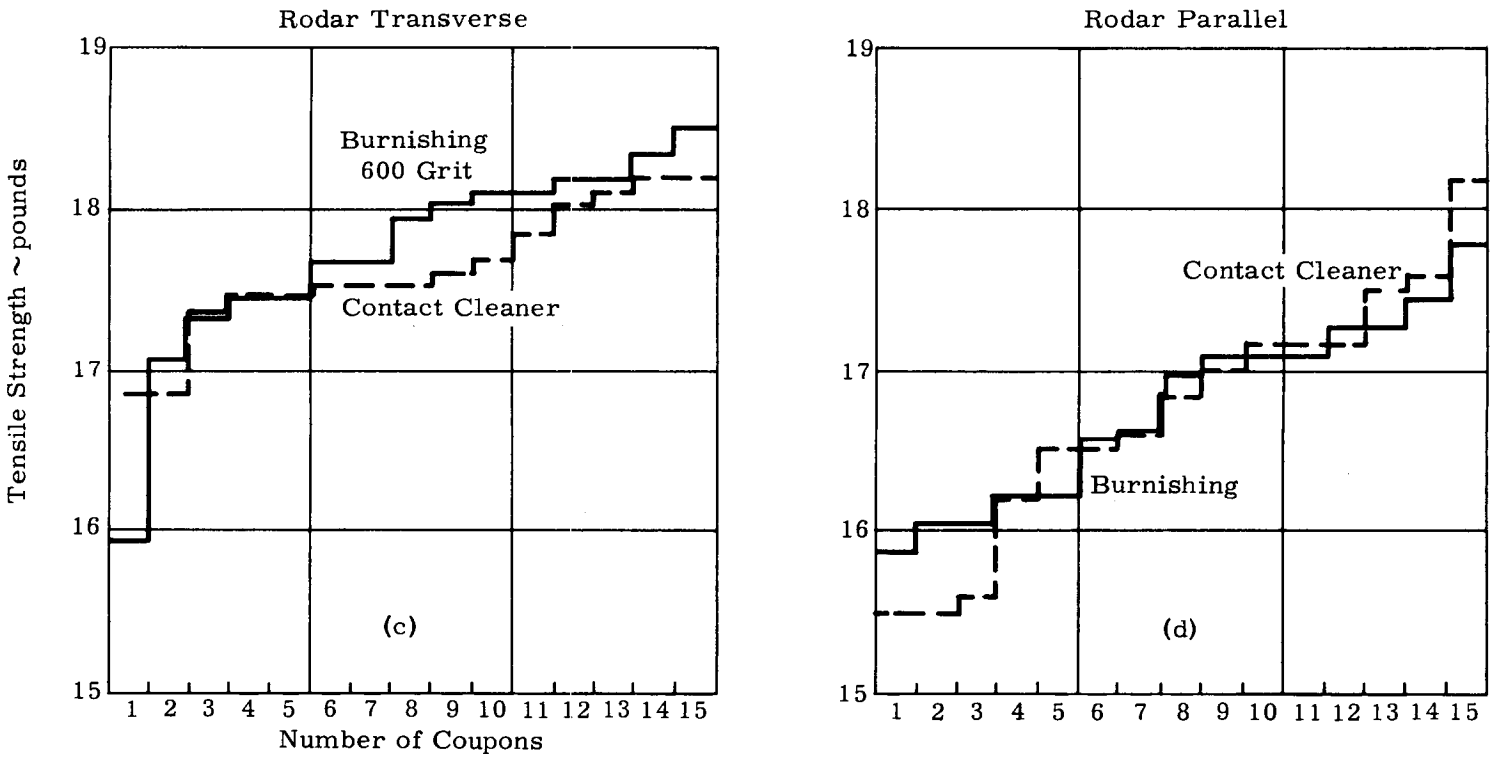
Note: Data arranged to reflect frequency of occurrence in the test series and magnitude.

Legend:

- - - - - - Ni Parallel Rodar-Trans

——— Rodar-Parallel Ni-Trans

Figure 10. Data Profile Analysis Rodar to Nickel "A" Ribbon



Pull tests are arranged in order of increasing magnitude.

Figure 11. Data Profile Analysis Gold Plated Rodar to Ni "A" Ribbon

anticipated that the harder component lead materials would not be as tolerant to lead orientation as the softer materials. This was shown to be true. While the softer materials deformed to produce optimum tip to wire contact despite weld orientation, the harder materials did not. Optimum weld parameters were established for the 9 o'clock position and the welds were made in both lead orientations with electrodes prepared with the 600 grit burnishing discs and the contact cleaners.

Analysis of the results shows that the standard 600 grit burnishing discs produce results equal to or better than those obtained through the use of the stainless steel contact cleaners.

Component lead orientation has a significant effect on weld strength, especially when the harder materials are being welded. Even though full weld pressure was used to dress the electrodes when the stainless steel contact cleaner was used (for optimum parallism), a pronounced variation in weld strength occurred when lead orientation was changed. In the more ductile materials, typified by OFHC soft copper, the welding electrodes made good electrical contact despite electrode orientation. The ductile lead material deformed. Even here the burnishing discs showed an advantage of lower sensitivity to orientation when weld schedules deviated from the optimum. Acceptable results were achieved with both tip cleaners in both orientations. Optimum results were achieved with the wire oriented transverse to the electrode axis.

B. VERIFICATION OF WELDABILITY RATING SYSTEM

A summary of the weldability of component lead materials is given in Table XIII. In this table it is apparent that weld operator and power supply are contributing factors in determining the weldability number. For a given operator, an early comparison on Alloy 152, gold plated, showed percent variation in weldability numbers of the order of 40 percent. However, as the weldability rating technique was improved, this percent variation was lowered to 10 percent on a similar material, gold plated, nickel "A". A considerably lower percent variation was obtained in the duplicate tests run on the bare nickel "A". Here values are very close. Major differences noted in the last two series of Alloy 152 and nickel "A" were in the percent variation which caused the numbers to differ.

Table XIV presents a comparison of weldability ratings obtained on the same component lead materials but with different weld electrode position. As was anticipated, the weldability of the lead materials was higher when welding was performed in the 180 degree opposed position as compared to the 9 o'clock position. The same relative order of merit is displayed, generally with some variation. Gold plated Dumet and bare OFHC copper

TABLE XIII

NASA Weldability Rating Verification

	AMT-NASA Lab EQ713202		AMT-ME Lab EQ712602	
Power Supply	Hughes VTW-30B		Hughes VTW-30B	
Weld Head	Hughes VTA-60		Hughes VTW-60	
Operator	A	B	A	B
Material				
Copper OFHC-Gold Plate			6.6	4.83
Copper OFHC-Bare and Contaminated			1.55	
Dumet-Gold Plate			4.08	
Alloy 152-Gold Plate	4.82		4.91	
	3.22			
Nickel "A" Bare	1.84	1.4	6.92	
			7.07	
Nickel "A" Gold Plate			8.04	
			8.86	
Kovar-Gold Plate	2.37	3.21	3.54	
Kulgrid 28-Bare	0.9		0.588	1.42
Alloy 180-Gold Plate	0.017			0.099

were most adversely effected by welding in the 9 o'clock position. The most weldable materials remained essentially high with OFHC copper appearing better in the 180 degree opposed position than stainless steel. In this instance, it is interesting to note that the weldability number of the SS pin did not change significantly with either electrode position. The larger inherent diameter of 0.032 permitted appreciable mutilation without lowering the SS pin strength below that of the ductile nickel "A" ribbon which was used in each instance. In the case of the other lead materials, the smaller diameter and lower strength permitted the deleterious effects of non-uniform deformation to reveal itself by affecting the weldability number, particularly in the 9 o'clock electrode position.

The deflection of tapered offset electrodes, which simulates the most critical welding conditions usually encountered in production, causes lower average weld strengths. Major lead material factors, which in combination with tip deflection affect this lower strength, are size, shape, relative hardness, and orientation of the leads between the electrodes.

TABLE XIV

Fine Screening 9 O' Clock
Wire Longitudinally Orientated
AMT NASA Activities Laboratory

Material	Reference Service Number	Weldability Average Ratings in Descending Order (9 o' clock)	(180 degrees)
Nickel (Gold Plated)	151	4.6	8.45
Stainless Steel 0.030 Inch Diameter Module Pins Bare	143	3.65	3.88
Copper (OFHC) Soft Gold Plated	148	2.475	6.6
Rodar Gold Plated	147	1.9	3.5
Alloy 152 Gold Plated	150	1.34	4.91
Dumet Gold Plated	145	0.85	4.1
Copperweld Gold Plated	154	0.816	-
Copper (OFHC) Bare and Contaminated	153	0.622	1.6
Kulgrid 28 Bare	144	0.101	0.6

Equipment used: Hughes VTW-30B EQ No. 712602
Hughes VTA-60 Weld Head 60A-789

C. IMPROVED METHOD OF DATA ANALYSIS

Further analysis of the weld test data used to arrive at a weldability number showed that single data exerted too great an influence on the final weldability number. The two factors, percent variation and minimum joint efficiency, both utilize the single low tensile value, with the single high tensile value also being used in percent variation. To minimize the effect of single points, a method was devised to use the average of the lowest five tensile values (see Figure 12) and the average of the highest five tensile values. Since the difference between the high five average and the low five average does not represent the full data spread, a constant was devised graphically on probability paper using statistical cumulative percents. A constant was established for sample populations of 10, 15, 20, 25 and 30.

Spread in data is established by the formula $S = K(T_{H5}-T_{L5})$ which then permits a more significant determination of the values percent variation and minimum joint efficiency

where:

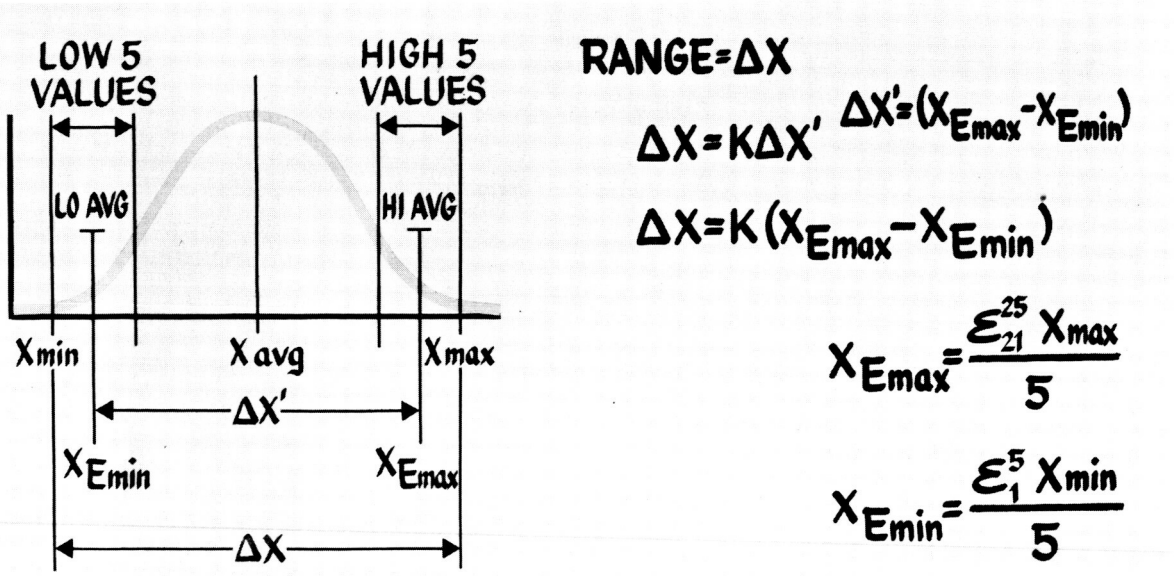


Figure 12. Weld Measurement

$$\text{percent variation} = \frac{\text{Spread}}{(\text{Average Weld Strength})}$$

and

$$\text{minimum joint efficiency} = \frac{(\text{Average Weld Strength} - 0.5\ \text{Spread})}{\text{Strength of Weaker Base Metal}}$$

To evaluate the improved formula, two isostrengths were run on gold plated 0.020 diameter Dumet with electrodes in the 9 o' clock position, and two lots of 25 pulls were made at the optimum setting. Weldability numbers were established by the original method and by the improved method. Weldability rating established by the original method differed by 14 percent. Ratings established by the improved method differed by 8 percent.

An additional advantage of the improved method is its ability to better detect differences introduced by a variable such as gold plating. Data on bare and gold plated 0.020 diameter nickel "A" wire welded to bare 0.012 by 0.030 inch nickel "A" ribbon were re-evaluated using only those points on the isostrengths that would not produce a defect which could cause a mission failure. Data obtained with electrodes in the 180 degree opposed position produce weldability numbers which were very close when calculated by the original method. When calculated by the improved method,

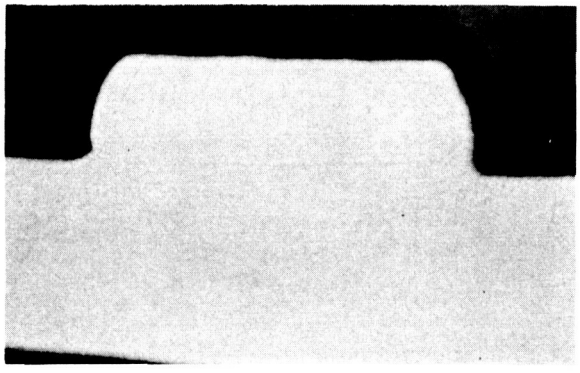
values were 8.5 for the gold plated nickel "A" wire and 5.75 for the bare nickel "A" wire, significantly different.

Welded specimens have been prepared with low, optimum, and high welding currents and with welding electrodes in the 9 o'clock position. Metallographic examinations are being conducted to demonstrate the effect of electrode position on welding heat distribution.

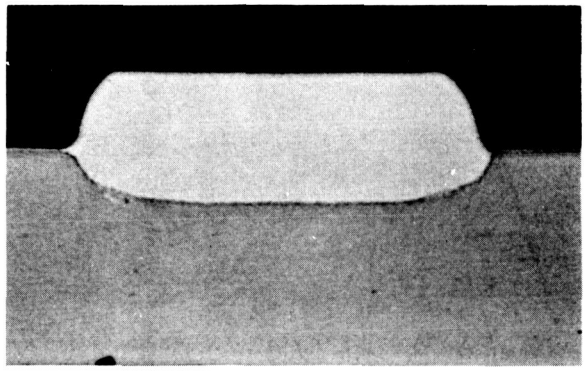
D. METALLOGRAPHIC INVESTIGATIONS

A series of photomicrographs were made of four typical weld joints. In each case, nickel, Kovar, Dumet, and OFHC copper were welded to nickel "A" ribbon. All component lead materials shown are 0.020 inch diameter and the nickel ribbon is 0.012 by 0.030 inch.

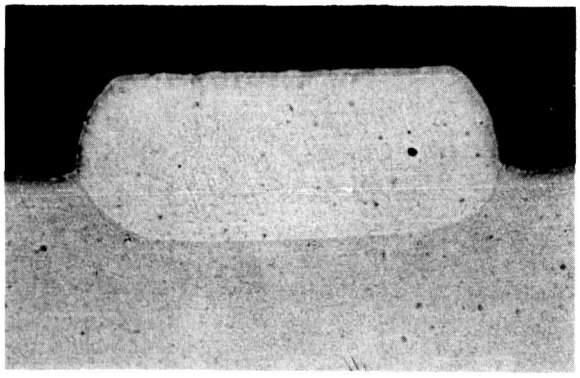
Figure 13 shows the weld joints produced at the optimum weld settings for the 180 degree opposed electrode position. These are also typical of



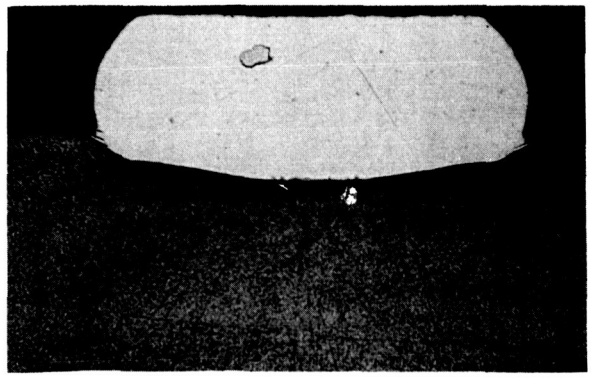
(A) 11 Watt Second
Bare Nickel "A" Wire



(B) 10 Watt Second
Gold Plated Dumet



(C) 6 Watt Second
Gold Plated Kovar



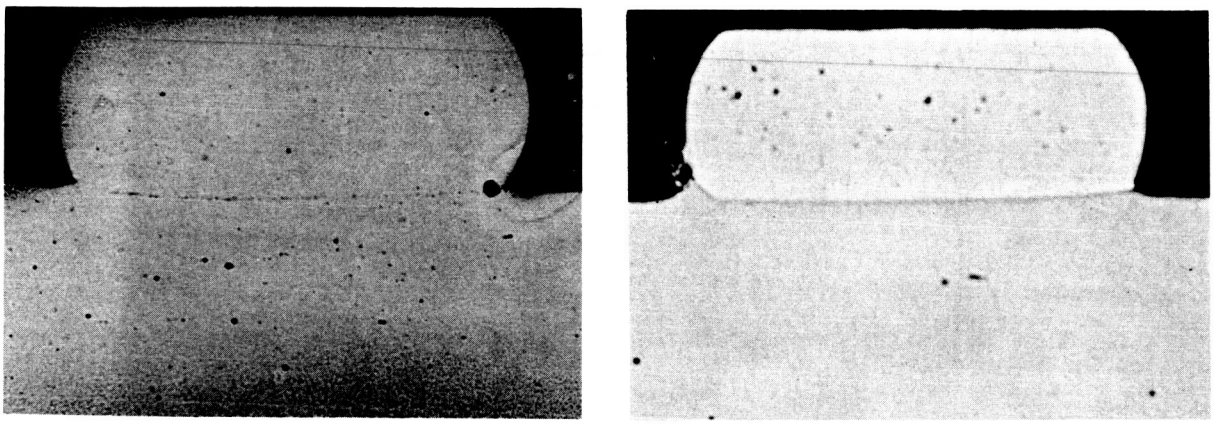
(D) 18 Watt Second
Gold Plated OFHC

Figure 13. Weld Joints at Optimum Weld Settings for 180 Degrees Opposed Electrode Position

welds obtained in the 9 o'clock position with the component lead longitudinal to the welding electrode face (parallel to the axis of the electrodes) and with the ribbon transverse to the electrode face.

Uniform welds were obtained in the 9 o'clock position for nickel, Kovar, and OFHC component leads as evidenced by results obtained at low watt/second values. Both nickel and Kovar weld joints were typical in Figure 14.

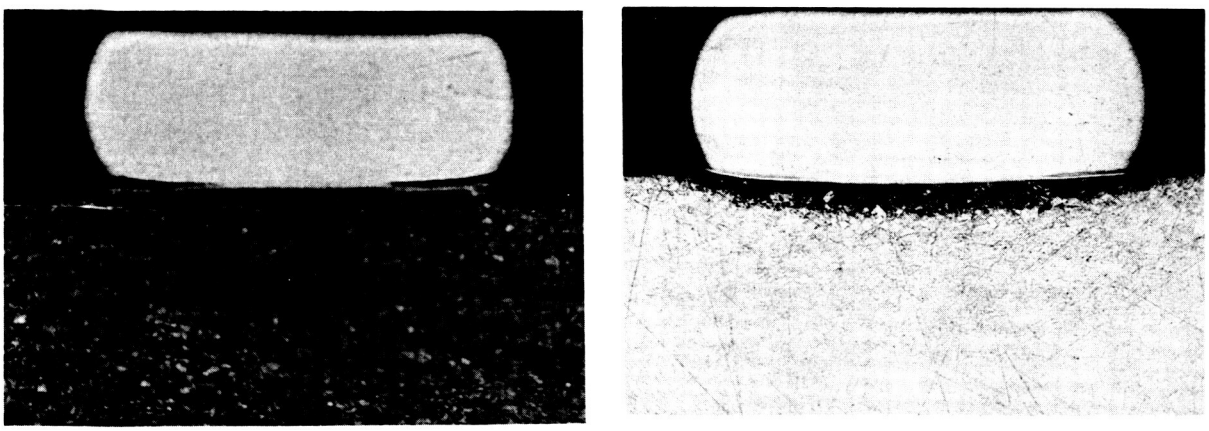
However, low weld heat initiated the weld at the center of the OFHC copper to nickel "A" ribbon in both the 180 degree opposed (Figure 15 (A)) and 9 o'clock (Figure (B)) welding positions so that a notch effect was produced



(A) 7 Watt Second
Bare Nickel "A" Wire

(B) 4 Watt Second
Gold Plated Kovar

Figure 14. Typical Weld Joints – Electrode in 9 O'Clock Position and Low Weld Heat (50X)



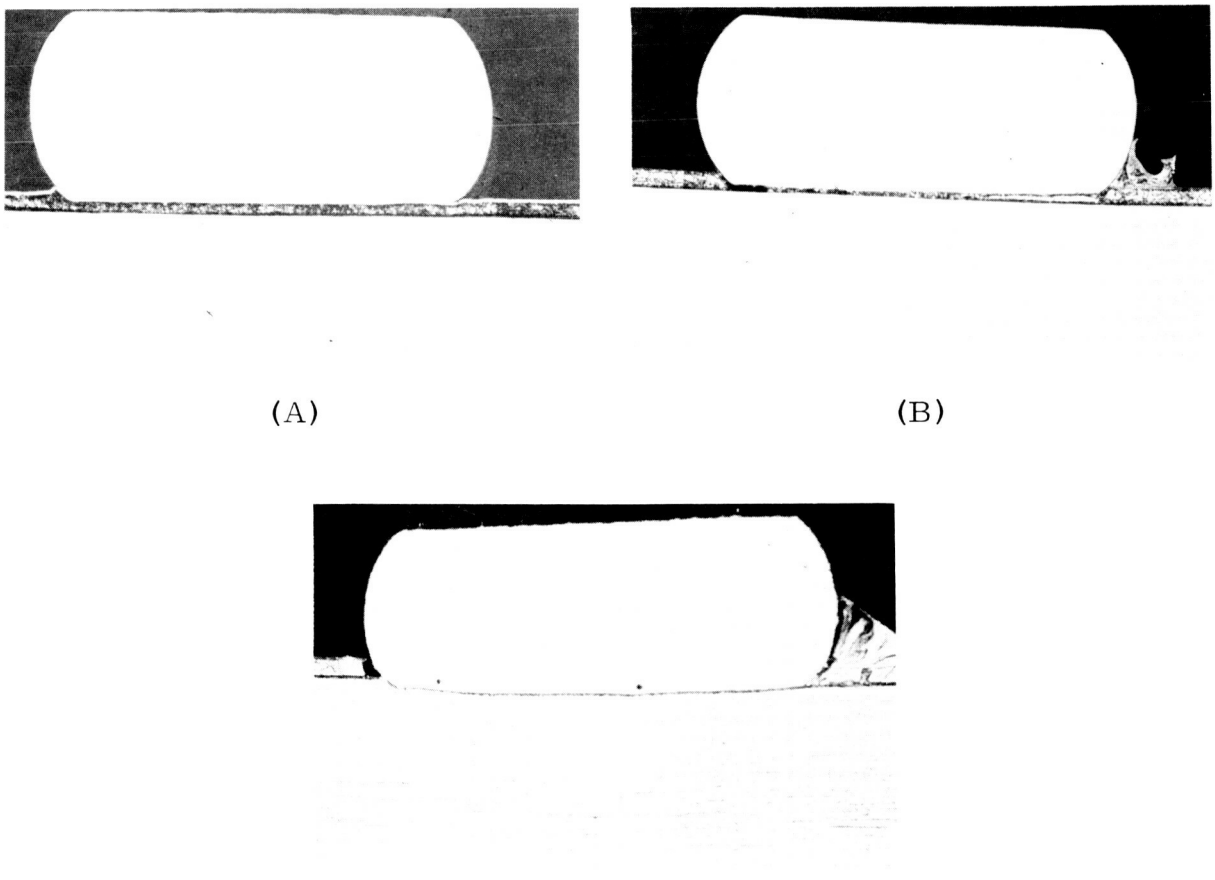
(A) 180 Degrees Opposed Position

(B) 9 O'Clock Position

Figure 15. Low Weld Heat – OFHC Copper to Nickel "A"

at the leading and trailing edges of the weld. In the case of Dumet, non-uniform setdown was evidenced in the 9 o'clock welding position as evidenced in Figure 16 (A), (B), and (C).

In the weld made at 9 watt/seconds (Figure 16 (C)) it is apparent that the weld was initiated at the heel of the weld as evidenced by incomplete fusion of the Dumet cone to the nickel ribbon. Note the presence of the copper sheath at the right of the weld joint. This condition can promote a notch effect where the copper material is much softer and weaker than either base metal and may account for the reversal of order of Dumet and Kovar with respect to weldability number.



(A) (B)

(C)

Figure 16. Effect of Electrode Deflection on Welding in 9 O'Clock Position

E. STATISTICAL ANALYSIS

The data of the top six materials evaluated during final screening were tested for control. Based on the NASA limit of 10 percent of the average full strength for a sample size of 50 tensile tests, limits were extrapolated for other sample sizes. Standard statistical tables were used to obtain the tolerance factor for normal distribution at 99 percent probability and 95 percent confidence level for sample sizes of 50, 25, and 10. Values are tabulated in Table XV.

TABLE XV

Extrapolation of Maximum Permissible Standard Deviation

Sample Size	Tolerance Factor for Normal Distribution[1]	Coefficient of Variance	Maximum Permissible Standard Deviation
50	3.126σ	10%	$0.10\overline{X}$
25	3.457σ	9%	$0.09\overline{X}$
10	4.433σ	7.07%	$0.0707\overline{X}$

As the sample size decreases, the coefficient of variation decreases as the inverse ratio of the tolerance factors for normal distribution found in standard statistical tables (Reference 10).

Table XVI presents data of the six optimum component lead materials evaluated during the fine screening phase of the program. Average pull strength, $\overline{X}$, standard deviation, σ, and coefficient of variation are included for comparison with calculated limits. As may be seen, all values fell within acceptable limits established for a sample size of 25. The first five materials fell well within the established limits with bare Nickel "A" wire and OFHC copper wire having the optimum values. Dumet wire came closest to the limit for the coefficient of variation, being 7.6 percent. The test results of these five materials indicated a sample size of 10 would give significant data since coefficient of variation of all five values was less than 7 percent. However, at this sample size, Dumet would not have met the acceptance criteria. A sample size of 25 developed acceptance limits sufficient to accept all six materials, including Dumet.

TABLE XVI

Comparison of Test Data with Permissible Limits

Fine Screen Data – Weld Electrode in 9 o'clock Position
All Welded to 0.012 by 0.030 in. Nickel "A" Ribbon

Material	Quantity	Average Pull Strength $\bar{X}$	Standard Deviation σ (lbs)	Maximum Permissible σ $0.09X^*$	Coefficient of Variation, V $\sigma/X \times 100$	Maximum Permissible V*
Nickel "A" Wire 0.020 in. Diameter (Au Plated)	25	17.9	0.683	1.61 lbs	3.8%	9%
Stainless Steel Pins 0.030 in. Diameter (Bare)	25	17.0	0.0527	1.53	5.3%	9%
OFHC Copper Wire 0.020 in. Diameter (Au Plated)	25	10.6	0.0318	0.95	3.2%	9%
Rodar Wire 0.020 in. Diameter (Au Plated)	25	16.9	0.736	1.51	4.4%	9%
Alloy 152 Wire 0.020 in. Diameter (Au Plated)	25	16.7	0.82	1.5	4.9%	9%
Dumet Wire 0.020 in. Diameter (Au Plated)	25	14	1.065	1.26	7.6%	9%

*Table XV

F. NON-DESTRUCTIVE TESTS

As a non-destructive test, excess noise measurements were made on sample welded joints. These tests were of no value since no detectable difference in noise level could be obtained from properly welded joints and joints that were made with insufficient energy. Further refinements in the equipment proved of little value and this method was discontinued.

G. TORSIONAL-FATIGUE TESTS

These tests were not included in the original scope of work but were investigated as a possible improvement over pure tensile type pull tests. Preliminary tests showed, however, that the base material was being fatigued much more than the joints and the test fixture was redesigned. This proved also of little value and the test was dropped because of the expense of preparing the test jigs and because of the inability to isolate the joints so that the joint would be stressed instead of the base metal at the point of attachment to the fixture. Furthermore, subsequent tests using the improved tensile machine in the torsion-shear mode showed that these tests were adequate for the screening of lead materials.

III. SUMMARY OF WELDABILITY

The materials and platings in Table XVII have been selected as showing the most consistent weldability:

TABLE XVII

Materials Showing Consistent Weldability

Material	Serial No.	Weldability Ratings In Descending Order			
Nickel (Au plated)	151	9 o'clock	4.6	180°	8.45 Avg
Stainless Steel 0.030 in. Diameter Module Pins Bare	143		3.65		3.88
Copper (OFHC) Soft Au Plated	148		2.475		6.6
Rodar Au Plated	147		1.9		3.5
Alloy 152 Au Plated	150		1.34		4.91
Dumet Au Plated	145		0.85		4.1

Note – Lead wire longitudinal and Nickel ribbon transverse on 9 o'clock setup.

High speed (approximately 8000 frames per second), color movies of the welding cycle have been made to show more clearly the phenomenon which takes place during the short time the weld current passes through the lead materials.

Also, infrared movies at approximately 500 frames per second were made to more clearly show the heat flow in the joint during the weld cycle. Although the speed of the IR movies was much slower, the time per frame was approximately the same as the color movies.

These IR movies show, however, that the heat flux developed at the lead material interfaces was significant and detectable. Further studies proved that this technique could be used as a non-destructive in-process test for welded joints. This effort should be continued in detail to optimize the procedures and establish sufficient data for proper analysis.

IV. SOLDERABILITY

A. INDUSTRIAL SURVEY

The industrial survey was conducted to uncover and evaluate solderability tests, study commercial methods of component lead surface preparation coatings and platings and the types of base material selected, and the reasons for their choice.

Appendix E lists all methods of solderability reviewed.

The industrial survey portion of Task I has provided 35 specifications and process documents pertaining to component lead composition, platings and pertinent industrial processes.

To up-date the wire materials as listed in Table III of Reference 11 and to gain more knowledge on lead plating and characteristics of component lead materials, 45 survey letters were sent to producers of wire billets, component wire and component manufacturers requesting the information. See Appendix F. Two new materials in the process of acceptance under MIL-STD-1276 were found. They are DHP (Deoxidized High Phosphorous) and DLP (Deoxidized Low Phosphorous).

Appendix G is an introductory letter and a completed form. Appendix H is a list of organizations which responded to the survey letter and other pertinent material.

Where attachment by soldering is the chief or sole method of joining, the survey proves copper to be the base material most in demand. Other materials were sometimes selected to serve the dual purpose of welding and soldering. Revision "A", a proposed change under MIL-STD-1276, recommends use of Type C component leads. Type C leads consist of tin-lead coated copper wire having limitations on total impurities, such as phosphorous, silver, and oxygen. A control also is held on the maximum and minimum thicknesses of coating both when electroplated or hot dipped. A control on the maximum thickness for soldering is unnecessary. Where the lead must adapt to a hole size or where the lead must be welded, the control of maximum thickness is important. Appendix I is a source list of material choices and pertinent articles related to materials.

While electroplating appears to be the most advantageous method of controlling thickness of wire plating, an absolutely concentric application is not always absolute, since the wire (cathode) circumference cannot be oriented to have all segments of its circumference equally facing the plating material (anode). In the hot dip process the solder thickness is most often controlled by passing the wire with molten solder or tin adhering to it through a small orifice in one or more thicknesses of heat resistant tape such as glass. Provided the surface of the basis metal is well prepared this is a satisfactory method of control within certain limits (Reference Mr. Cashman, Hudson Wire Company).

B. INITIAL MATERIAL SCREENING

Appendix J is a record of 74 materials, surface conditions and platings investigated during this study.

The experiments consisted of mounting short lengths of wire in a printed circuit board and soldering on a wave solder machine (Figures 17 and 18). These first wires were not plated or coated. A sample test sheet is provided (Figure 19). However a short time span was employed between the time these wires were formed and cut to size before actual soldering. The time never exceeded 4 hours. The freshly cut ends of the wire thus will show compatibility as in Figure 20, or incompatibility as in Figure 21, at the toe or point at which the wire was severed.

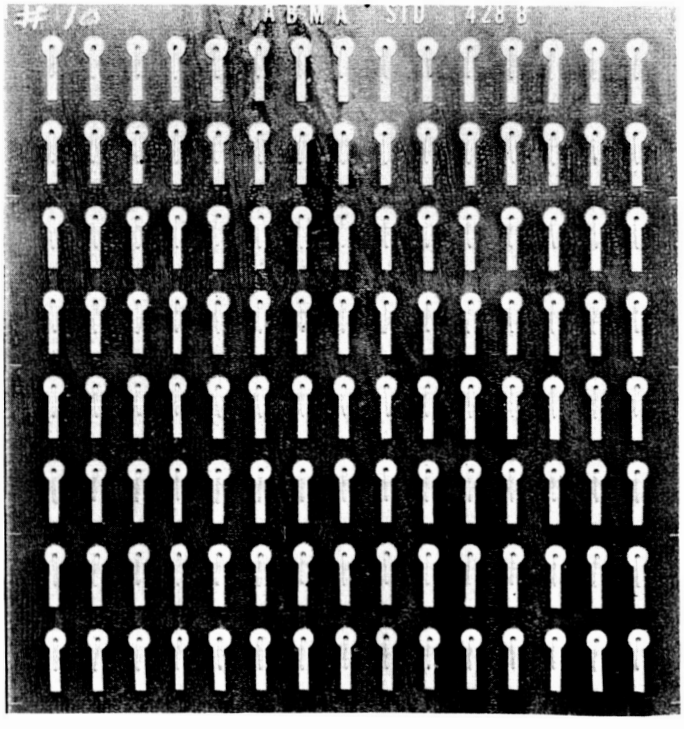


Figure 17. Printed Circuit Board

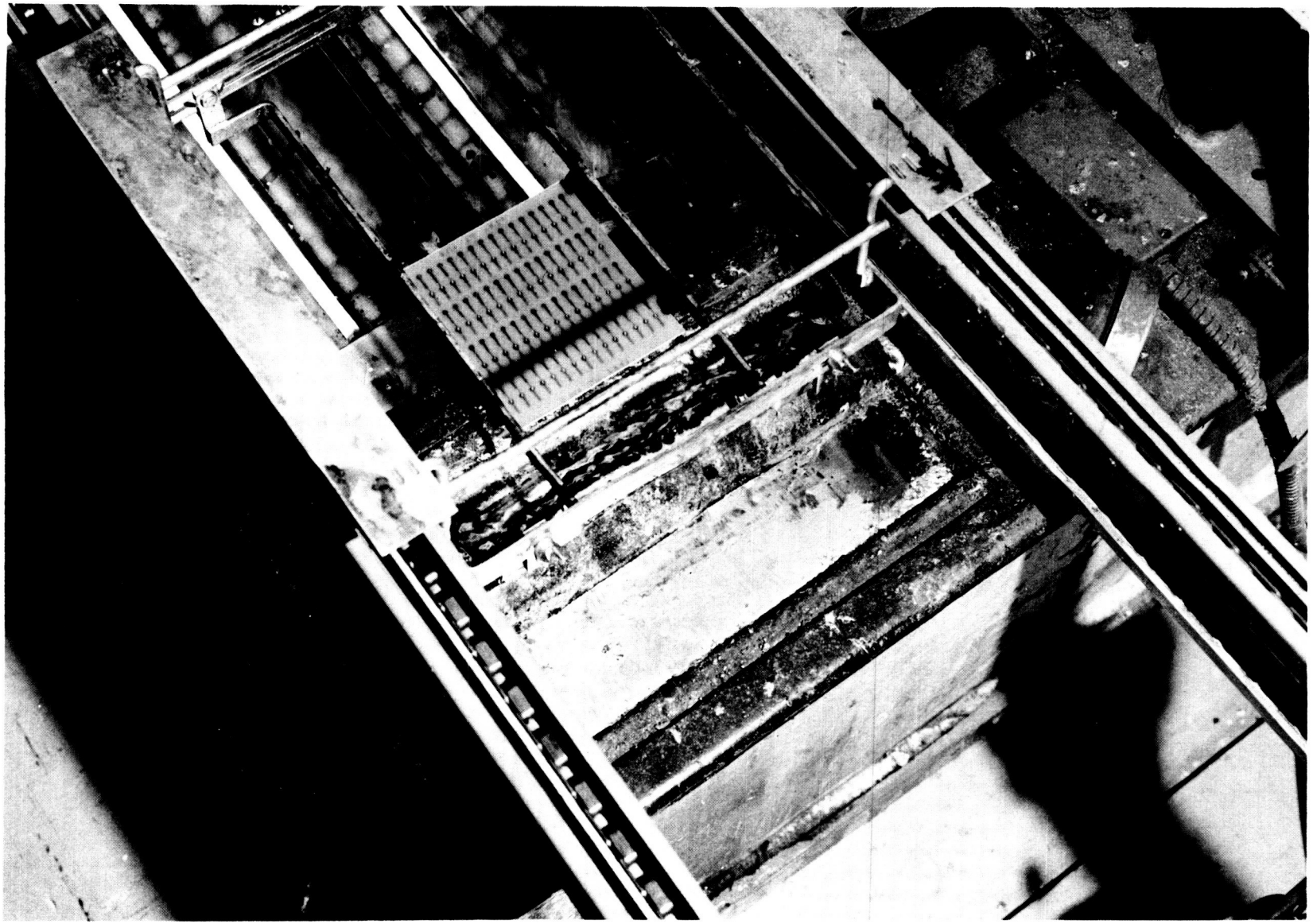


Figure 18. Board Mounted in Wave Solder Machine

Flow Solder	Board Type ABMA STD-428B
	Board No. 9 Row No. 3
Wire: Soft Copper 0.020 in. (0.508 mm)	P.O. No. 714647
Specification: QQ-W-343 Type S	S.O. No. 102189
Surface Prep: Tin Plate per MIL-T-10727A Type I	
Electro Plate Thickness 0.0001 to 0.0002 inch	
Flux: 25% WW Rosin - 75% Isopropyl Alcohol 99% Purity by weight	
Flux Spec: Federal Spec. No. LLL-R-6266	

Joint	Demarcation	Joint	Demarcation
1	Heavy	16	Heavy
2	Heavy	17	Pronounced - Heavy
3	Heavy	18	Pronounced - Heavy
4	Heavy	19	Heavy
5	Heavy	20	Heavy
6	Heavy	21	Heavy
7	Heavy	22	Heavy
8	Heavy	23	Heavy
9	Heavy	24	Heavy
10	Heavy	25	Heavy
11	Pronounced - Heavy	26	Heavy
12	Pronounced - Heavy	27	Heavy
13	Heavy	28	Pronounced - Heavy
14	Heavy	29	Heavy
15	Heavy	30	Slight

Remarks: Degreased in Trichlorethylene vapors conveyor speed - 11 inches per minute; Pot at 496°F wire cut and formed 9-17-64; flow soldered 9-21-64. 1) Line of demarcation generally heavy on both sides of bent over wire. 2) Heel coverage good. 3) Toe coverage good. 4) Five joints had pronounced ragged edge at line of demarcation otherwise solder was smooth. 5) Solder bright on all joints. 6) Coverage good.

Figure 19. Sample Test Sheet

On the basis of this information, decision was made to eliminate tantalum as a candidate material. Rough screening also indicated that bare nickel unless well protected to prevent passivation, or unless exceptionally high heat could be applied, or active fluxes were employed would not be the optimum for soldering. This could not be construed as a statement that nickel cannot be soldered, but where heat sensitive components are employed bare nickel should not be used. Where it becomes mandatory to use nickel at low sol-

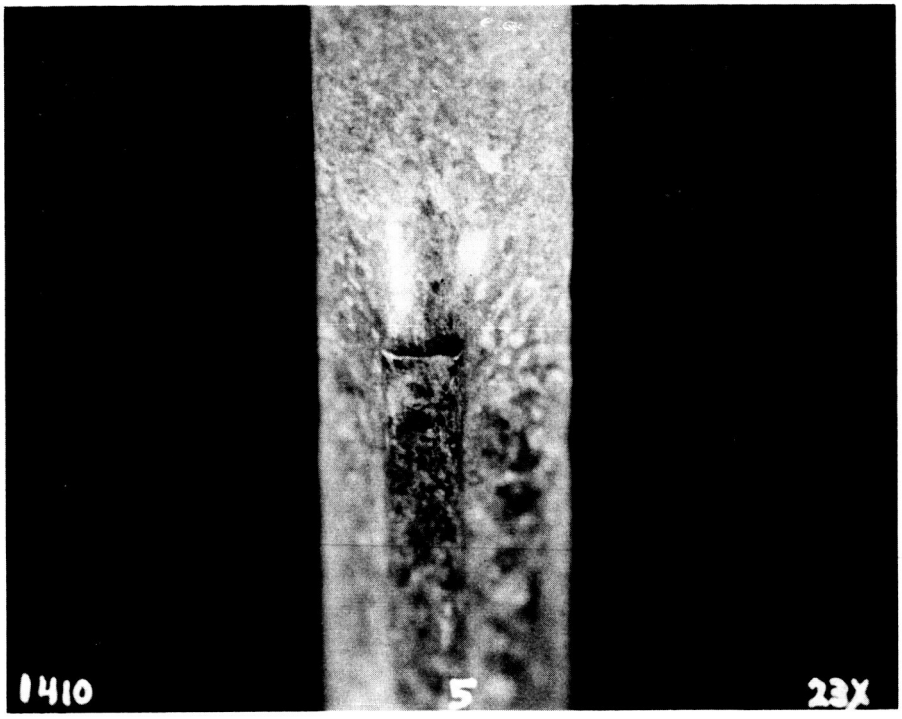


Figure 20. Wire Compatibility

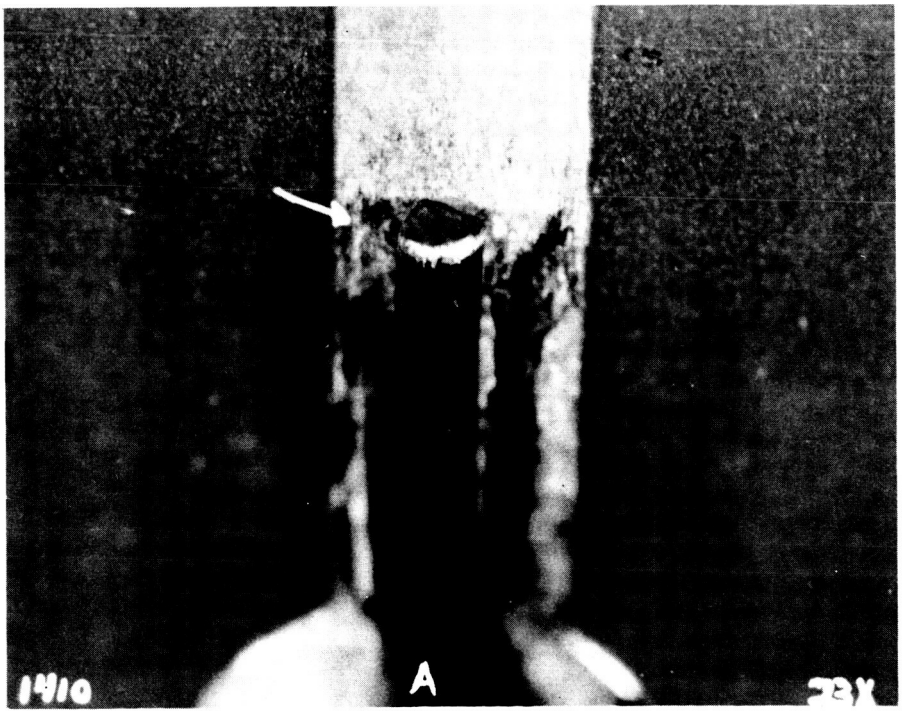


Figure 21. Wire Incompatibility

dering temperatures, electrotinned or gold will enhance solderability provided the plating is applied over a well activated nickel surface (Appendix K).

Although Appendix I under the heading of Nickel A does not reflect a great quantity of experimentation with Nickel A observe Dumet (2) which is a nickel strike over 99.9 percent minimum copper covered with gold. The nickel strike is 0.00127 millimeter (0.000050 inch) to 0.0025 millimeter (0.000100 inch). The gold plating on the nickel is applied per MIL-G-45204, Type I, Class 1, thickness 0.00127 millimeter (0.000050 inch) to 0.0025 millimeter (0.000100 inch). The material used in this test was plated with Au to a maximum of 0.00178 millimeter (0.000070 inch). This material qualifies under MIL-STD-1276 Type D. In addition Appendix I shows nickel used as an under plating in work performed with alloy 152 and also phosphor bronze.

C. ROUGH SCREENING

To avoid measuring degree of contamination rather than base material itself it was necessary to determine a cleaning and surface preparation which would reduce the effects of surface condition to a minimum. Appendix K is a record of satisfactory cleaning methods prior to plating. OP98 proved most effective for hot dip tin and tin alloy applications.

Since gold resists oxidation and remains unaffected under high temperatures environments, it is widely used. In a situation which will allow a choice, gold should not be used. When confronted with the necessity of utilizing gold as a soldering surface, the minimum heat required should be applied in the shortest elapsed time.

The undesirable effects of reworking can be minimized by carefully removing old coating by utilizing flux, tin coated copper braided shield or stranded wire with heat. Flux and hot tin the surface immediately. Base materials with high nickel content will passivate rapidly if left unprotected. In instances where gold or any coating has been placed over nickel or nickel alloys without proper activation the retinning will be difficult requiring high temperature and will possibly never be a good joint.

Rough screening tests prove that electro tin plate, 0.0051 millimeter (0.0002 inch) to 0.0102 millimeter (0.0004 inch) thick will provide a more compatible surface than electro tin plate 0.0025 millimeter (0.0001 inch) to 0.0051 millimeter (0.0002 inch). When surfaces are clean and the coating or plated surface is 0.0051 millimeter (0.0002 inch) or more, little difference can be detected between a surface protected with fresh hot dip or by fresh electro tin plate. These tests were confined to flow soldering applications which will be discussed further under Solder Tests and Theory

elsewhere in this report. Electro tin plated surfaces reflowed under hot oil will not show a more solderable surface than electro tin surface only. However, any process which will decrease the porosity of the plating will more adequately protect the basic metal during shelf life and handling. A decrease in porosity can be also accomplished by hot dip in tin alloy solder. In this case the thickness is also increased allowing additional protection. If unsatisfactory cleaning has been practiced before coating, plating, reflowing or hot dipping, the condition cannot be disguised with mild fluxes and moderate (500°F or less) soldering temperatures.

D. SOLDER TEST AND THEORY

The entire electronic packaging industry, especially the missile and manned flight vehicle programs, has from its inception required a simple solderability test. The test must prove or disprove solderability and should be:

1 Non-destructive;

2 Incorporate a measurable unit;

3 Translate manufacturing procedures into a recognizable application;

4 Establish a high confidence level.

In addition, the test should be:

1 Inexpensive;

2 Utilize easily attainable materials;

3 Require as little space as possible;

4 Create a minimum of safety hazards;

5 Be easily installed by manufacturers, consumers, vendors and customers.

The requirements of government agencies for solderable component leads demonstrate a need for a reliable test. Component manufacturers provide many different types of base metals and sheath these component leads in a variety of protective platings. Because of the complexity of manufacturing requirements there must be a variety of available materials, but the diversity of materials gives rise to problems. A few of these problems are glass to metal seals, and cold molded and hot molded resistors. A reliable

test with a capacity to grade material is required. The test should not provide go and no-go criteria but should be able to place materials in their proper place between the optimum of solderability and the unacceptable condition.

Two suppliers may furnish identical base metals in a component lead and plate or hot dip with the same tin lead alloy. However, when attempting to solder, one may give good results, the other be troublesome. To merely specify material and platings is not a solution.

The difference in the leads of two like components can be found in the cleaning process, the assembly process involved in manufacturing the components, or storage environment variations. Many of the problems of rework are caused by such unknowns and variations. Rework of parts often causes damage by over exposure to heat not only of the troublesome component but of good components and supporting structures. Time involved to rework or replace unsolderable parts may more than double the cost.

1. Problems

A component manufacturer must decide whether it is more economical to purchase bare wire for the component and then plate the wire at his own facility, or to have the wire manufacturer preplate the wire. Utilization and the processes required to install the wire are prime considerations. For example, in transistor manufacturing a hermetically sealed joint is required between a glass component body and the component lead. The lead is used primarily for mechanical retention and to complete the electrical circuit; therefore, a metal is required whose coefficient of expansion matches that of the seal or a satisfactory combination of materials must be used including a conductive metal which will provide such a seal. The component lead must also be solderable. It must be determined if hot heading is necessary; if so, at what temperature and for what length of time consistent with economical manufacturing. Hot heading of transistors utilizing Kovar, Rodar may require hot temperatures above 850°F. After the hot heading is completed and at the time of assembly into the component, a bonding temperature of 600 to 650°F may also be required.

After processing, how solderable is the product offered for sale? Investigation is more likely if the destruction of a good part is not required.

The consumer also has a problem. Should the shipment be accepted or returned? If shipment proves to meet electrical requirements and if it could be proven solderable by a non-destructive method, it would be acceptable. But how is solderability determined?

2. Solution of Problem

Significant and repeated efforts have been made in the past to determine solderability.

Component leads are accepted or rejected in the United States under MIL-STD-202 Method 208, which is similar to EIA Standard RS-178A. In this test a component lead after fluxing with a prescribed flux is lowered into a solder bath with the axis normal to the solder surface allowed to dwell for a predetermined period of time and then withdrawn at a controlled rate of speed. To evaluate the results, the lead is examined under 10X magnification to determine if 95 percent of the area is covered with a new uniform adhering coating of solder. Solder of 60Sn/40Pb as utilized naturally converts to a solid at 361°F upon removal. If solder were the same viscosity as water, if might well have revealed the degree of solderability. It has, however, turned to a solid before flowing away. Therefore, the sheath of solder encases and mechanically clings to the surface concealing areas which are unsolderable because of the inactive fluxes required by the space industry. In parts of Europe the J. A. tenDuis solderability test method is popular and has some merit. The tenDuis method entails lowering a fluxed component lead with the axis of a straight lead horizontal to the work table centrally located over a heat source supporting a solder ball. To evaluate solderability, the elapsed time required for the solder ball to encompass or wrap around the lead is recorded. Experiments with a modified model revealed a tendency to record increasing solderability after the initial test piece. Flux residue from the preceding piece was responsible. A complete cleaning of the heat source after each test specimen is removed from the device is required. Close control of time between deposit of ball on heat source and lead contact must be observed as the ball oxidizes rapidly. A 5 second dwell will be much less oxidized than a ball allowed to dwell 20 seconds. The method is more parallel to hand soldering. Leads must be tightly clamped and straightened to bisect the solder ball. Autonetics, Downey, California, utilizes a sophisticated version of this device.

The Pessel solderability test method as utilized at RCA entails wrapping a component lead with a solid piece of wire solder (0.010 inch diameter) one full turn around the component lead. The lead is immersed in Carbowax 400 at 383 ± 4°F. The contact angle is measured as shown in Figure 22. Adherence of the coating is also tested by subjecting the wire to at least four turns about a mandrel twice the wire diameter ±10 percent. Flaking or peeling under 5 to 10X magnification is cause for rejection. The test can be destructive or non-destructive depending upon whether the lead can be straightened. Soldering without flux does not provide a parallel to actual soldering conditions.

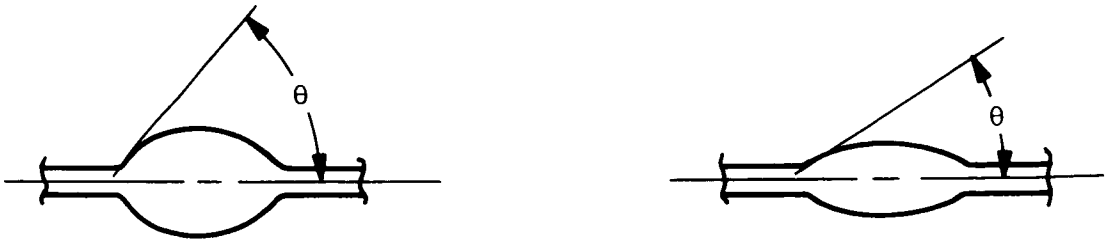


Figure 22. Contact Angles

Tin Research Institute of England with offices at Columbus, Ohio, have used spread testing to evaluate fluxes, base metal coating, and platings. A strip of material plated with the desired material is clamped into an electrical energy source. A solder pellet and measured flux is centralized in the strip. Current of about 500 amperes at 0.6 volt for 5 seconds is applied. The current is automatically reduced to maintain the temperature at a steady value for 30 seconds allowing the solder to spread. A visual judgement is made or the area is computed by means of a planimeter.

Pessel has also developed a variation for evaluation of various brands of activated rosin cored solder wire. By forming a figure 4 with the solder and then trimming out the portion where the horizontal leg loops the vertical leg of a figure 4, a fairly accurate amount of solder is provided in a desired shape. After treating the area to be spread in an oven, the solder specimen is placed on the base specimen and the specimen placed in an oven and allowed to spread. The results are measured by use of a micrometer applied across the center of the spread material to the underside of the base specimen.

Another variation of the spread test has been used at the Martin Company to evaluate fluxes, both cored or liquid (Figure 23). When a cored solder is evaluated, a measured amount (0.5 gram ±1.5 percent) is placed into a tube (Pyrex is recommended) centrally located over and normal to a 2 inch by 2 inch by 1/32 inch thick material (coupon) of the type to be utilized with the solder in production cycle. The coupon supported in a retainer with the lower end of the cored solder resting against it as a result of the pull of gravity is lowered onto a heat source, in this case a solder pot. As the solder melts it spreads over the surface of the coupon. The coupon is allowed to dwell on the heat source until all visual evidence of spreading ceases.

In the case of liquid fluxes the entire top surface of the coupon is coated with the flux and 1/2 gram of solid wire solder is used. The remainder of the procedure is the same as described in the previous paragraph. The measurement of the spread is made by a planimeter.

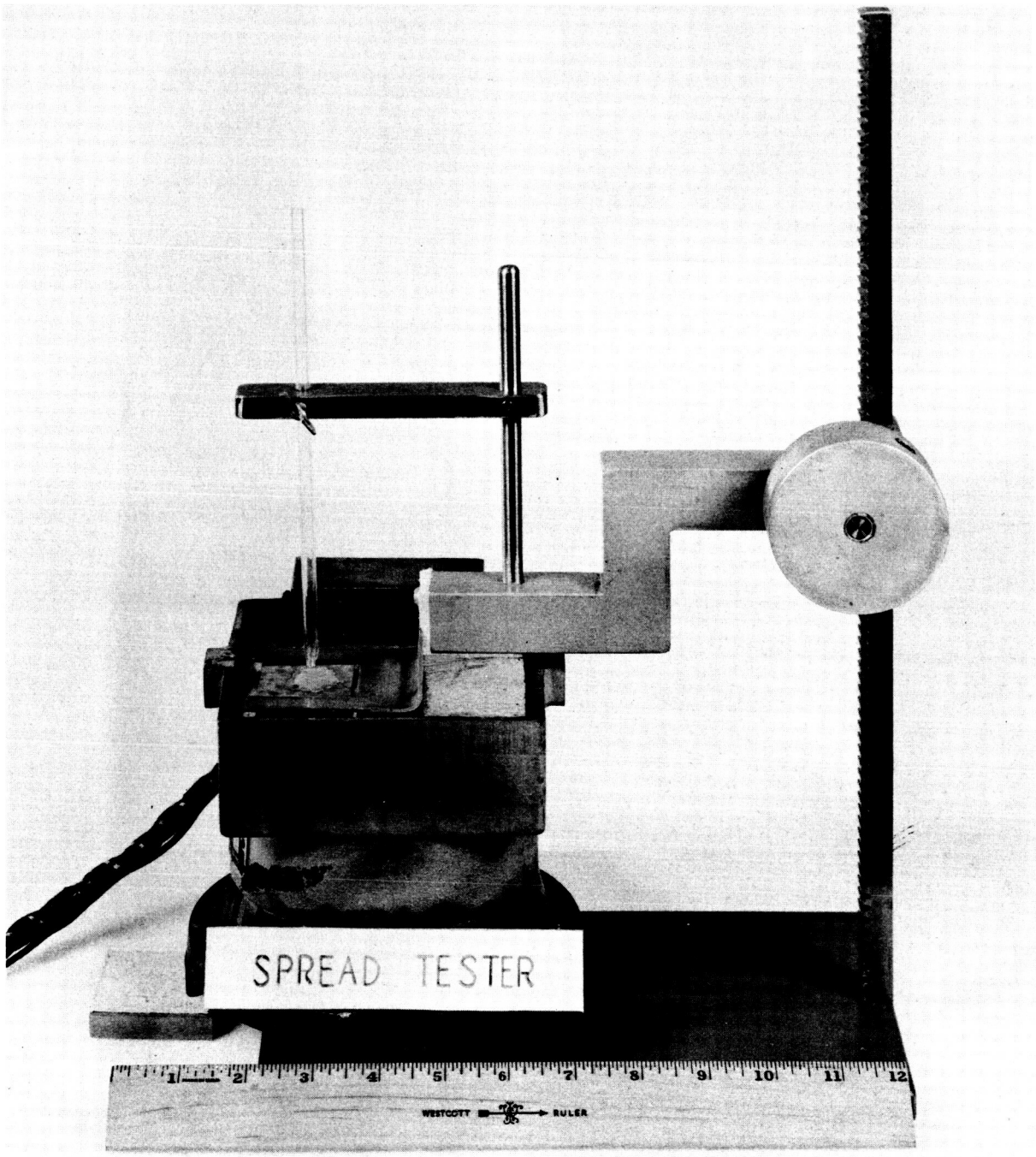


Figure 23. Spread Tests

The wire industry has for some time employed twisting wire (two strands) together at about 1/2 inch for a full 360 degree twist. Flux and solder are allowed to wick (capillary action) up between the two wires when a heat source is applied. By measuring the rise of solder, solderability is determined.

The merits of plated surfaces on wire are sometimes evaluated by tightly coiling wire about a mandrel, much like a coiled spring is formed, in order to induce surface cracks and determine adherance of plating.

All these tests are useful. However, generally their lack of parallel to the soldering operation renders them less useful for solderability detection of component leads. The droplet test developed at Martin-Orlando does follow the soldering operation closely and, in addition, meets all the nine requirements set forth in the opening paragraph. A description of the test follows:

3. Droplet Solderability Test

a. Facilities

1 Solder pot: Capacity 10 pounds or more; thermostatically controlled from 480 to 500°F;

2 Oil heat source: Solder pot of at least 500°F capability, thermostatically controlled to ±5°F;

3 Fifty milliliter stainless steel beaker;

4 Calibrated millimeter 20X microscope;

5 Five-sixteenth inch diameter mandrel stainless steel 2 3/4 inch length minimum;

6 White lint free gloves (nylon);

7 Suspension system for 50 milliliter beaker (if solder pot is used for oil heat source); Figures 24 and 25 show heat source and suspension system assembled;

8 Three beakers pyrex or metal (50 milliliter): one for flux, one for post solder dip cleaning, and one for post oil dip cleaning;

9 Needle nosed pliers with insulated handle guards or plastic sleeves;

10 Four by four by one half inch metal or fiber block.

Oil beaker bath should be enclosed on bottom by the heat source. The diameter should be enclosed by the heat source for 3/4 of its total length.

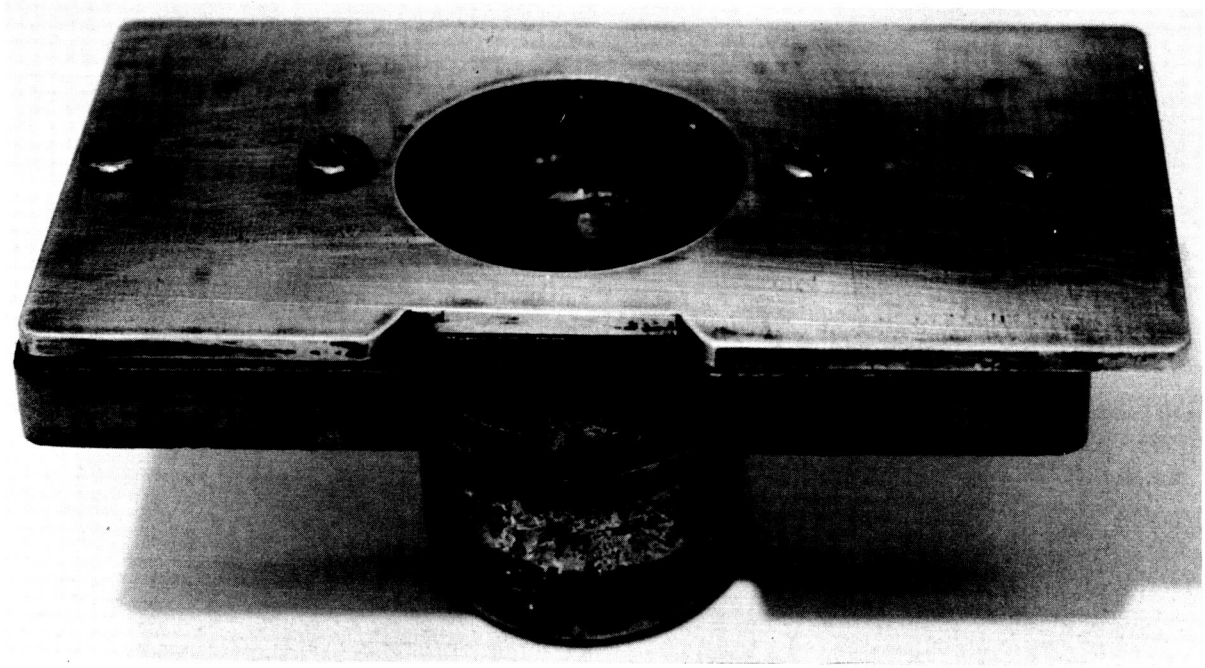


Figure 24. Suspension System

Figure 25. Suspension System and Heat Source

b. Test Procedure

Step 1: Form Lead

Form leads around 5/16 inch diameter mandrel by clamping the end of the wire to the mandrel with the thumb of right hand. Mandrel is also held with right hand. Pull component around mandrel with left hand. Lint free gloves should be worn. (See Figure 26 and component second from left in Figure 27.)

Step 2: Flux

Fill small glass beaker 1/2 to 3/4 full with 25 percent water white rosin and 75 percent isopropyl alcohol by weight (Specification MIL-E-14256). The type of flux utilized during the actual production soldering operation may be substituted.

Immerse lead for 10 seconds to depth above the tip of the hook formed as shown in Figure 28. Use needle nosed pliers 7/8 inch minimum from loop of hook.

Step 3: Solder Dip

Immerse in hot solder bath, composition Sn60, Specification QQ-S-571, (60 percent tin) at 480 - 500°F to a depth where the tip of the hook disappears below the solder bath level as shown, and agitate rapidly (approximately 4 strokes/second, stroke length 1 inch long) in a horizontal plane. Remove lead after 4 seconds, speed of withdrawl 10 to 15 inches/minute will retain solder icicle at "A" (Figure 29 and component third from left in Figure 27).

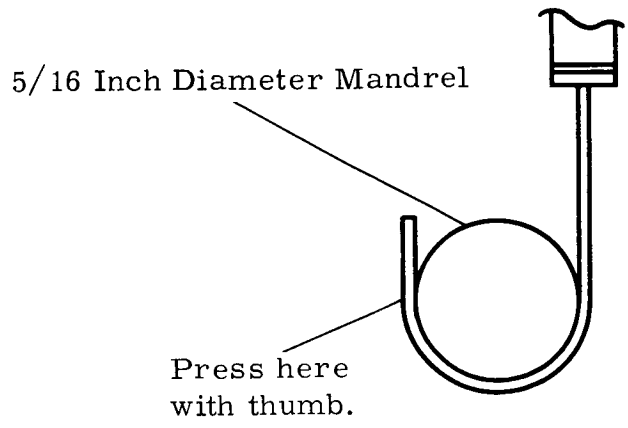


Figure 26. Mandrel Application

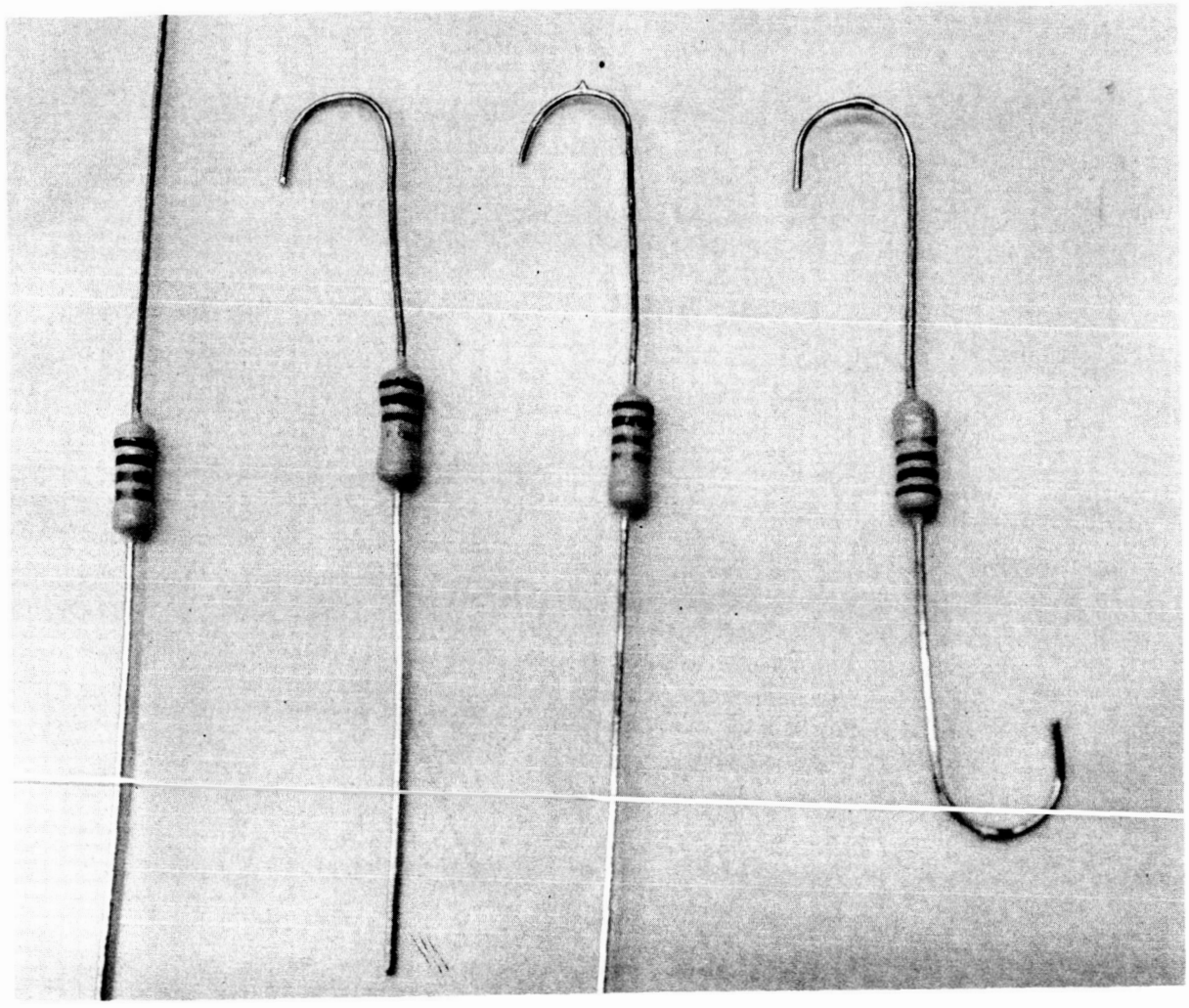


Figure 27. Droplet on Component Lead

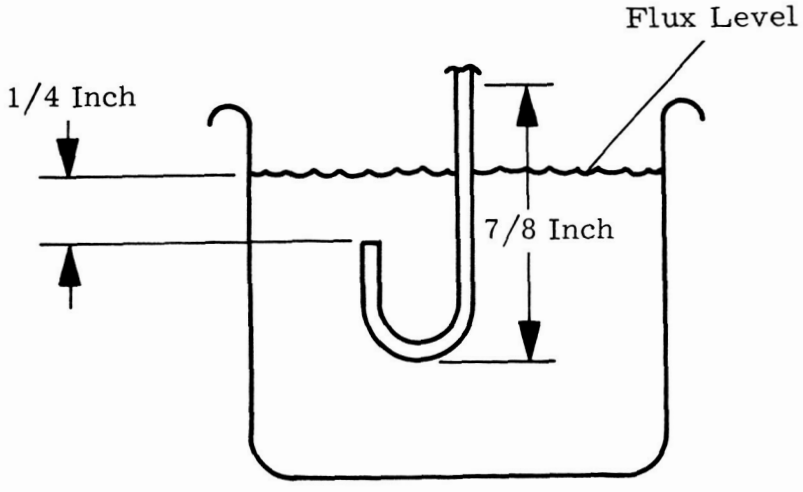


Figure 28. Lead Immersion

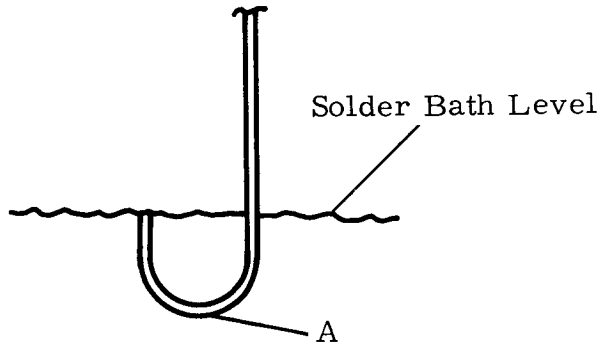


Figure 29. Icicle Formation

Step 4: Clean

Immerse lead in trichlorethylene liquid at room temperature to remove flux residue. If the production soldering at a particular installation utilizes water soluble fluxes, substitute water or solvent in that particular soldering operation for which the test is performed.

Step 5: Reflow - Form "Droplet"

Fill oil bath container (50 milliliter stainless steel beaker) half full with hydrofol tin fat No. 50 and allow to melt in heat source. (See Appendix L of Materials.) Avoid filling container to top before oil is completely heated. Continue adding small quantities until beaker is 3/4 (minimum) filled. Allow liquid to reach 480 - 500°F.

Grasp component lead utilizing needle nose pliers as in Step 2 and immerse to a level as in Step 3. Allow to dwell stationary for 30 seconds. Remove smoothly from oil bath, 10 to 15 inches/minute. Retain for no less than 10 seconds allowing solder to solidify under the hot oil coat.

Step 6: Clean

Fill small glass or metal beaker with trichlorethylene and agitate leads in bath until oil is removed.

Step 7: Measurement

Lay component on 4 by 4 x 1/2 inch block and tape in place as shown in Figure 30. Measurements should be made using a calibrated microscope. A piece of masking tape or dark paper directly under the loop will assist in defining the droplet outline.

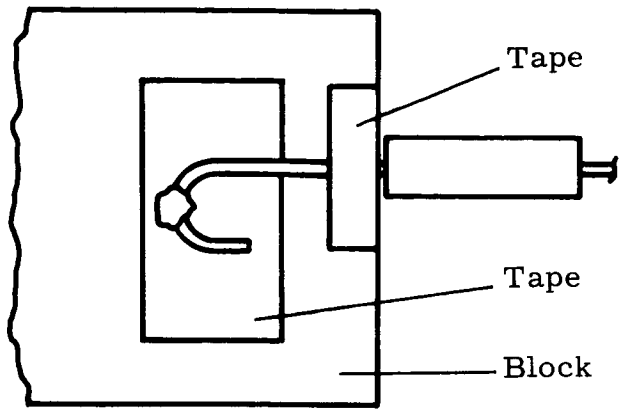


Figure 30. Component Placement

Solderability is determined as shown in Figure 31, by the component far right in Figure 27, and by the following equation:

$$S = \frac{KL_1 + L_2}{D-d}$$

The following considerations apply to the equation:

1 When droplet has not reflowed over top of lead, consider $L_1 = 0$.

2 When solder has spread out over lead so that L_2 cannot be measured readily, consider $L_2 = L_1$.

3 K for screening of lead material stock has been determined to be 10.

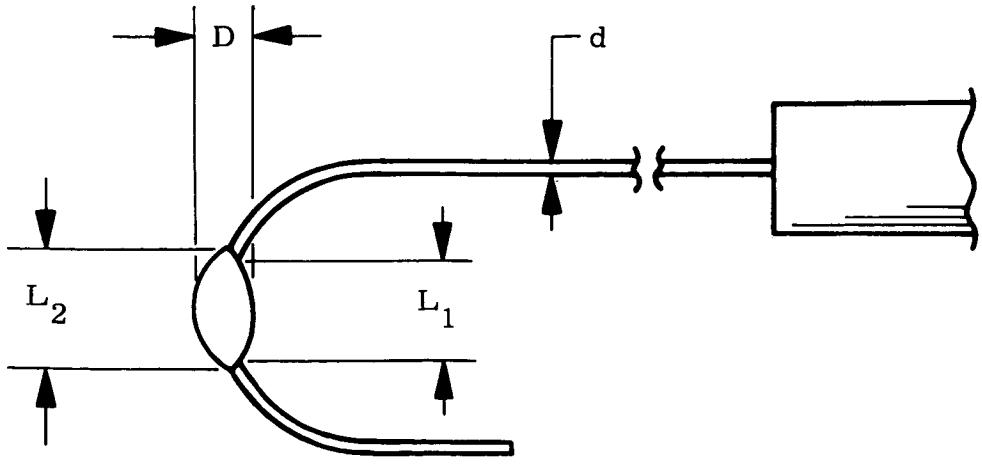


Figure 31. Solderability

When evaluating stranded wire alter the procedure in Step 1 and 3 as follows:

Step 1: Prepare wire as shown in Figure 32 to preserve the lay of strands by sliding insulation back on stranded wire utilizing mechanical wire strippers. Before forming the wire around the mandrel, re-lay the strands as follows: hold insulation 'A' in righthand, insulation 'B'. in lefthand. Rotate insulation 'A' in direction of the original lay until wire in the stripped area begins to show signs of kinking. The stranded wire is now ready to bend around the mandrel.

Step 3: Withdraw wire from solder pot at the rate of approximately 60 ft/min.

c. Test History

In developing the droplet test extensive experimentation was required; experiments with specimen lot sizes ranging from 2 to 70 were evaluated.

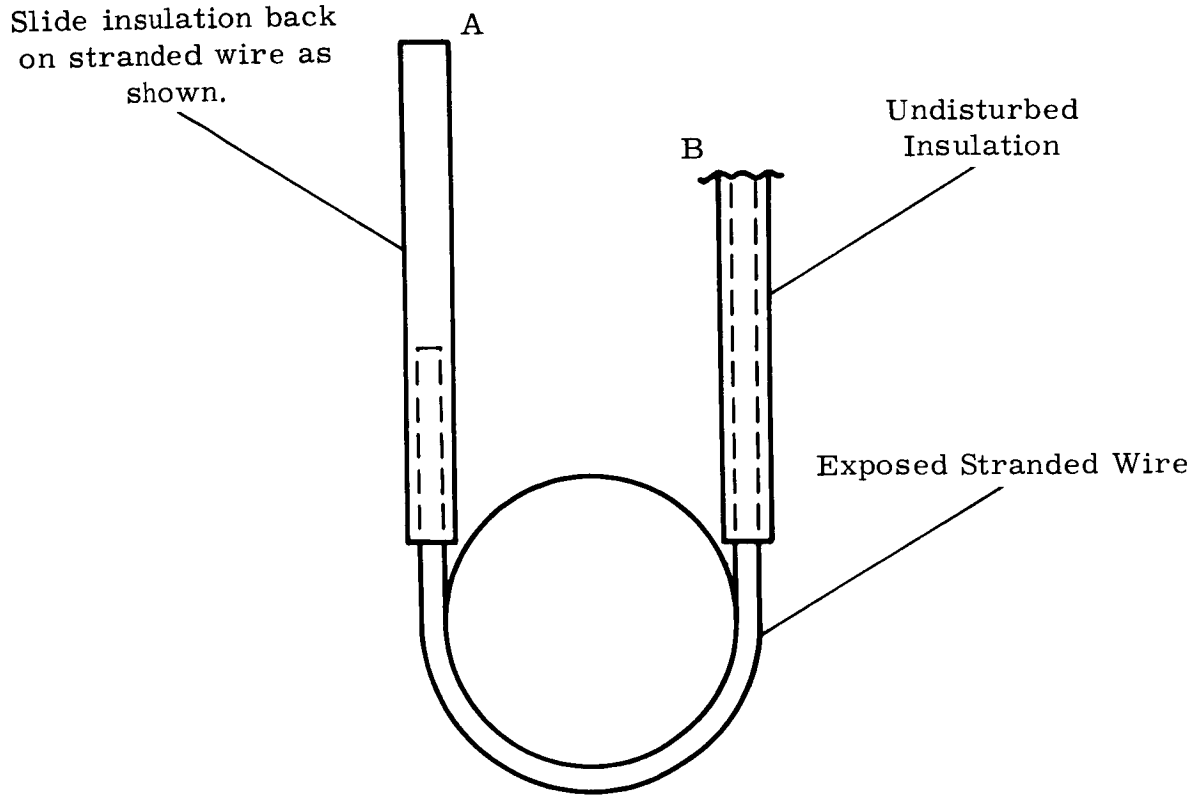


Figure 32. Preparation of a Stranded Wire

The fishhook evolved from a configuration much like Figure 33. This configuration appears easy to measure, however, the droplet forms at point "A" or "B" where a measurement is impossible. Conversely, the fishhook configuration will allow for orientation other than absolute vertical without affecting results.

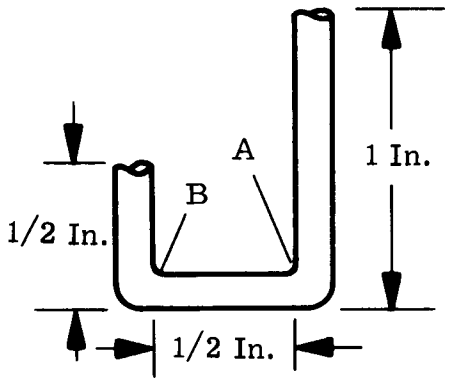
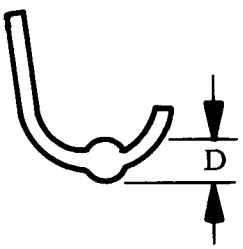


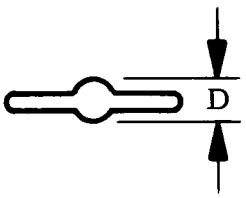
Figure 33. Basic Fishhook Design

Studies were conducted to optimize the loop configuration size. Different loop configurations of various sizes were studied and the half round loop of 5/16 inch diameter was selected as the best in terms of proper ball formation and ease of use. Two different measurement techniques were tried in order to determine the most accurate way of measuring the solder drop width as shown in Figure 34a and 34b. Seventy-one samples were measured with only a 0.6 percent difference. Since the method of Figure 34a is easier to locate on the microscope, it was chosen as the standard technique.



As measured from side of loop.

(a)



As measured from the closed end of loop.

(b)

Figure 34. Droplet Measurements

It was originally decided to use a flow solder technique for the droplet test instead of the dip process since the flow technique more accurately represents the method used to attach the components to a printed circuit board. While the difference is small for hot dipped or electro-plated tin coatings, there is a large variation where gold plated leads are tested. It appears that the gold plating is washed away by the flowing solder and the soldering takes place on the undercoat or base metal.

Further study proved that by agitating the component leads as specified in Step 3 the flowing action of a solder fountain could be closely duplicated. Thus the need for more elaborate equipment was eliminated. The following oils were evaluated:

1 Dow Corning No. 44 grease;

2 Peanut oil, Martin Number 08-514-925 GL manufactured by Sessions at Atlanta, Georgia;

3 Dow Corning No. 704;

4 Gafanol E-400 Polyethylene Glycol;

5 Carbo Wax 400 Polyethylene Glycol;

6 Hydrofol Tin Fat No. 50.

Hydrofol Tin Fat No. 50 manufactured by Archer Daniels, Minneapolis, Minnesota, was chosen. Considering odors, change in viscosity under heat, the residual capacity of the oil to absorb moisture, Hydrofol Tin Fat No. 50 most closely met all parameters.

The temperature of the solder pot was controlled at 480°F to 500°F to closely follow automatic soldering processes. A manufacturer using hand soldering could provide the test with a heat source similar to those in use to determine whether incoming components would be troublesome in that particular manufacturing installation.

The flux, 25 percent water white rosin and 75 percent isopropyl alcohol by weight, was chosen because:

1 No activators are present other than rosin.

2 A great many tests now required on military standards require this flux. See section on specification recommendations.

3 When utilizing a more active flux, two types of material with a solderable difference will appear the same. Where the absolute difference in materials is required, as in this program, the flux as specified is recommended.

The program established that the "S" factor in the test of two different gage size wire otherwise identical will provide dissimilar S factors. The formula is: $S = (KL_1 + L_2)/D\text{-}d$; however before the final formula was evolved, and at the time wire size study was conducted, the formula was $S = L/D\text{-}d$. Using this equation a variation of 34 percent existed between 24 gage and 20 gage wire of the same type. An adjusting factor of 1 per each 0.0035 inch difference in wire sizes was tried; Table XVIII shows the result when 16 gage wire is used as the base. All other gages are the same type wire, which for this test was OFHC copper.

TABLE XVIII

Adjusted S Factor

Test No.	Gage	Wire Diameter	Base Diameter Minus Wire Diameter	Adjustment Factor	S	Adjusted S
3040	20	0.0320	0.0188	5.4	10.9	16.3
3041	22	0.0253	0.0255	7.3	8.9	16.2
3042	24	0.0201	0.0307	8.8	7.7	16.5

Note: 16 gage (0.0508 inch diameter) used as base.

Test No. 3040, wire size is 20 gage = 0.0320 inch. Subtract wire diameter from base (16 gage) diameter = 0.0408. 0.0508 - 0.0320 = 0.0188. Divide this difference by 0.0035 to obtain the adjustment factor: 0.0035 ÷ 0.0188 = 5.37 round off to nearest tenth = 5.4.

Calculate S for wire using $S = \frac{L}{D\text{-}d} = \frac{2.62}{1.05\text{-}0.81}$ 10.9

Add adjustment factor of 5.4 to S (10.9) to obtain adjusted S = 16.3.

This approach seemed to offer a reasonable answer to the problem of uniformity between various wire sizes since the percent variation between gages now dropped from 34 percent to only 1.2 percent for 20 gage as compared to 24 gage wire. As more tests were run using this technique on larger gage wires (18 and 16 gage) it was noted that the droplet of solder did not always completely cover the top inside portion of the hook formed in

the test specimen. This caused the solderability factor S to be read as 0 and thus introduced large errors in the readings for the larger gage wires. Various techniques were investigated to correct this problem such as changes in the reflow oil temperature, different speeds of withdrawal from the solder dip and oil baths and changes to the basic solderability equation. Wire gage or size warrants further study beyond the scope of this program.

The droplet test does show solderability of stranded wire, but readings of spread L_1 and L_2 are more difficult to appraise than in the case of solid wire. A difference in the lay of the strands from specimen to specimen will vary the reading and introduce another variable.

As a result, extensive investigations were conducted to improve the droplet solderability test. The results of these investigations were reported in a separate report. Reference Droplet Solderability Test dated 11 March 1965. Various methods were studied for both the solder dip and the oil reflow techniques. A new formula using a weighting factor was established. Speeds of withdrawal, temperatures, and dwell times were investigated.

The droplet test offers a distinct advantage over the tenDuis and Pessel tests in that it may be used on stranded wire (with an accelerated withdrawal from the solder dip) whereas the two other tests cannot. Feasibility has been proven although the techniques have not been perfected.

This proposed solderability test has been documented as a patent disclosure by S. Osborne and will be assigned to NASA. A letter to this effect from Martin-Orlando patent attorney, J. Renfro, was issued. Reference Martin Letter No. 65-50877 from New Business Contracts.

The formula for determining the S factor has been expanded to permit evaluation of materials with low solderability. This has been achieved by modifying the original formula of $S = L/(D-d)$ to $S = (KL_1+L_2)/D-d$ (Figure 31). Thus, materials which do not have an L_1 dimension may still be rated. The dimension L_1 is very significant in rating materials with good solderability and therefore must be weighted by some factor K. In addition, weighting L_1 permits more effective separation of poor solder joints from acceptable joints and acceptable solder joints from superior solder joints. K factors of 1, 5, 6, 8 and 10 have been tried. The ability of solder to flow completely around the test wire on 480 to 500°F oil emmersion is one of the important indications of solderability. When this does not occur, the L_1 dimension is zero indicating a fault in the solderability of the test wire. In comparing two lead materials with generally similar solder flow characteristics, the wire with generally similar solder flow characteristics, the wire which does not wet all the way around has demonstrated a

fault and must be penalized. Analysis of test data of two groups of wires with K taken as 1, has developed S values which are within 1 1/2 percent of each other. In one case, one fault was present (absence of L_1); in the other, four faults were present. As chance would have it, D and L_2 numerically compensated for this unbalance. To present these materials numerically and graphically in the correct relationship, a K factor of 6, 8, and 10 was evaluated. K factor 10 provided the best descrimination and placed the wire lot with four faults at a level of approximately 60 percent of the wire lot with one fault.

In addition, as may be seen from Figure 35, horizontal lines have been drawn to arbitrarily group the wire lots into three regions. These are: questionable, useable, and desirable. Most commercial materials will fall within the acceptable region with S values of 10 to 60. Difficulty is anticipated with materials with S values below 10 while few if any commercial materials are expected to exceed S values above 60. This data is based on 24 gauge material. No cross-correlation has been attempted between different gauges. It is anticipated that correlation is possible with the development of a proper K value for each wire gauge or exploring the relationship of S/d where S is the solderability number and d is wire diameter.

As can be seen from Figure 35, the 60/40 hot-dipped surfaces are superior to the electro-tinplated surfaces except for the gold plated Kovar samples. The hot-dipped gold plated Kovar lead was some 63 points below the electro-tinplated Kovar lead. Investigations showed that the hot-dipping process washed the gold plating away and the solder was then left to adhere to the Kovar lead. This then accounted for the large difference in the S values obtained for EP and HD Kovar leads and would indicate a potential problem in re-using components such as transistors, a problem for consideration in future work.

For example, during a spread test on gold plate, particularly when flux was added, mass solder and gold agglomeration occurred. This means, superficially at least, gold plating appears good until resoldering or continued solder contact is encountered.

The hot-dipped Dumet lead material gave superior results with smaller variations than did the hot-dipped OFHC copper leads. This was an interesting development and subsequent investigations revealed a probable cause. According to Mr. Bradley of General Electric, the copper used in Dumet contains approximately 0.015 percent phosphorous. This small amount of phosphorous combines with the oxygen and prevents copper oxides from forming during the soldering process and thus improves solderability. OFHC copper does not contain as much oxygen as DLP (Dumet copper), however it also does not contain the phosphorous. Therefore, the oxides which form

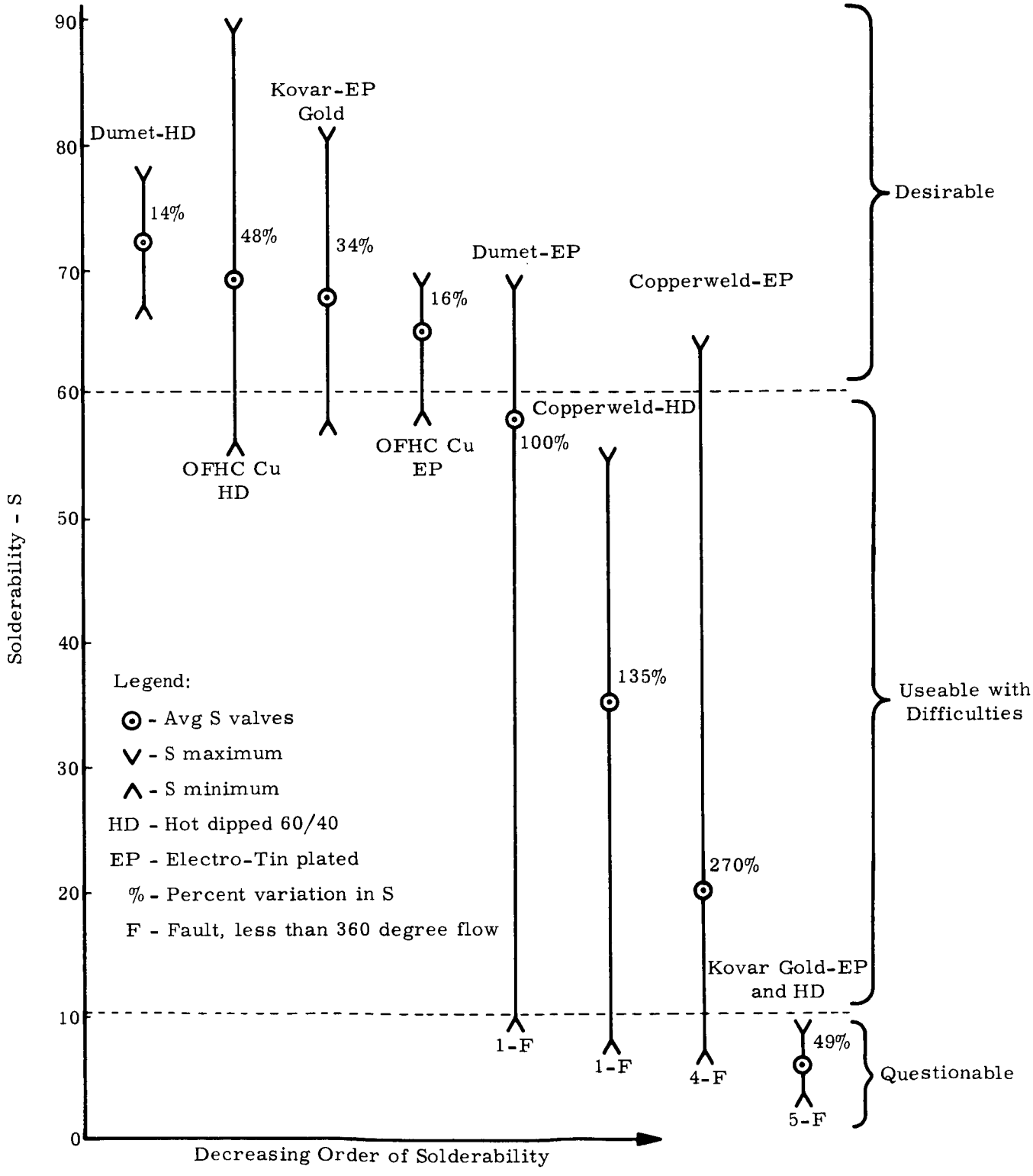


Figure 35. Droplet Test Results

on OFHC copper during soldering require removal by fluxes while the phosphorous oxides of Dumet sublime at soldering temperatures and do not require removal by fluxes.

OFHC copper, however, is not so far below the Dumet in solderability and does have a higher conductivity due to the smaller amounts of oxygen and phosphorous it contains.

4. Theory of Wetting

In order to determine an acceptable solderability test a review of the theory of wetting is necessary. H. J. Osterhof and F. E. Bartell (Journal of Physical Chemistry, V34, 1930) divide wetting into three chief categories:

1 Adhesional wetting

2 Spread wetting

3 Immersional wetting.

For the application of this study wetting is the tendency of a solid to be wetted by liquid solder. Adhesional wetting is shown in Figure 36, spread wetting in Figure 37, and immersional wetting in Figure 38.

Mr. Osterhof and F. E. Bartell consider adhesion tension the most reasonable measure of wetting. The droplet test is composed of adhesional and immersional wetting in the icycle forming stage. By the use of hot oil, the results of immersional and adhesional wetting are translated into a variation of spread wetting for measurement. One liquid (oil) supports another liquid (solder) while it is allowed to spread. The spread is controlled by the compatibility of the surface (component lead) with the liquid (solder).

The loop or fishhook design was chosen to make the immersion position approximately normal to the solder bath but still does not require exact 180 degree positioning to form an icicle on the lead. After the icicle is formed, immersion in hot oil forms the droplet. The droplet presents an angle of wetting which can be readily measured, in "spread wetting" the desired angle of 0 degree. The more compatible the surface and the more adaptable the flux and solder used, the more closely the angle will approach 0 degree. The first configuration, Figure 39, represents a less solderable material or surface than the second, Figure 40.

Each wire gage because of the circumference dimension has its own particular number representing an acceptable level of solderability. For

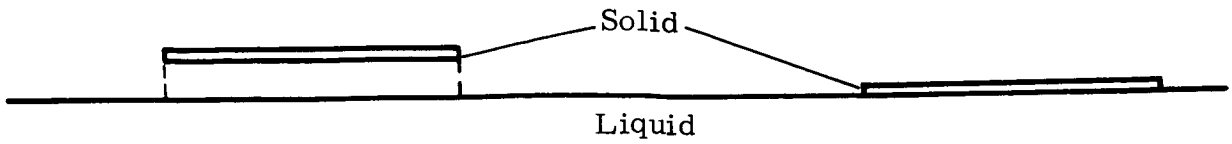


Figure 36. Adhesional Wetting

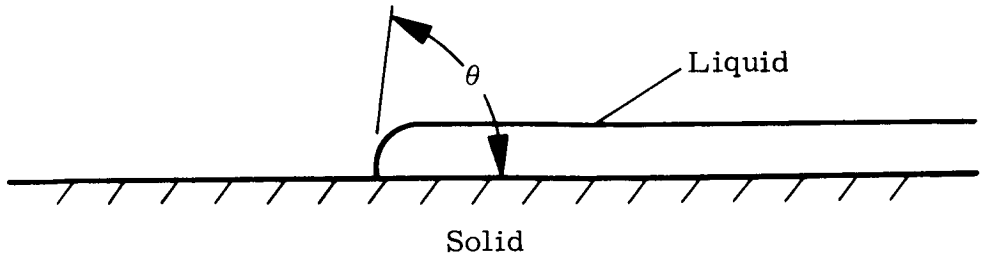


Figure 37. Spread Wetting

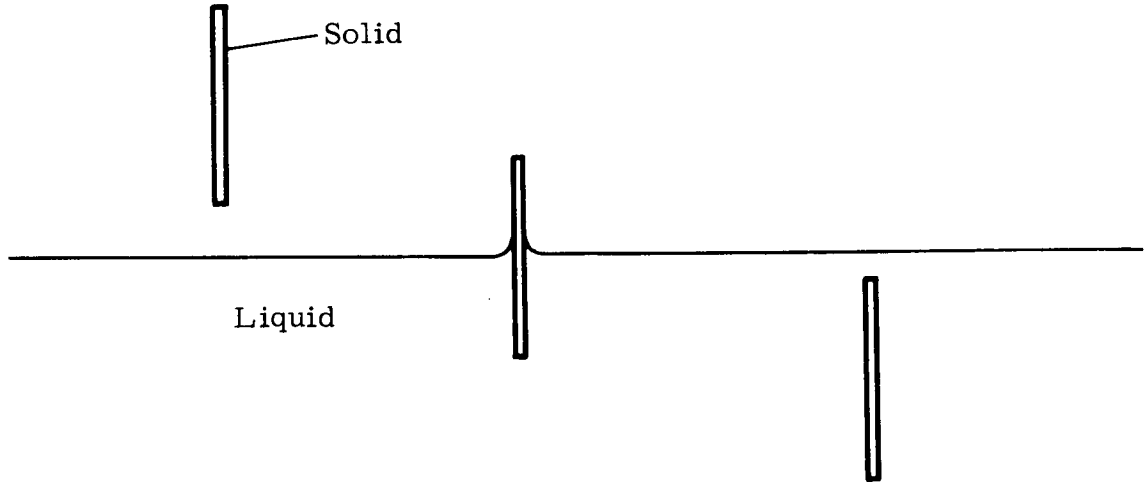


Figure 38. Immersional Wetting

instance, an 18 gage component lead and a 24 gage component lead both made by the same processes, plated at the same time, subjected to the same installation processes into the component, and soldered at the same time will exhibit different inherent flow characteristics in the soldering operation. A degree of solderability less than the optimum will be more pronounced on the larger diameter wire. The droplet test again closes the gap of doubt to a point of confident appraisal.

The adoption of smaller components and component lead sizes in packaging concepts has made it appear that more solderable surfaces are now being furnished. However, after proper correlation has been established, the droplet test will reveal the degree of solderability on any round wire.

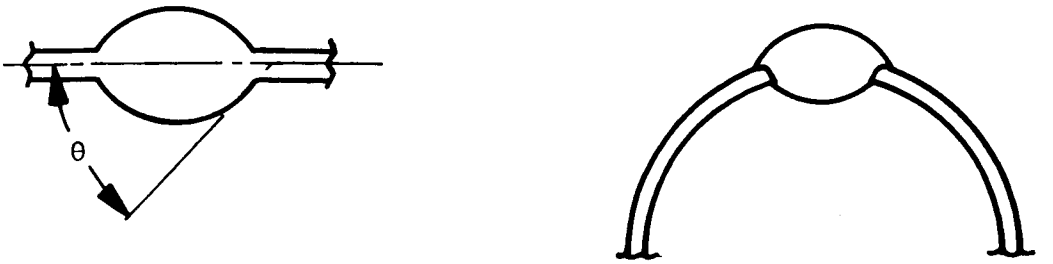


Figure 39. Spread Wetting, Configuration 1

Figure 40. Spread Wetting, Configuration 2

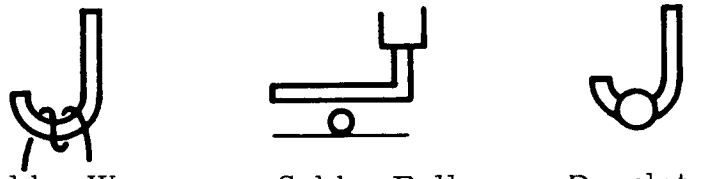
The inclusion of the "K" factor in the formula is designed to recognize the exceptional merits of component leads which will permit the solder to completely encompass the lead. The adoption of L_2 into the formula allows less solderable leads to be rated. For 24 gage wire most commercially prepared and processed components will lie in a zone between 10 and 60. Leads recording a number below 10 will be troublesome. If it were not necessary to expose components to elevated temperatures and other deteriorating environments during assembly of the component, much higher ratings would be attainable.

The droplet test provides for utilization of flux that will be actually used during the soldering operation. The soldering temperature may be paralleled by adjusting the solder pot temperature to that utilized during the manufacturing process. The forming of the icicle as in Figure 29 is consistent with automatic soldering and dip soldering. It will also reveal troublesome areas encountered in hand soldering.

Experiments were performed to correlate a relationship between flat ribbon and round wire as rated by the droplet test. There is ample evidence from experiments that flat ribbon can be rated by using the droplet test.

Work would, however, be necessary beyond the scope of this program to set "S" factors for the many sizes of flat ribbon utilized.

Figure 41 gives a comparison of the three most applicable non-destructive tests for component lead solderability. The modest outlay of time and equipment makes the droplet test most desirable.



	Solder Wrap	Solder Ball	Droplet
Simulates Production	No	Yes	Yes
Component Lead Heated	Yes	No	Yes
Non-Destructive	?	Yes	Yes
Positive	No	Yes	Yes
Discrete	No	Yes	Yes

Figure 41. Non-Destructive Tests for Lead Solderability

The peel test was used extensively in the fine screening phase of this program. Figure 42 is a typical assembled and soldered test board. The boards were of G-10 0.062 inch thick glass laminate with 2 ounce copper (0.711 millimeter) (0.028 inch). The material is certified to MIL-P-13949C. The copper laminate was etched away leaving 20 strips (10 to a side) of copper laminate 2.393 millimeter (0.09375 inch) wide by 25.40 millimeter (1.000 inch) long. The copper was carefully cleaned (Process OP-98) and preserved in that condition by an organic copper surface preservative (copper seal). All joints were inset 6.35 millimeter (0.250 inches) from laminate ends to ensure peeling in the joint and not the laminate. Each joint was controlled by a gage block to a length of 6.25 millimeters (0.250 inches) and taped in place. After flow soldering, 15 of the 20 joints were pulled to destruction. See Figure 43. The pull test machine was a Hunter mechanical force gage model D-50-T. The rate of pull was 25.40 millimeter (1.000 inch) per minute. The conveyor was controlled at 260.35 millimeter (101/4 inch) ±5 percent for all boards. Wave was controlled at 5.56 millimeters (7/32 inch). Lead joints were carefully protected

Figure 42. Typical Assembly and Solder Test Board

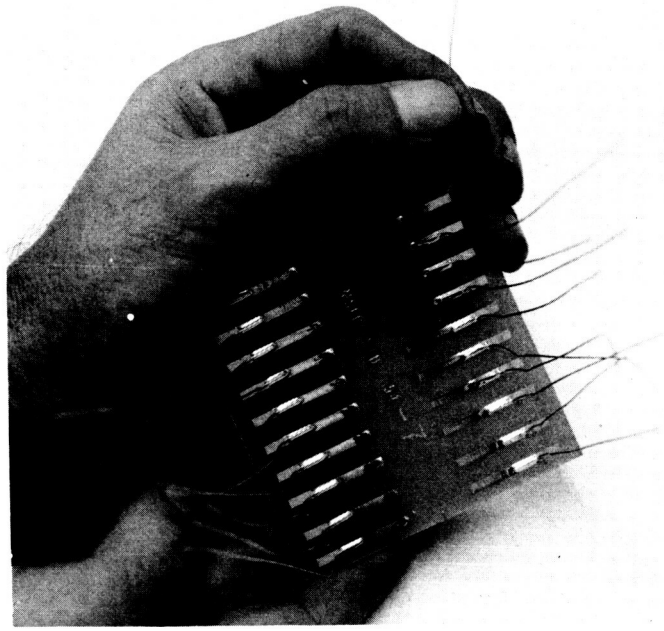


Figure 43. Pull Test Machine

against stress while orienting the lead into position for the destructive pull test. A typical test analysis sheet is shown in Figure 44. The data are ambiguous when consideration is given to the fact that all types of wire in the soft condition vary widely. For example, copper weld with a copper sheath over an iron core in the soft condition is not as soft as a solid copper wire in the soft or annealed condition.

This difference in rigidity becomes a factor as the wire bends or has a tendency to spring back into original position during the removal from the solder fillet. Table XIX shows the results of the peel tests.

MSFC-STO-154-11
Rate Pull = 1 In./Min

Experiment No. 2008

Solder: 63 SN/37 Pb at 495°F
Flux: 25 percent WW Rosin/75 percent Iso Alcohol
Surface: 60 SN/40 Pb OP-98 at 500°F
OFHC Copper Wire: PR SO Diameter 714647

Peel Test

Specification No.	Pound	Specification No.	Pound
1	2.9	11	3.3
2	2.6	12	3.0
3	3.2	13	3.0
4	2.8	14	2.8
5	2.8	15	3.0
6	2.9	16	
7	3.1	17	
8	3.1	18	
9	3.0	19	
10	3.0	20	

Total	44.50
Average	2.97
High	3.3
Low	2.6
Difference	0.7
0.7/2.97 =	23.5 percent

Figure 44. Destructive Test Analysis Sheet

TABLE XIX

Peel Pull Tests

Experiment No.	Wire No.	Material	Plating	Thickness in Microinches	Cleaning	Peel Strength in Pounds		
						Low	Average	High
2011	I	OFHC Copper	Gold over Nickel Strike	50 to 50		1.2	1.68	2.1
2003			Electro - Tin SN 100%	180 to 220		2.2	2.74	3.9
2008			60/40 Hot Dipped		OP-98	2.6	2.97	3.3
2012	II	Nickel "A"	60/40 Hot Dipped		Activated and placed in inert atmosphere until just prior to soldering.	1.5	2.01	2.6
2009			60/40 Hot Dipped		AJAX cleaned and fluxed with Kester 1544.	1.5	2.08	2.9
2010			Gold	50 to 70		0.6	1.35	2.1
2001	III	Type K	Gold	50 to 70		0.9	1.12	1.9
2002			Gold	50 to 70	AJAX cleaned then hot dipped in 60/40.	0.7	1.21	1.5
2004	IV	Dumet (Unborated)	Electro - Tin	100 to 200		1.4	1.80	2.5
2006			60/40 Hot Dipped		OP-98	3.1	3.40	4.0
2005	V	Copper Weld	Electro - Tin	100 to 200		1.5	2.14	2.8
2007			60/40 Hot Dipped		OP-98	3.2	4.34	5.7
2014	VI	OFHC Copper	Gold	50 to 70	Appendix K A, B, C(3)	1.6	2.28	2.8

E. SURFACE STUDIES

A review of the electrochemical properties of active and passive surfaces on nickel and iron indicated that the state of the surface could be determined by running current-voltage plots and observing the Flade potential (potential at which the current reaches a maximum value in the transition from active to passive potentials). An active surface would have a relatively low Flade potential because of its ability to begin reacting sooner with electrolytically generated oxygen.

Experiments have been conducted to verify this low potential. Samples of pure nickel wire in various states of surface activity were used as the anode in a one normal electrolyte of potassium hydroxide. A platinum gauze was used as the cathode. Using a model XV Sargent Polarograph, the voltage was increased on the cell from 0 to 1 volt at 0.1 volt/minute, and current was recorded at a sensitivity of 0.4 microampere per millimeter of chart, for a 0.031 x 0.012 x 1.0 inch sample. Pure nickel wire, activated in 50 percent hydrochloric acid, showed a rapid increase in current at 0.35 volt, reaching the Flade potential at 0.41 volt, then dropping off rapidly to a minimum at 0.45 volt, indicating reaction of oxygen with the nickel surface. From 0.45 volt and up, the current increased rapidly, indicating oxygen being generated faster than it could react with the nickel (Figure 45). Samples passivated in air or in a flame showed little to no Flade potential dropoff current, indicating that the surface was already covered with oxides of nickel.

The technique of using accurate voltage-current plots of electrolyzed materials to determine surface activity was used to measure several promising lead materials (Table XX). The onset of passivation was detected in five of the nine materials tested. All materials were cleaned and activated in warm 75 percent hydrochloric acid.

A study of references on the passivity of copper indicated that a copper anode will become passive during the electrolysis of potassium sodium tartrate. Tests were conducted on freshly cleaned copper in 1 normal $KNaC_4H_4O_6$ to determine if a Flade potential (onset of passivation) was detectable. A sharp drop in current with increasing applied voltage was noted, beginning at 0.25 volt and reaching a minimum at 0.65 volt, referenced to a platinum cathode. No difference was observed, however, for copper cleaned in chromic acid, which in practice is a more stable surface to staining and surface oxidation.

The measurement of an "apparent" Flade potential was accomplished, but unlike the nobler metals, copper appears to be insensitive to various cleaning treatments which are known from previous experience to give varying degrees of surface stability.

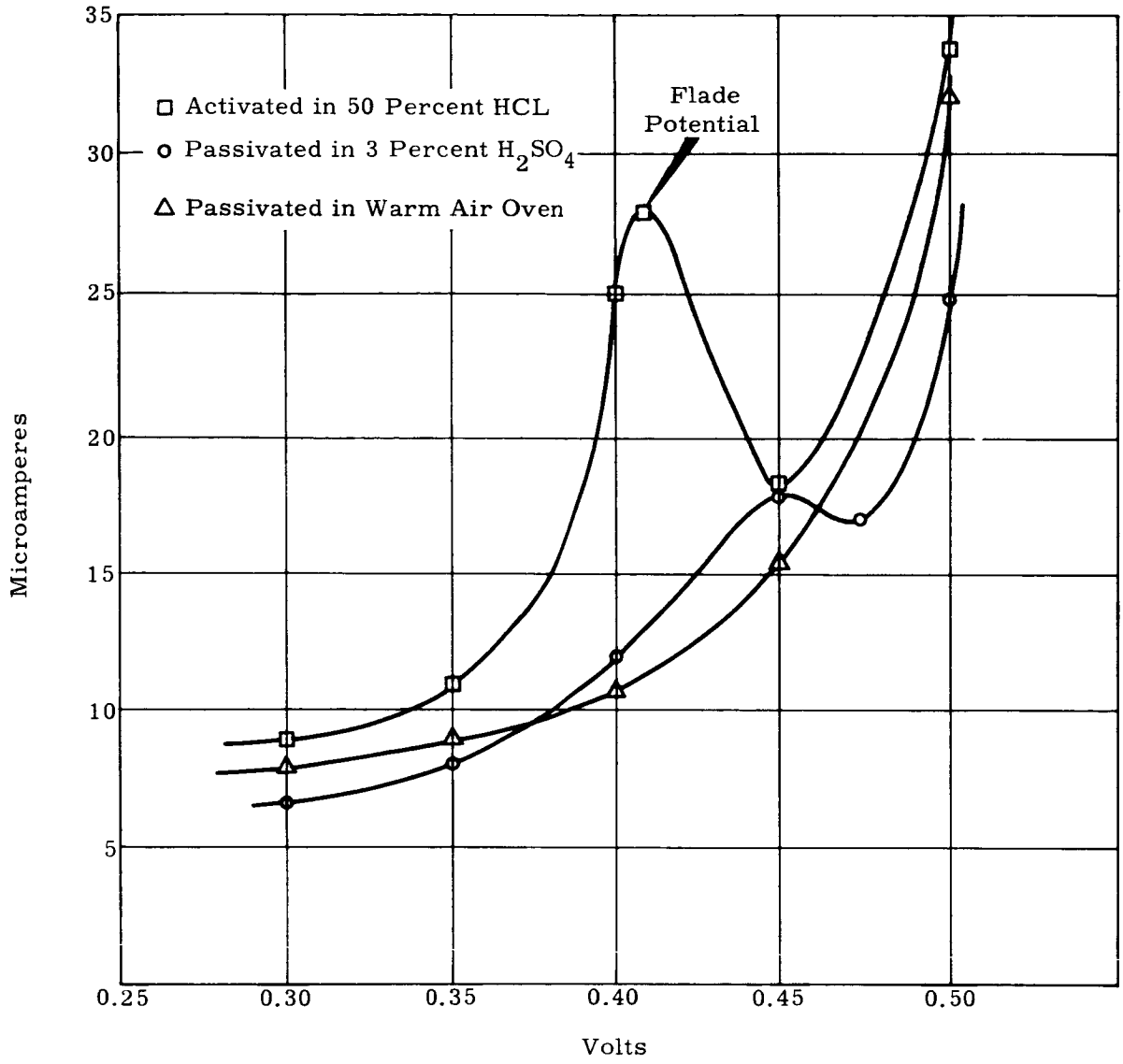


Figure 45. Surface Chemistry Studies

Photomicrographs reveal a general stress line developed in hard copper, Figure 46a, as compared with Photo Figure 46b, 1/2 hard copper and Figure 46c, soft copper. Figure 46d, QQ-W-343 copper when compared with Figure 46e OFHC reveals the difference in structure. Figure 46e OFHC has been closely controlled 0.0002 to 0.0004 percent while in Figure 46d the oxygen content is in the magnitude of 0.02 to 0.05 percent or 100 times greater. Element content other than copper are much higher in copper material shown in Figure 46d. For soldering, material in the soft annealed condition is in optimum condition. Cleaning process providing a matte surface is preferred over smooth polished surfaces. The need for protection after cleaning prior to soldering is mandatory.

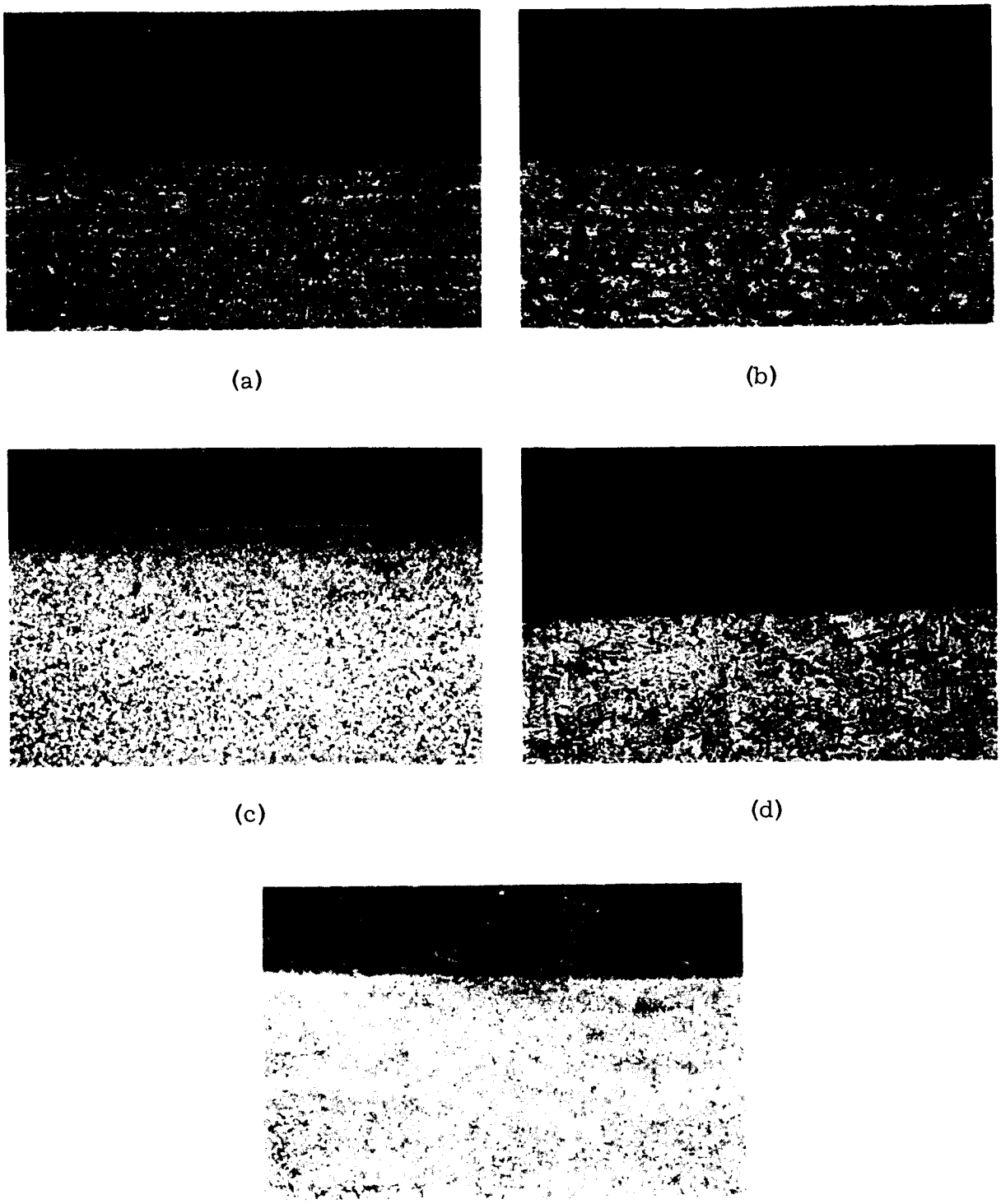


Figure 46. Copper Stress Lines

TABLE XX

Surface Activity

Material	Passivation Potential (Anodic)
Nickel "A"	0.457 volt
Kovar	0.445 volt
Alloy 90	0.510 volt
Alloy 152	None
Alloy 180	0.490 volt
Tantalum	None
Stainless Steel	0.387 volt
Copper	None
60-40 Solder	None

The copper and solder reacted chemically with the 1N KOH electrolyte as soon as it was immersed. The tantalum, being a valve metal, gave a low, constant current for all values of applied voltage. Alloy 152 gave a plot which is typical of a passivated noble metal.

The contamination studies performed using an IR spectrophotometer failed to yield any conclusive data. Further examination indicated that the weld machine variables and soldering techniques tended to mask the small changes caused by minute contaminates and absorbed gases. It was decided, therefore, to postpone any further tests with the IR spectrophotometer until such time as the weld equipment and solder techniques could be improved until the contaminates and adsorbed gases would be the predominate variables.

Micro-photographs were made to determine if concentricity of various platings existed and would therefore cause problems in welding and soldering. When the plating procedures as outlined in Appendix K were followed there were no detectable problems with concentricity, and therefore this problem was reduced to a lower priority and was not investigated further.

F. STATISTICAL ANALYSIS

1. Procedure

Analysis of variance indicates surface treatment to be the most significant factor for the eight experiments reported. The treatment described as "OP-98 Cleaned" yields obviously superior results. Among the solder joint classes so treated, Experiment No. 2007 (Copper weld, mean pull

MSFC-STD-154-7
Rate Pull = 1 In./Min

Experiment No. 2007

Solder: 63 SN/37 Pb
Flux: w/25 percent WW Rosin/75 percent Iso Alcohol
Surface: 60 SN/40 Pb at 500°F OP-98 Cleaned Copper Weld Wire

Peel Test

Specification No.	Pound	Specification No.	Pound
1	4.4	11	4.1
2	5.2	12	4.2
3	3.9	13	4.2
4	4.1	14	3.2
5	5.1	15	4.5
6	5.7	16	
7	5.3	17	
8	4.1	18	
9	3.5	19	
10	3.8	20	

Total	60.80
Average	4.35
High	5.7
Low	3.2
Difference	2.5

25/4.35 = 57.4 percent

Figure 47. Experiment No. 2007 Test Results

strength 4.34 pounds σ = 0.723 pounds) and Experiment No. 2006 dumet (unborated), mean pull strength 3.40 pounds σ = 0.312 pounds had the highest mean strengths and were compared with one another. See Figures 47 and 48.

Comparison of their means (with an adjustment for unequal variances) produces a significance of more than 99.9 percent. This significance cannot be taken literally, however, since it represents a comparison of two preranked values rather than two values from randomly selected experiments. If the sample means and standard deviations hold true in subsequent

MSFC-STD-154-6
Rate Pull = 1 In./Min

Experiment No. 2006

Solder: 63 SN/37 Pb
Flux: 25 percent WW Rosin/75 percent Iso Alcohol
Surface: 60 SN/40 Pb at 500°F w/Kester 1544
OP-98 Cleaned
Dumet Wire: PR SO Diameter 775183
(Unborated)

Peel Test

Specification No.	Pound	Specification No.	Pound
1	3.2	11	3.3
2	3.2	12	3.3
3	3.6	13	3.6
4	3.0	14	4.0
5	3.9	15	3.7
6	3.6	16	
7	3.1	17	
8	3.1	18	
9	3.1	19	
10	3.3	20	

Total	51.0
Average	3.40
High	4.0
Low	3.1
Difference	0.9
0.9/3.4 =	26.4 percent

Figure 48. Experiment No. 2006 Test Results

experiments, it would be possible to confirm the superiority of copper weld over dumet (unborated) at a significance level of 99 percent with as few as seven pull tests for each treatment. This superiority will be demonstrated with confidence of 90 percent.

A listing of the steps of the analysis follows; detailed computations are available if desired:

1 Bartlett's test for homogeneity of variances demonstrated sufficient homogeneity for using standard analysis of variance techniques.

2 Analysis of variance showed significant differences among surface treatments.

3 Comparison of variances for Experiments No. 2006 and No. 2007 showed high significance level for different standard deviations:

$$F = \frac{0.5226}{0.0971} = 5.38 \Rightarrow P(F \geq 5.38 \Big|_{f_1 = 13,\ f_2 = 14}) \cong 0.3 \text{ percent}$$

Consequently, Welch's test for two samples with unequal variances was used.

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{S_1^2/n_1 + S_2^2/n_2}} = \frac{4.34 - 3.40}{\sqrt{\frac{0.5226}{14} + \frac{0.0971}{15}}} = 4.50$$

$$f' = \frac{\left(S_1^2/n_1 + S_2^2/n_2\right)^2}{\frac{\left(S_1^2/n_1\right)^2}{f_1} + \frac{\left(S_2^2/n_2\right)^2}{f_2}} = \frac{\left(\frac{0.5226}{14} + \frac{0.0971}{15}\right)^2}{\frac{\left(\frac{0.5226}{14}\right)^2}{13} + \frac{\left(\frac{0.0971}{15}\right)^2}{14}} = 17.41$$

$$P(t \leq |4.50|) > 0.999$$

Confirmatory experiment:

Assume: $\mu = 4.34 - 3.40 = 0.94$, $\sigma = \sqrt{0.5226 + 0.0971} = 0.787$

Solve: $u_{0.10} \in N(0.94, 0.787\eta^{-1/2}) \cong t_{0.99}$ for η

$$f' = (\eta - 1)\left(1 + \frac{2\,S_1^2\,S_2^2}{S_1^4 + S_2^4}\right) \Rightarrow f' \cong 1.244\,(\eta - 1)$$

The minimum integral value for which $u_{0.10} \geq t_{0.99}$ is $\eta = 7$.

The graphs of Figure 49 and Table XXI summarize the significant information developed during experiments numbered 3113, 3115, 3116, 3117 and 3118, Figures 50 through 54.

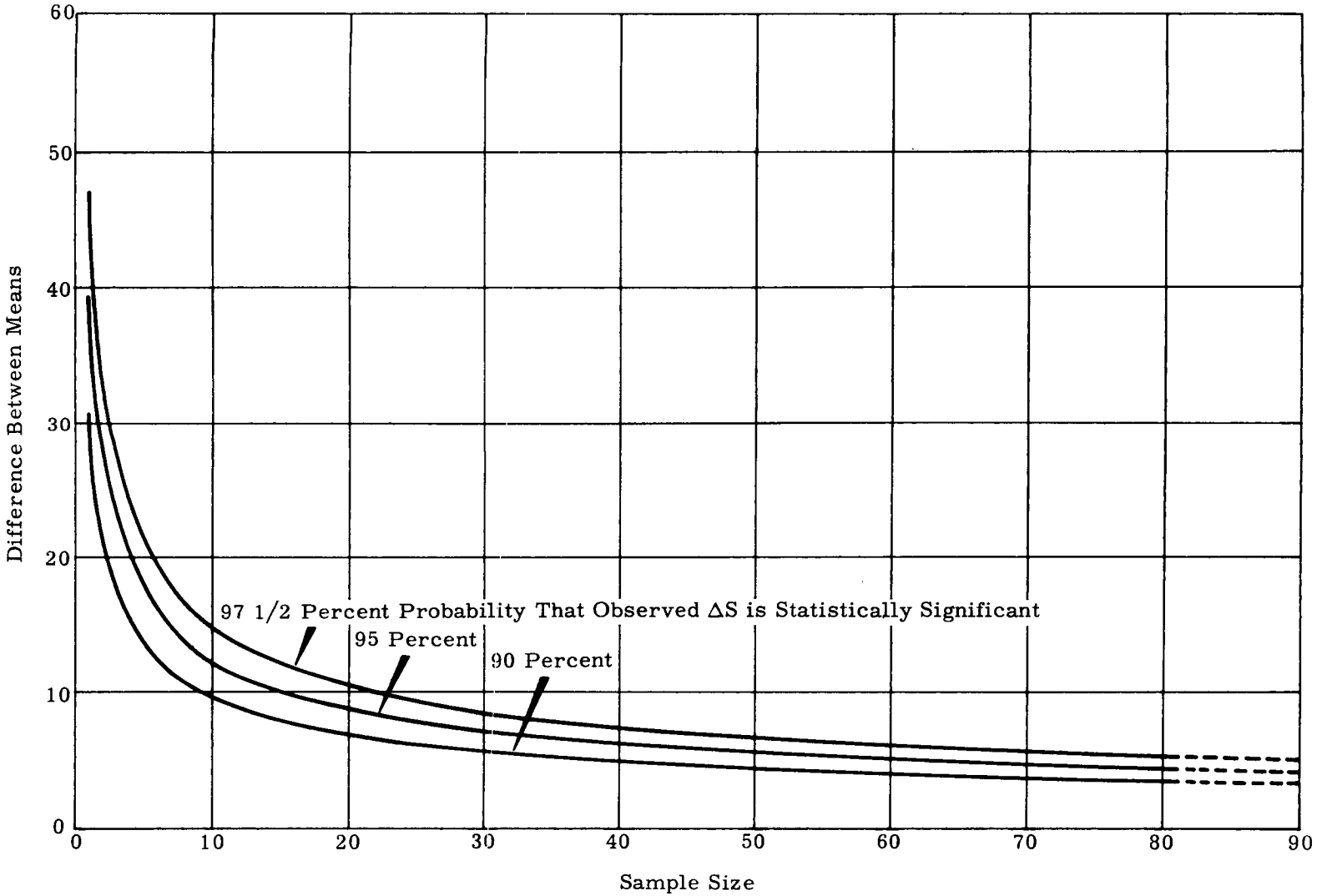


Figure 49. Sample Size Required to Detect Differences in Mean S Values

Experiment No: 3113
Wire Size: 24 gage (0201) OFHC
Surface Preparation: P-31041F
Coating: Sn 0.00018 - 0.00022
Method: End Dip F Agitation
Oil: Hydrofol Gliceride
Configuration: 5/16 diameter mandrel

	(mm)					Remarks
No.	L1	L2	D (mm)	d (mm)	10L1 + L2	D-d
1	1.7	1.6	0.80	0.51	18.6	0.29 = 64.3
2	1.8	1.7	0.70	0.51	19.7	0.19 = 103.5
3	1.9	1.7	0.75	0.51	20.7	0.24 = 86.4
4	1.8	1.7	0.75	0.51	19.7	0.24 = 82.2
5	1.6	1.6	0.70	0.51	17.6	0.19 = 93.0
6	1.8	1.6	0.70	0.51	19.6	0.19 = 103.0
7	1.7	1.7	0.80	0.51	18.7	0.29 = 64.5
8	1.7	1.8	0.80	0.51	18.8	0.29 = 65.0
9	1.8	1.8	0.80	0.51	19.8	0.29 = 68.6
10	1.7	1.4	0.80	0.51	18.4	0.29 = 63.5
11	1.2	2.2	0.80	0.51	14.2	0.29 = 49.0
12	0.0	2.1	0.70	0.51	2.1	0.19 = 11.0
13	1.8	1.6	0.70	0.51	19.6	0.19 = 103.0
14	1.8	1.6	0.70	0.51	19.6	0.19 = 103.0
15	1.8	1.4	0.70	0.51	19.4	0.19 = 102.0
16	1.9	1.8	0.80	0.51	20.8	0.29 = 71.5
17	1.9	1.8	0.75	0.51	20.8	0.24 = 86.7
18	0.0	1.1	0.70	0.51	1.1	0.19 = 5.8
19	1.8	1.7	0.78	0.51	19.7	0.24 = 5.8
20	2.0	1.7	0.80	0.51	21.7	0.29 = 74.7
21	1.7	1.4	0.75	0.51	18.4	0.24 = 76.7
22	0.0	2.0	0.80	0.51	2.0	0.29 = 6.9
23	1.9	1.6	0.70	0.51	20.6	0.19 = 108.0
24	1.8	1.5	0.70	0.51	19.5	0.19 = 102.5
25	1.6	1.3	0.75	0.51	17.3	0.24 = 72.2
26	1.7	1.7	0.80	0.51	18.7	0.29 = 64.5
27	0.0	2.1	0.80	0.51	2.1	0.29 = 7.3
28	1.7	1.5	0.70	0.51	18.5	0.19 = 64.0
29	1.7	1.7	0.80	0.51	18.7	0.29 = 64.5
30	1.8	1.8	0.75	0.51	19.8	0.24 = 68.5
Totals		2004.00				
S = (average)		71.6				

Figure 50. Experiment No. 3113 Test Results

Experiment No: 3115
Wire Size: 24 gage (020) OFHC
Surface Preparation: OP-98
Coating: 60 Sn/40 Pb
Method: End Dip in Pot F Agitation
Oil: Hydrofol Gliceride
Configuration: 5/16 diameter mandrel

	(mm)				Remarks	
No.	L1	L2	D (mm)	d (mm)	10L1 + L2	D-d
1	1.8	1.8	0.75	0.51	19.8	0.24 = 82.5
2	1.9	1.4	0.80	0.51	20.4	0.29 = 70.4
3	1.8	1.8	0.80	0.51	19.8	0.29 = 68.3
4	1.9	1.8	0.75	0.51	20.8	0.24 = 86.7
5	1.8	1.6	0.80	0.51	19.6	0.29 = 67.7
6	1.9	1.8	0.80	0.51	20.8	0.29 = 71.7
7	1.8	1.3	0.80	0.51	19.3	0.29 = 66.6
8	1.8	1.8	0.70	0.51	19.8	0.19 = 104.8
9	1.8	1.7	0.80	0.51	19.7	0.29 = 68.0
10	1.7	1.3	0.80	0.51	18.3	0.29 = 63.1
11	1.7	1.7	0.80	0.51	18.7	0.29 = 64.5
12	1.7	1.6	0.70	0.51	18.6	0.19 = 97.9
13	1.9	1.7	0.70	0.51	20.7	0.19 = 108.9
14	2.0	1.8	0.80	0.51	21.8	0.29 = 75.2
15	1.8	1.6	0.75	0.51	19.6	0.24 = 81.6
16	1.9	1.7	0.75	0.51	20.7	0.24 = 86.3
17	1.7	1.5	0.70	0.51	18.5	0.19 = 97.4
18	2.0	1.9	0.85	0.51	21.9	0.34 = 64.4
19	1.8	1.5	0.75	0.51	19.5	0.24 = 81.3
20	2.0	1.7	0.80	0.51	21.7	0.29 = 74.8
21	1.8	1.5	0.70	0.51	19.5	0.19 = 102.6
22	1.9	2.0	0.85	0.51	21.0	0.34 = 61.8
23	1.7	1.7	0.70	0.51	18.7	0.19 = 98.4
24	1.7	1.7	0.70	0.51	18.7	0.19 = 98.4
25	2.0	2.0	0.85	0.51	22.0	0.34 = 64.7
26	2.1	1.9	0.85	0.51	22.9	0.34 = 67.4
27	1.8	1.5	0.75	0.51	19.2	0.24 = 81.2
28	1.8	1.2	0.70	0.51	19.2	0.19 = 101.0
29	1.9	1.8	0.80	0.51	20.8	0.29 = 71.7
30	1.8	1.8	0.80	0.51	19.8	0.29 = 68.3
Totals		2224.3				
S = (average)		79.5				

Figure 51. Experiment No. 3115 Test Results

Experiment No: 3116
Wire Size: 24 gage (B20) MIL-STD-1276
Surface Preparation: MIL-G-45204, Type I, Class 1
Coating: Au 0.00005 - 0.000070
Method: End Dip in Pot F. Agitation
Oil: Hydrofol Gliceride
Configuration: 5/16 Diameter Mandrel

	(mm)				Remarks	
No.	L1	L2	D (mm)	d (mm)	10L1 + L2	D-d
1	1.8	1.8	0.80	0.51	19.8	0.29 = 68.3
2	1.4	2.2	0.70		16.2	0.19 =
3	1.9	1.9	0.80		20.9	0.29 = 72.1
4	1.9	1.7	0.80		20.7	0.29 = 71.4
5	1.8	1.9	0.85		19.9	0.34 = 58.5
6	1.9	1.8	0.90		20.8	0.39 = 53.4
7	1.9	1.7	0.85		20.7	0.34 = 60.8
8	1.8	1.9	0.80		19.9	0.29 = 68.6
9	1.8	1.7	0.80		19.7	0.29 = 68.0
10	1.9	1.7	0.80		20.7	0.29 = 71.4
11	2.0	1.9	0.90		21.9	0.39 = 56.1
12	1.9	1.7	0.90		20.7	0.39 = 53.2
13	1.7	1.8	0.80		18.8	0.29 = 64.9
14	1.6	1.6	0.85		17.6	0.34 =
15	1.8	1.9	0.80		19.9	0.29 = 68.6
16	1.8	1.6	0.80		19.6	0.29 = 67.5
17	1.7	1.6	0.80		18.6	0.29 = 64.1
18	1.7	1.5	0.75		18.5	0.24 = 77.1
19	1.9	1.8	0.80		20.8	0.29 = 71.7
20	1.8	1.8	0.80		19.8	0.29 = 68.4
21	1.9	1.8	0.90		20.8	0.39 = 53.3
22	1.9	1.7	0.80		20.7	0.29 = 71.4
23	1.7	1.5	0.80		18.5	0.29 = 63.8
24	1.9	1.4	0.85		20.4	0.34 = 60.0
25	1.9	1.6	0.80		20.6	0.29 = 71.0
26	1.7	1.8	0.80		18.8	0.29 = 64.9
27	1.8	1.7	0.80		19.7	0.29 = 67.9
28	1.8	1.8	0.75		19.8	0.24 = 82.5
29	1.8	1.6	0.80		19.6	0.29 = 67.6
30	1.8	1.7	0.80	0.51	19.7	0.29 = 67.9
Totals		1854.4				
S = (average)		33.0				

Figure 52. Experiment No. 3116 Test Results

Experiment No: 3117
Wire Size: 24 gage (020) Dumet
Surface Preparation: P-31041F
Coating: SN 0.0001 - 0.0002
Method: End dip pot F Agitation
Oil: Hydrofol Gliceride
Configuration: 5/16 diameter mandrel

	(mm)					Remarks
No.	L1	L2	D (mm)	d (mm)	10L1 + L2	D-d
1	1.8	1.7	0.85	0.51	19.7	0.34 = 57.9
2	1.8	1.7	0.85	0.51	19.7	0.34 = 57.9
3	1.8	1.7	0.80	0.51	19.7	0.29 = 67.8
4	1.8	1.8	0.85	0.51	19.8	0.34 = 58.2
5	1.8	1.8	0.80	0.51	19.8	0.29 = 68.4
6	1.7	1.4	0.70	0.51	18.4	0.19 = 96.8
7	1.8	1.5	0.80	0.51	19.5	0.29 = 67.2
8	1.8	1.6	0.75	0.51	19.6	0.24 = 81.7
9	1.9	1.9	0.90	0.51	20.9	0.39 = 53.6
10	1.8	1.6	0.70	0.51	19.6	0.19 = 103.2
11	1.7	1.5	0.80	0.51	19.5	0.29 = 63.8
12	1.8	1.6	0.80	0.51	19.6	0.29 = 67.6
13	2.0	1.8	0.85	0.51	21.8	0.34 = 64.3
14	2.0	1.7	0.80	0.51	21.7	0.29 = 74.7
15	1.8	1.7	0.80	0.51	19.7	0.29 = 68.0
16	1.8	1.9	0.80	0.51	19.9	0.29 = 68.6
17	2.1	1.9	0.90	0.51	22.9	0.39 = 59.0
18	1.7	1.7	0.80	0.51	18.7	0.29 = 64.5
19	1.8	1.3	0.70	0.51	19.3	0.19 = 101.7
20	1.8	2.0	0.80	0.51	20.0	0.29 = 69.0
21	2.0	1.9	0.80	0.51	21.9	0.29 = 75.5
22	2.0	2.0	0.85	0.51	22.0	0.34 = 64.7
23	1.9	1.7	0.80	0.51	20.7	0.29 = 71.5
24	1.8	1.8	0.85	0.51	19.8	0.34 = 58.4
25	1.9	1.6	0.80	0.51	20.6	0.29 = 71.1
26	1.8	1.7	0.80	0.51	19.7	0.29 = 68.0
27	1.7	1.6	0.80	0.51	18.6	0.29 = 69.2
28	1.8	1.9	0.85	0.51	19.9	0.34 = 58.5
29	1.8	1.8	0.80	0.51	19.8	0.29 = 68.2
30	1.9	1.8	0.80	0.51	20.8	0.29 = 71.8
Totals		1934.0				
S= (average)		69.1				

Figure 53. Experiment No. 3117 Test Results

Experiment No: 3118
Wire Size: 24 gage (020) Dumet
Surface Preparation: OP-98
Coating: 60 SN/40 Pb
Method: End Dip in Pot F Agitation
Oil: Hydrofol Gliceride
Configuration: 5/16 diameter mandrel

	(mm)				Remarks	
No.	L1	L2	D (mm)	d (mm)	10L1 + L2	D-d
1	1.8	1.4	0.75	0.51	19.4	0.24 = 81.1
2	1.9	1.5	0.80		20.5	0.29 = 70.6
3	1.7	1.7	0.75		18.7	0.24 = 78.0
4	2.0	1.7	0.80		21.7	0.29 = 74.8
5	1.9	1.8	0.80		20.8	0.29 = 71.7
6	1.8	1.6	0.80		19.6	0.29 = 67.5
7	1.8	1.8	0.80		19.8	0.29 = 68.2
8	1.8	1.7	0.80		19.7	0.29 = 67.9
9	1.8	1.6	0.70		17.6	0.19 =
10	1.8	1.5	0.75		19.5	0.24 = 81.3
11	1.9	1.9	0.90		20.9	0.39 =
12	1.7	1.7	0.80		18.7	0.29 = 64.6
13	1.9	1.7	0.85		20.7	0.34 = 63.8
14	1.9	1.9	0.80		20.9	0.29 = 15.6
15	1.9	1.8	0.80		20.8	0.29 = 75.3
16	1.9	2.0	0.90		21.0	0.39 = 53.9
17	1.8	1.7	0.75		19.7	0.24 = 82.2
18	1.7	1.5	0.70		18.5	0.19 = 97.5
19	1.7	1.6	0.75		18.6	0.24 = 77.4
20	1.8	1.6	0.80		19.6	0.29 = 67.7
21	1.8	1.7	0.80		19.7	0.29 = 68.0
22	2.0	1.9	0.90		21.9	0.39 = 56.1
23	1.9	1.8	0.85		20.8	0.34 = 64.2
24	1.7	1.7	0.70		18.7	0.19 = 98.4
25	1.9	1.8	0.80		20.8	0.29 = 75.2
26	1.7	1.7	0.80		18.7	0.29 = 64.5
27	1.8	1.7	0.75		19.7	0.24 = 82.1
28	1.7	1.7	0.75		18.7	0.24 = 77.0
29	1.8	2.0	0.80		20.0	0.29 = 69.0
30	1.9	1.7	0.85	0.51	20.7	0.34 = 63.8
Totals		2037.4				
S = (average)		356.4				

Figure 54. Experiment No. 3118 Test Results

Table XXI, lists the values of the discriminant S in terms of its increasing value. The mean value for S has an observed minimum value of 66.37 for experiment 3116 and an observed maximum mean value of 82.09 for experiment 3113. The range within which there exists a 90 percent probability that the true value of $\bar{S}$ lies is given for each of the five values of $\bar{S}$. The precision of measurement for the mean S value indicates that the true mean has a high probability of lying within about ±5 percent of the value measured in each experiment with a sample size of 30.

TABLE XXI

Range of Values for S

Experiment No.	Mean Value	Mean Range for True Value	Individuals Range of Values (includes 90%)
3116	66.37	63.94-68.81	53.06- 79.69
3117	69.50	65.84-73.16	49.46- 89.53
3118	72.50	68.86-76.15	52.53- 92.47
3115	79.89	75.46-84.32	55.63-104.15
3113	82.09	76.62-87.55	54.23-109.95

The fourth column of Table XXI indicates the range of values to be expected for the individual values of S for each experiment. The range of values given opposite the experiment number can be expected to include 90 percent of the individual measured values of S. The lower limits of each range are very close in value, while the upper limits have a considerable spread. This spread is due to an increasing lack of measurement precision with increasing values of S and is in the direction of optimum solderability or the direction where soldering problems do not occur. The lack of precision occurs when the operator attempts to estimate where the solder has discontinued its spread. Where good soldering conditions and techniques exist, solder flows out gradually and thins out to surface joined with no line of demarcation or point of beginning visible. Therefore, as leads are less solderable, the more accurate the measurement; or as the need to know and determine solderability increases, the more accurate the method of measurement.

The observed increase in standard deviation does not appear to be significant in a statistical sense for samples of size 30. The great deal of overlap in the ranges for individual S values indicates that the equation for S is lacking in discriminatory ability and the measurement of the constituents of S

is lacking in precision. These two factors result in the need for large samples to detect significant changes in values of S where S is large, above 60.

In experiment 3113, Figure 50, (having the highest values of S and the least precision of measurement items 12, 18, 22 and 27 are significantly different from the remaining data and require an explanation as to the cause of their lack of conformity. They all had a zero value for L_1 which is not consistent with the remaining measurements of this experiment.

There have been examples legion in number that no two solder joints or solderability test specimens are exact duplications of another even with no known variables existing. There also has been a history on electro tin plate which proves this material incapable to resist the rigors of shelf life on the same plane as hot dipped surfaces. The thickness of hot dipped surfaces in these experiments is thicker than the electro tinned surfaces. OFHC copper, once having left its inert atmosphere environment while being refined, has no residual deoxidants present to resist further oxidation by subsequent heating if exposed to oxygen when not adequately protected.

Work with this program and efforts of the Tin Research Institute in the past strongly suggest electro tin plate in this instance to be of insufficient thickness for periods in excess of 7 months.

Figure 49 has three graphs relating the differences between mean values of S and sample sizes required to detect such differences at three different levels of probability. The precision of measurement used for these curves was that determined for experiment 3113 and was the largest measured. Larger sample sizes are therefore required than would be determined if measurements were more precise.

As an example of the use of Figure 49, if a difference of 15 S units from 70 to 85, was the smallest difference of practical significance, then a sample size of four measurements would be sufficient. That is, four specimens of each wire would be measured of each of the experiments to be compared.

Figure 49 also indicates that where a difference of three exists in mean S value between two types of leads, these two types should be rated equal.

All dimensions L_1, L_2, and D appear susceptible to more precise measurement. These numbers with one more significant figure should reduce experimental error and the sample sizes needed. The standard deviation of L_1 and L_2 is presently about 0.14 millimeter when both measurement errors and ability to define the limits of L_1 or L_2 are combined.

2. Conclusions

The values of Table XXI give the relative order of the five typical experiments. The only significant difference between adjacent pairs indicates that experiment 3115 (Figure 51) has an S value significantly higher than experiment 3118 (Figure 54). Other significant differences are 3118 significantly larger than 3116 (Figure 52), 3115 greater than 3116 and 3117 (Figure 52), and 3113 greater than 3116, 3117, and 3118. These differences are greater than can be accounted for by experimental error.

S values discriminate only on the basis of comparing means of large sample sizes. Individual readings overlap considerably.

Improved precision of measurement of L_1, L_2 and D would improve discriminating power of the S equation.

The cause of anomalies in experiment 3113 bears investigation.

V. SOLDERABILITY FINE SCREENING

A. FINE SCREENING

After rough screening as described earlier the candidate materials were reduced to the following eight types:

1. OFHC 60 Sn/40 Pb hot dip
2. OFHC Sn electro plate
3. Dumet 60 Sn/40 Pb hot dip
4. Dumet Sn electro plate
5. Copperweld 60 Sn/40 Pb hot dip
6. Copperweld Sn electro plate
7. MIL-STD-1276 Type K
8. MIL-STD-1276 Type K and 60 Sn/40 Pb hot dip.

These materials were subjected to:

1. Peel tests (see Table XIX, page 67)
2. Spread tests
3. Droplet test.

In addition to those materials listed, special attention was given to:

1. Effects of electro tin thickness on solderability
2. Ultrasonic tinned wire
3. Nickel because of its wide use in today's space industry
4. Kovar and Rodar plating other than gold.

Fine schreening included comparisons of the thickness of electro tin plate to solderability. It was noted in the rough screening stage that electro tin plate of 0.0051 mm to 0.0102 mm when freshly plated produced soldering closely approaching that of hot solder dip surfaces. Plating of 0.00457 mm to 0.00559 mm was used generally. Spread tests were conducted in experiment 1009 which used OFHC 0.0025 mm to 0.0051 mm electro tin plate with spread of 0.375 in.^{2}. In experiment 1011, OFHC 0.0051 mm to 0.0102 mm electro tin plate was used with spread of 0.310 in.^{2}. This represents a 22 percent decrease in spread of the thicker electro tin plate. The droplet test verified what had been observed during the rough screening or flow soldering of leads. The thicker electro tin plate provided a 9 1/2 percent increase in the "S" factor. This S factor on 0.0051 mm to 0.0102 mm electro plated material resulted in 1/2 percent less S factor value than wire of same type hot solder dipped. It must be accepted that electro tin surfaces of the thickness of 0.0051 mm to 0.0102 mm are as effective as hot dip surfaces for periods up to 6 months or more as a protective solderable cost.

B. EVALUATION OF ULTRASONICALLY PRE-TINNED LEADS

An evaluation of the OFHC copper leads which were ultrasonically pretinned with 60 Sn/40 Pb by NASA-Huntsville was performed and compared with hot dipped 22 gage OFHC copper leads prepared by AMT. The results of this comparison are given in Table XXII.

Photomicrographs of these specimens were made to verify the observation made in Table XXII. Photomicrograph Figure 55 reveals an intermetallic formation and the rough uneven surface of the copper lead. Photomicrograph Figure 56 does not show the intermetallic, however, it does show the extreme unevenness of the wire. The dark area in photograph Figure 56 is the solder.

Other tests were run on copper wire immersed in hot solder for varying lengths of time. In all cases the copper was dissolved in the solder in direct proportion to a time-temperature relation. It appears that the ultrasonic technique speeds up this migration effect by a washing action but is uncontrolled so that inclusions and varying degrees of diameter reduction occur in the base wire. Although the solder bonds made on ultrasonically pretinned copper are stronger on the average than hot-dipped copper of comparable gage diameter, the uncertainty which exists because of the base wire tensile strength reduction would indicate that this technique could only be used on the larger diameter gages (above 16 gage) which are not normally used on electronic components subject to mounting on printed circuit boards.

C. OTHER SPECIAL TESTS

Nickel, bare, is not the most solderable material; neither is it unsolderable. Where high soldering temperatures may freely be applied or if more

TABLE XXII

Ultrasonic versus Hot Dipped Leads

Test	Ultrasonic Tinned (60/40)				Hot-Dipped (60/40)			
	High	Low	Avg	Difference	High	Low	Avg	Difference
Peel Test	6.3	3.2	4.4	71.5%	3.3	2.6	3.0	24%
Visual Inspection Flow Solder	Rough and Uneven, Pitted				Good, Slight Line of Demarcation			
Droplet Test "S" Factor	7.5 Avg				8.9 Avg			
Remarks:	Five wires were broken or seriously weakened during the peel test. Although the peel strengths were higher, caused by the rough finish of the wire, the variation in strengths was excessive. Tensile strength of 22 gage OFHC copper is 19.5 lb. This shows the reduction in strength caused by the ultrasonic pretinning.				Peel tests showed smooth solder fillets and all joints failed due to wire pulling from solder bond. There were no broken wires.			

Figure 55. Ultrasonic Pretinned Wire

Figure 56. Hot Dipped Wire

active fluxes are permitted, it will solder with moderate success. Where an automatic soldering principle is employed, the nickel should be electro tin plated to protect the nickel from passivation. A bare nickel wire protected until just prior to soldering by an inert gas will not exceed the bonding strength of copper. See Table XIX. When gold plated only, this nickel proved to provide less reliable joints than those nickel joints hot dipped.

In studies with Kovar and Rodar both droplet tests and spread tests indicate a copper flash 0.00051 mm (0.000020 in.) under gold to be of no value. Tests did indicate copper flash under electro tin was solderable. However, the flowing of electro tin under high temperature makes its application unrealistic.

In order to verify previous results with gold plating over copper, a droplet test was performed on 24 gage OFHC copper wire plated with 50 to 70 microinches of gold. The S index factor was 65.6 as compared to OFHC copper 60/40 hot dipped which had an S index number of 79.5. This is a difference of 13.9 which is significant. Resoldering of the gold plated leads increased the S factor to 72 which indicates the gold plating has been removed by the solder and the original copper surface is being soldered.

As shown in the above figures, gold platings over copper are less desirable than are solder coatings. This important difference in S numbers of 13.9 points was obtained under ideal laboratory plating conditions. However, in actual practice the difference would undoubtedly be worse since less than ideal conditions exist in most plating shops. Note that the statistical analysis has shown that ΔS's in excess of 10 are significant and cannot be accounted for by variations in technique but are probably a result of variations in material or surface conditions.

Gold platings on less solderable materials such as Kovar/Rodar for example may be of value if the base material has been prepared properly and cleaned prior to plating. However, if these leads are subjected again to soldering operations their solderability drops to an extremely low level and they are almost completely unexceptable (Reference Figure 57). This test of gold plated Kovar which, when re-dipped, simulates the reworking or resoldering of transistor leads. Such rework is performed often because of the cost of P/C and M/L board assemblies, and shows that the problem of surface preparation and plating is one of no small magnitude. This problem requires investigation and study beyond the scope of this program.

The fact to emphasize is that since gold does not oxidize at room temperature it does in theory provide an excellent protection for maintaining solderable surfaces. This potentially strong advantage can only be fully

exploited through improved process plating knowledge and additional technology on base metal surface treatment prior to plating.

Such future work which would allow the exploitation of gold plated surfaces to be included in the soldering operation should include the effects of plating thickness, nickel or other metal sublayers, dispersion of gold throughout the solder with subsequent aging, and gold embrittlement.

D. RESULTS OF FINE SCREENING TESTS

Thirty samples of each of the following lead materials were tested using the droplet test in order to determine the effects of hot tin coatings as opposed to electro tin platings for copper leads and to evaluate the gold plating of Kovar lead materials.

1. OFHC copper – 60/40 hot tin dipped
2. Dumet – 60/40 hot tin dipped
3. OFHC copper – electro tin plated
4. Dumet – electro tin plated
5. Kovar – electro plated with gold.

The results of these tests are shown in Figure 57. It should be noted that the results are plotted based on only 28 samples for each material since the high and low value for each sample was dropped from the average to allow for operator error. After the results were plotted, calculations were performed using all thirty samples. The results were nearly the same and the order of merit did not change.

As can be seen from Figure 57 the hot dipped surfaces are superior to the electro tin plated surfaces. This difference increases with time, and for storage periods longer than 6 months the hot dipped tin surfaces are far superior to the electro tin plates.

Although the thickness of the hot dipped coating is difficult to control it can be maintained within printed circuit tolerances, and the superior results and smaller variations obtained with the hot dipped coatings seem to justify its selection over electro tin plated surfaces.

After the fine screening was completed the following lead materials and platings were selected as the best for solderability:

1. OFHC – 60/40 hot dipped: This material and coating continually performed in a predictable manner approaching the optimum when reasonable care was taken in preparation for coating.

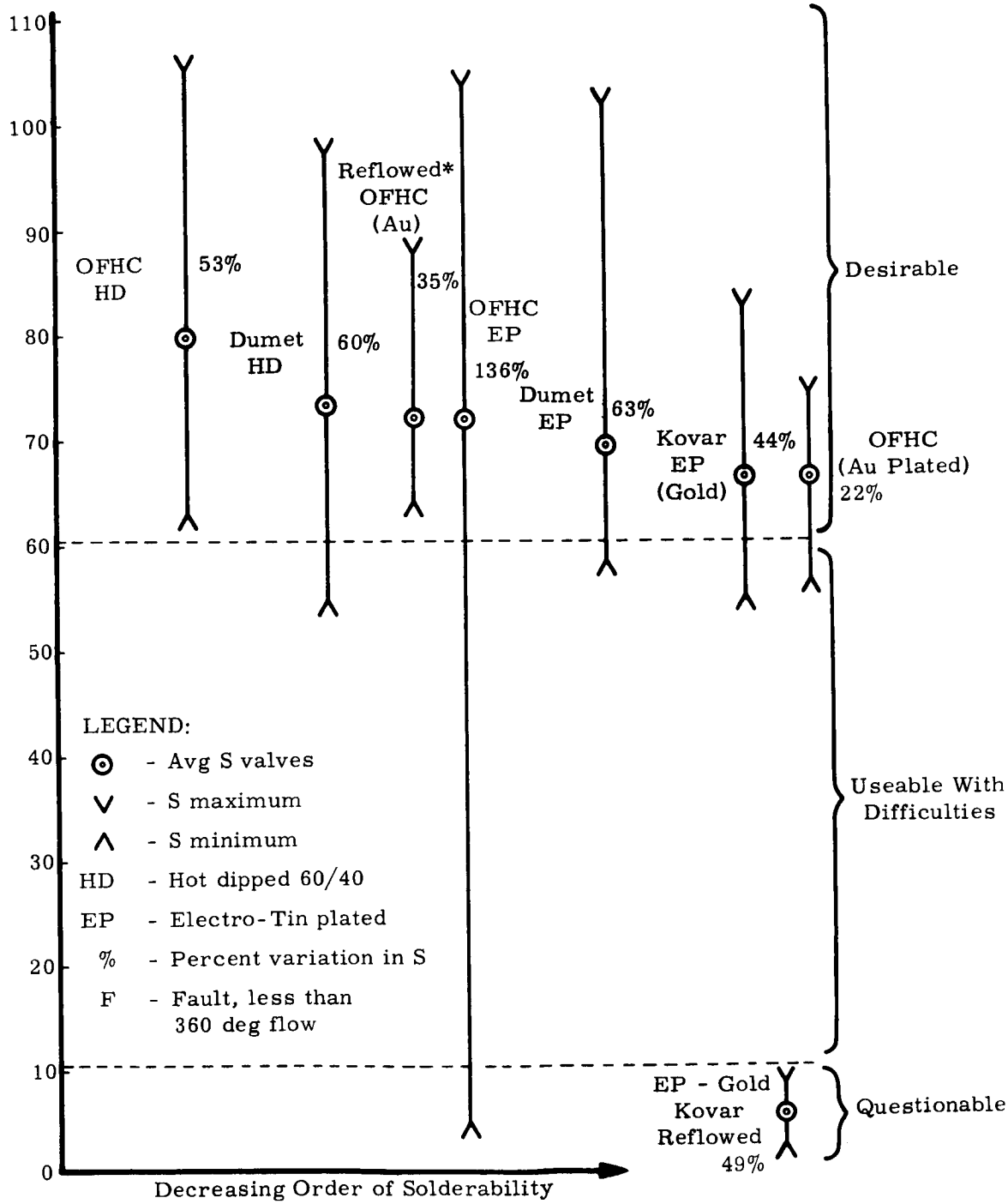


Figure 57. Solderability Merit

2 Dumet – (Deoxidized copper) – 60/40 hot dipped: This material was only slightly below the OFHC copper in performance; however, the metaloidal deoxidizers must be carefully controlled since a slight increase, above 0.015 percent phosphorus, will cause a decrease in conductivity.

3 OFHC copper – electro tin plated: Although this material is rated superior for solderability its "S" factor is approximately 10 points below the hot dipped coating and exhibits considerable variations from the average. Also, the electro tin plated surface deteriorates rapidly with time.

4 Dumet – electro tin plated: This lead material is only slightly below the hot dipped Dumet in solderability; however, the variations from the average are greater, and, as in 3 above, the plating surface deteriorates with time.

5 Kovar – gold plated (MIL-STD-1276 Type K): This material is consistently below the other four materials in solderability but must be considered because of its ability to be bonded to glass. Kovar or Radar, however, should be plated with gold to maintain a degree of solderability. Rework or flow soldering tends to wash away the gold plating and renders the lead poorly solderable . . . a point of consideration for future program effort.

A copper flash of 20 microinches followed by 400 microinches of electro tin plating offers some improvement in the solderability of Kovar (Table XXIII). However, due to the glass to lead sealing temperature often used with Kovar this plating combination cannot be used.

Samples of electro gold plated Kovar and electro tin plated Kovar were allowed to dwell for 30 seconds on a hot plate to simulate the hot temperature encountered in the glass sealing operation. The gold plated Kovar was unaffected while the tin plated Kovar turned a rust red and was completely unsolderable.

The condition of the parent metal surface and its preparation prior to plating is the primary factor which determines the solderability of copper, nickel, and nickel alloys. Gold over coats or plating which protect the base metal do offer some advantage in solderability provided the parent metal is properly cleaned and prepared for the gold plating.

The problem of gold plated Kovar, however, is a problem of no small magnitude at best, and deserves much attention beyond the scope of this program.

TABLE XXIII

Kovar (MIL-STD-1276 Type K)

Test No:	1	2	3
Plating	Electro plated gold under 60/40 hot dip	Cu flash under electro tin plate.	Electro plated gold
S Factor	6	24	66

NOTE: Test No. 3 and Test No. 1 are plated the same except for the 60/40 hot dip for Test No. 1. This condition is the same as reworking the joint or flow soldering. That is, the hot dip process washes away the gold and leaves only the Kovar surface. There should be a new plating process or coating developed for Kovar so that the solderability may be maintained at the relative high value for Test No. 3 even after repeated soldering operations.

E. SPECIFICATION RECOMMENDATIONS

One of the most important and sensitive areas affected by a new process or material's specification are the existing specification or lack of specifications governing the application and control of processing and materials. Test procedures and controls have been developed for special purposes by many organizations. Some of these organizations are:

1 Government: Federal, Military

2 ASTM

3 EIA

4 IEC

5 IPC

Component lead solderability is controlled by MIL-STD-202 method 208. A close parallel to this specification is EIA Standard RS-178A. A component lead after fluxing with a prescribed flux is lowered into a solder bath with the axis normal to the solder bath surface allowed to dwell beneath the surface a predetermined period of time and then withdrawn at a controlled rate of speed. The lead is examined under 10X magnification to determine if 95 percent of the area is covered with a new uniform adhering coating of solder.

The droplet test retains all applicable features of this test. Table XXIV lists the duplications and similarities.

TABLE XXIV

Droplet Test versus MIL-STD-202

	MIL-STD-202 Method 208	Droplet Test
Solder		
Specification 60Sn QQ-S-571	Yes	Yes
Flux		
Specification MIL-E-14256 Type W	Yes	Yes
Procedure		
On lead attached to Components	Yes	Yes
Components as Received	Yes	Yes
Non-destructive	Yes	Yes
Immersion in flux	Yes	Yes
A number utilized to Evaluate	Yes	Yes

Differences also exist, but they offer an improvement in favor of the droplet test. By reviewing MIL-STD-202 method 208 it can be seen that the manner of dipping the leads is inadequate. Method 208 of the specification states after fluxing, "Immerse the lead in the hot solder bath for a prescribed time period, then withdraw at a measured rate of speed." If the solder upon withdrawal remained in a liquid form, unsolderable areas could be detected. However, the solder chills to a solid sheathing over much or all of such areas. The droplet test allows such areas to be revealed while under the reflowing action of the oil. Further study of MIL-STD-202 Method 208 will show that microscopic examination to measure and count discontinuities in the surface is very tedious and particularly difficult on a cylindrical surface unless a point of beginning is marked. To be certain where a new coat of solder begins or ends on a comparatively bright surface entails some judgement on the operator's part. It appears that in the light of these facts the droplet test is a significant improvement over the recognized method of solderability detection.

Martin-Orlando recommends, therefore, that the Droplet Test, as cited in this report, be used in place of the present MIL-STD-202 method 208 as a solderability test for lead materials.

Martin-Orlando also recommends that the following lead materials be used and specified in NASA Specifications and Procedures when superior solderability must be obtained:

Type	Plating or Coating
OFHC	60/40 hot dipped
Dumet (Deoxidized Copper)	60/40 hot dipped
OFHC	Electro tin plated minimum of 200 microinches
Dumet (Deoxidized Copper)	Electro tin plated minimum of 200 microinches
Kovar/Rodar	Gold plated 50 to 200 microinches

OFHC copper conforming to ASTM Specification B-170-59 which covers wirebars, billets and cakes of oxygen-free electrolytic copper produced without the use of residual metallic or metalloidal deoxidizers.

This satisfies the requirement of component lead materials. For extremely critical electronic applications a selected grade may be obtained. The select grade OFHC designated "Certified" is governed by the following in addition to ASTM Specification B-170-59.

- Oxygen content is controlled 0.0002 to 0.0004 percent by weight
- Electrolytic tough pitch copper usually contains 0.02 to 0.05 percent oxygen
- Copper, 99.96 percent by weight, minimum
- Phosphorus less than 0.0003 percent
- Sulfur less than 0.0040 percent
- Zinc less than 0.0003 percent
- Mercury less than 0.0001 percent
- Lead less than 0.0010 percent
- Electro tinning per MIL-STD-10727A P-31041F 0.0002 minimum to 0.0004 is satisfactory
- Hot dipping process was Ajax cleaned OP-98 process 60 SN/40 Pb solder

Electro tinning of 0.0002 or greater gives initial results closely approaching that of hot solder dip. Resistance to shelf life environment proves hot dip to be the most durable.

Dumet per MIL-STD-1276 Type "D" except gold plating is deleted and a well cleaned copper surface per Ajax cleaned OP-98 cleaned, is provided for hot dipping with 60 SN/40 Pb at 500°F with a flux comparable to Kesters 1544. Electro tin plating per MIL-T-10727A Type "I" process P-31041F with a thickness of electro tin plate 0.0002 min to 0.0004 is acceptable.

Other material per MIL-STD-1276 Type "K" includes Kovar, Rodar and other trade names. Gold plating is included under specification per MIL-G-45204, Type "I", Class 1. The plating thickness should be 0.000050 to 0.000200 inches.

Martin also recommends that the following lead materials be selected and specified in NASA Specifications and Procedures when superior weldability is required.

Type	Plating
Nickel "A"	Gold - 50 to 70 microinches
Stainless Steel	Bare
OFHC Copper	Gold - 50 to 70 microinches
Kovar/Rodar	Gold - 50 to 70 microinches
Alloy 152	Gold - 50 to 70 microinches
Dumet	Gold - 50 to 70 microinches

The government has proposed a revision "A" to MIL-STD-1276 weldable lead for electronic component parts. The proposed revision adds a solid copper wire Type "O." Types of wire presently included in the specification are shown in Table XXV.

The revision "A" has added Type C material and in addition made changes in the Type K requirement allowing a less rigid control of composition. Attention is called to this welding control document in the soldering section because the solid copper Type C involved is solderable. It is solderable depending upon the care exercised in the initial cleaning prior to plating or hot dipping. Tin-lead coating is not specified as electrolytic plated or hot dip. It indicates either or both may be used. The thickness is, however, controlled to a maximum and minimum tolerance. The maximum thickness is controlled for welding purposes and also to prevent difficulty in insertions of oversized leads in holes.

The attention given to minimum thickness is important to solderability to protect the basic metal in storage manufacturing. However, this is of no particular meaning unless either a flux of sufficient strength is permitted in the hot dipping or careful cleaning is practiced just prior to plating or coating. A practice of merely degreasing copper prior to plating or coating

TABLE XXV

MIL-STD-1276 Wire Types

Type	Examples
K	Kovar, rodar Au plated and Ni flash Au plated (glass to metal seals)
D	Dumet Ni Fc core Cu sheath (deoxidized) Au plated, bare or Ni flash under Au plate
N	
N-1	Bare nickel ribbon and wire
N-2	Nickel ribbon and wire Au plated

is not adequate. A recognized copper etching process should be employed, a process that will provide a matte surface and not a highly polished surface.

The plating processes as given in Appendix K produced reliable platings for this study and Martin recommends that these processes be included in future NASA specifications and made a part of present specifications where high reliability is a prime consideration.

The copper utilized in Type D material is satisfactory when made of deoxidized copper as prepared by the General Electric Company. Again attention must be given to the preparation before plating or coating.

It should be noted OFHC copper is well within the scope specified for copper under Type C of MIL-STD-1276A. Deoxidized copper also may be within this specification. When the deoxidized copper is further restricted by the specification DLP (deoxidized Low Phosphorous (0.013-0.004 percent it is within specification. ETP (Electrolytic Tough Pitch) is too high in oxygen, the oxygen content being 0.02 to 0.05 percent. The phosphorous content does affect the conductivity of copper when quantities in excess of 0.015 are in existence. It should be noted then when OFHC copper is heated to temperatures of 1472°F, a scale forms which is stubbornly adherent. This adherent scale is useful in copper to glass seals but must be carefully avoided when a solderable surface is desired. Therefore, the specification should state the upper temperature limit to which this wire may be subjected, if the wire is to be used as a solderable lead material.

Martin-Orlando recommends that the method used in section 3 page 9 and section C page 28 of this report be used and specified in NASA Specifications and Procedures as the method for determing the Weldability Index numbers of component lead materials. Further, Martin recommends that additional study be performed on this technique to optimize the ability to differentiate between similar materials.

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11. Martin Company, OR 3977P, "Establishment of Standards for Compatibility of Printed Circuit and Component Lead Material," May 1964

APPENDIX A

LIST OF EQUIPMENT MANUFACTURERS SURVEYED

Hughes Electron Tube Division
Oceanside, California

Aerojet General Corporation
Azuza, California

Unitek Corporation
Weldmatic Division
950 Royal Oaks Drive
Monrovia, California

Raytheon Company
Commercial Apparatus and
Systems Division
Production Equipment
Department
225 Crescent Street
Waltham 54, Massachusetts

Weld Tek
1701 South Main Street
South Bend 23, Indiana

Taylor Winfield Corporation
Warren, Ohio

Federal Welder and Machinery

IBM Industrial Products Division
Attn: Mr. T. B. McCullough
Sales Engineer
1000 Westchester Avenue
White Plains, New York

Sippican Corporation
Marion, Massachusetts

General Electric
General Purpose Department
Bloomington, Illinois

Texas Instruments, Inc.
Industrial Products Group
Apparatus Division
3609 Buffalo Speedway
Houston, Texas 77006

APPENDIX B

INDUSTRIAL USERS OF WELDING EQUIPMENT (ELECTRONIC COMPONENT LEAD WELDS)

Partial List of satisfied customers using Hughes Aircraft Company, Vacuum Tube Products Division, welding equipment as of 31 December 1962:

The Bendix Corporation
Southfield, Michigan

The Bendix Corporation
Teterboro, New Jersey

California Resistor
Santa Monica, California

General Atomic
San Diego, California

General Dynamic

Astronautics
San Diego, California

Eastman Kodak Company
Rochester, New York

General Electric
Phoenix, Arizona

Eitel-McCullough
San Carlos, California

Endevco Corporation
Pasadena, California

Gould National
Batteries, Incorporated
St. Paul, Minnesota

Librascope
San Marcos, California

General Electric
(Defense System Department)
Syracuse, New York

General Electric
(Cathode Ray Tube Department)
Syracuse, New York

Minneapolis-Honeywell Regulator
Company
Minneapolis, Minnesota

Minneapolis-Honeywell Regulator
Company
Hopkins, Minnesota

Marquardt Corporation
Van Nuys, California

Martin Company
Orlando, Florida

Micromodular Corporation
Anaheim, California

Motorola Incorporated
Scottsdale, Arizona

Ormco
Covina, California

Phillips Petroleum
Idaho Fall, Idaho

Sperry (Utah Division)
Salt Lake City, Utah

Taylor Instrument Company
Rochester, New York

Texas Instrument
Dallas, Texas

Tung-Sol Electric
Incorporated
Bloomfield, New Jersey

U.S. Atomic Energy
(Union Carbide Nuclear)
Oak Ridge, Tennessee

Western Electric Company
Lee's Summit, Missouri

Dale Electronics
Columbus, Nebraska

Dyna-Mod Electronics
Corporation
East Rochester, New York

Control Logic, Incorporated
Natick, Massachusetts

TYPICAL USERS OF WELDMATIC EQUIPMENT

Leaders of American Research and Industry

ACF Industries, Incorporated
Admiral Sales Corporation
Aerojet-General Corporation
Aerospace Corporation
Aeronutronics Division,
Ford Motor Company
Aerovox Corporation
Airearch Manufacturing
Company
University of Alabama
Allen-Bradley Company
Allis-Chalmers Manufacturing
Company
Ampex Corporation
Amphenol-Borg Electronics
Corporation
University of Arkansas
Atlas Chemical Company
Atomic Energy Commission
Automatic Electric Company
Autonetics Division,
North American Aviation
Company
Avco Corporation
Baldwin-Lima-Hamilton
Corporation
Beekman Instruments,
Incorporated
Bell Aerosystems Company
Bell Telephone Laboratory,
Incorporated
The Bendix Corporation
Boeing Company
Bourns, Incorporated
Brown University
Burroughs Corporation
California Institute of Technology
Cannon Electric Company
Caterpillar Tractor Company
CBS Laboratories
Chance Vought Corporation
Chrysler Corporation
Clarosial Manufacturing Company,
Incorporated
Collins Radio Company
University of Colorado

Columbia University
Continental Aviation and Engineering Corporation
Cornell-Dubilier Electronics Division, Federal Pacific Electric Company
Corning Glass Works
Crucible Steel Company of America
Cutler-Hammer
Dalmo, Victor, Incorporated
Douglas Aircraft Company, Incorporated
Dow Chemical Company
Dresser Products, Incorporated
Duke University
E. I. duPont de Nemours and Company, Incorporated
Eaton Manufacturing Company
Edgerton, Germeshausen and Grier, Incorporated
Eitel-McCullough, Incorporated
Electronic Speciality Company
Electronics Corporation of America
Elgin National Watch Company
Endevco Corporation
Englehard Industries, Incorporated
Fairchild Camera and Instrument Corporation
John Fluke Manufacturing Company, Incorporated
Foster Wheeler Corporation
Friden, Incorporated
General Dynamics Corporation
General Time Corporation
General Instrument Corporation
General Motors Corporation
General Precision, Incorporated
General Radio Company
General Electric Company
Giannini Controls Corporation
Gilfilian Brothers
Gillette Safety Razor Company
The B. F. Goodrich Company
Graybar Electric Corporation
Gulton Industries, Incorporated
Halliburton Company
Hamilton Standard
Hazeltine Corporation
Hercules Powder Company
Hewlett-Packard Company
Hughes Aircraft Company
International Business Machine Corporation
University of Illinois
International Resistance Company
International Telephone and Telegraph Corporation
Johns Hopkins University
Kaiser Engineers
University of Kansas
Kawecki Chemical Company, Incorporated
Kennecott Copper Corporation
Keystone Camera Company, Incorporated
Eastman Kodak Company
Kollsman Instrument Corporation
Leach Corporation
Lear Siegler, Incorporated
Litton Industries
Lockheed Aircraft Corporation
Machlett Laboratories, Incorporated
Magnavox Company
Marquardt Corporation
Martin-Marietta Corporation
Massachusetts Institute of Technology
Melpar, Incorporated
University of Michigan
Microdot, Incorporated
Microwave Electronics Corporation

Honeywell
University of Minnesota
Minnesota Mining and Manufacturing Company
Monsanto Chemical Company
Motorola, Incorporated
National Bureau of Standards
National Cash Register Company
National Research Corporation
United States Naval Avionics Facility
North American Aviation
Nortronics
Northwestern University
Nuclear Corporation of America
Olin Mathieson Chemical Corporation
Packard Bell Electronics
Pan American World Airways
University of Pennsylvania
Perkin Elmer Corporation
Phaostron Instruments and Electronics
Philco Corporation
Phillips Petroleum Company
University of Pittsburgh
Pratt and Whitney Aircraft
Price Electric Company
Purdue University
Radiation, Incorporated
Radio Corporation of America
Raytheon Company
Rohr Corporation
Rosemount Engineering Company
Ryan Aeronautical Company
Sanborn Company
Scovil Manufacturing Company
Servomechanisms, Incorporated
Servonic Instruments, Incorporated
Sonotone Corporation
Southwest Research Institute
Space Technology Laboratory, Incorporated
Sperry Rand Corporation
Sprague Electric Company
Stanford University
Sylvania Electric Products
Tektronix, Incorporated
Telecomputing Corporation
Texas Instruments, Incorporated
University of Texas
Thiokol Chemical Corporation
Transitron Electronic Corporation
Union Carbide Corporation
United Carr Fastener Company
United Control Corporation
United Electro Dynamics
United Aircraft Corporation
United States Bureau of Mines
United States Time Corporation
University of California
University of Southern California
Varian Associates
Victoreen Instrument Company
Ward Leonard Electric Company
University of Washington
Weirton Steel Company
Wems Incorporated
Western Electric Company
Westinghouse Electric Company
University of Wisconsin
Xerox Corporation
Zenith Radio Company

WELLS ELECTRONICS, INCORPORATED

Representative Users of Weltek Equipment

Applied Physics Laboratory,
Johns Hopkins University
Silver Springs, Maryland

Centralab

ACF Electronics

Stewart Warner Electronics

Lear Siegler
Grand Rapids, Michigan

Sprague Electric
North Adams, Massachusetts

Hermaseal

Bowmar Instruments

Ballastran

Eastman Kodak

Dahlberg Manufacturing

Mayfiar Molded Products

Johnson, Matthey and
Mallory

Minneapolis-Honneywell
St. Petersburg, Florida

Kaman Aircraft

Automation Alloys

Chicago Aerial

Delta-F, Incorporated

ITT Federal
Fort Wayne, Indiana

V-M Corporation

Western Electric
Chicago, Illinois

Potter and Brumfield

Mallory Capacitor
Huntsville, Alabama

Texas Instruments

Knowles Electronics

Transitron

NASA
Huntsville, Alabama

Bell Telephone Laboratories
Whippany, New Jersey

Amphenol Borg
Broadview, Illinois

Chrysler Missile Division
Detroit, Michigan

Amp, Incorporated
Harrisburg, Pennsylvania

Collins Radio
Richardson, Texas

CTS of Berne

General Electric Company
Philadelphia, Pennsylvania

Vector Manufacturing

Rosemount Engineering

Control Data Corporation
Minneapolis, Minnesota

Matrix, Electronics

Burroughs
Plainfield, New Jersey

Burroughs
Detroit, Michigan

Lear Siegler
Santa Monica, California

Goodyear Aircraft
Akron, Ohio

Tripplett Electrical Instruments

Litton Systems
Canoga Park, California

Ling-Temco-Vought

Brown Engineering
Huntsville, Alabama

Minneapolis-Honeywell Regulator
Minneapolis, Minnesota

Sprague Electric
Visalia, California

CTS of Elkhart

Hathaway Instruments
Denver, Colorado

Syncro
Hicksville, Ohio

Ford Instruments
Long Island, New York

General Electric
Pittsfield, Massachusetts

Electro-Ceramics

Lockheed
Sunnyvale, California

Methode Manufacturing Company
Chicago, Illinois

Standard Controls

Mallory Controls
Frankfort, Indiana

MIT Instrumentation Laboratories
Cambridge, Massachusetts

P. R. Mallory
Indianapolis, Indiana

Bell Telephone Laboratories
Murray Hill, New Jersey

Nu-Line

U.S. Naval Ordnance Laboratories

Boeing Aircraft
Seattle, Washington

Detroit Arsenal

Biometrics

Perfect Circle

Naval Avionics
Indianapolis, Indiana

Sprague Electric
Bennington, Vermont

General Electric
Lynchburg, Virginia

Detronic Industries

Astro Electronics

Shallcross

Philco Corporation
Palo Alto, California

Airesearch

Sandia Corporation
Albuquerque, New Mexico

Nortronics
Hawthorne, California

G. T. Schjeldahl

Western Electric
Greensboro, North Carolina

AVCO Corporation
Cincinnati, Ohio

Westinghouse
Elmira, New York

Martin Company
Orlando, Florida

Beltone Electronics
Chicago, Illinois

Univac
St. Paul, Minnesota

Philco Corporation
Lansdale, Pennsylvania

Minneapolis-Honeywell
Philadelphia, Pennsylvania

Raytheon
Sudbury, Massachusetts

Barnes Engineering

General Motors Tech Center

Carborundum Company

Autonetics
Anaheim, California

General Electric
Phoenix, Arizona

RCA
Somerville, New Jersey

Kistler Instruments

RCA
Camden, New Jersey

Martin Company
Denver, Colorado

Sprague Electric
Rockville, Maryland

Sandia Corporation
Livermore, California

Canadian Marconi
Montreal, Canada

Spectrol Electronics
Industry, California

MIT Aracon Laboratories
Concord, Massachusetts

Fairchild Semiconductor
Mountain View, California

Witkens Instrument and Research
Walnut Creek, California

Douglas Aircraft

Sage Electronics

Winston Research

Bell Laboratories
Reading, Pennsylvania

IBM
Poughkeepsie, New York

Continental Devices

Elgin Laboratories
Waterford, Pennsylvania

Hewlett Packard

Hart Manufacturing

Northern Electric

Lifkin

Blass Antenna Electronics
Long Island, New York

Rocketdyne

General Dynamics Astronautics

Publication Engineers
(Robert Martin)

General Electric
King of Prussia, Pennsylvania

Consolidated Electrodynamics

University of Minnesota

Motorola
Phoenix, Arizona

Tessler and Weiss, Incorporated

Bendix
South Bend, Indiana

Bendix
Mishawaka, Indiana

CTS Research
West Lafayette, Indiana

Computing Devices of Canada

Energy Conversion Devices,
Incorporated

Cook Electric

U.S. Time Corporation

APPENDIX C

WELDABILITY PHASE I
LITERATURE SEARCH

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Investigation to Establish Feasibility of Resistance Welding Techniques. Lockheed Aircraft Corporation, Sunnyvale, California. No. AD-277 884 62-4-2 IDEP.

Weldable Leads for Electronic Component Parts. MIL-STD-1276.

Reliable Welding by Charles J. Heslin. Industrial Comp Division, Raytheon Company, Newton, Massachusetts.

Component Lead and Interconnection Materials for Welded Electronic Modules. MSFC-SPEC-270. NASA.

Standard Fabrication of Welded Modules. MSFC-STD-271.

Welding for Electronic Packaging, School of Reliability and Quality Assurance, Huntsville, Alabama. RQA/E2.

Welded Connections. Product Engineering Magazine 5 August 1963.

APPENDIX D

WELDABILITY PHASE I
EQUIPMENT USED

The Hughes Vacuum Tube Products Division power supplies, Model No. VTW-30B and VTW-30C (Figure 58) were selected for use on this program because they were representative of the type used by industry according to a survey, and favorable experience with this particular equipment in the Martin-Orlando Manufacturing Division.

Figure 58. Hughes Power Supply, Model No. VTW-30C

The welding head used was a Hughes Model VTA-60 (Figure 58). This selection was made because of design simplicity, ruggedness, positive stop provisions, and the use of high conductivity gold plated current carrying components. It was felt that this welding head would minimize process variables in the welding system.

Precision Wire Gage – This special gage (Figure 58) was fabricated to accomplish precise measurement of wire diameters and weld set down. Graduations were in ten thousandths of an inch.

Constant rate tensile test machine (Figure 59). The measuring head on this equipment was a Hunter Model D-50-T.

Mechanical force gage graduated 0-50 pound range in 1/2 pound increments. All other parts of the machine were fabricated in plant to produce a tester with constant pull rate characteristics.

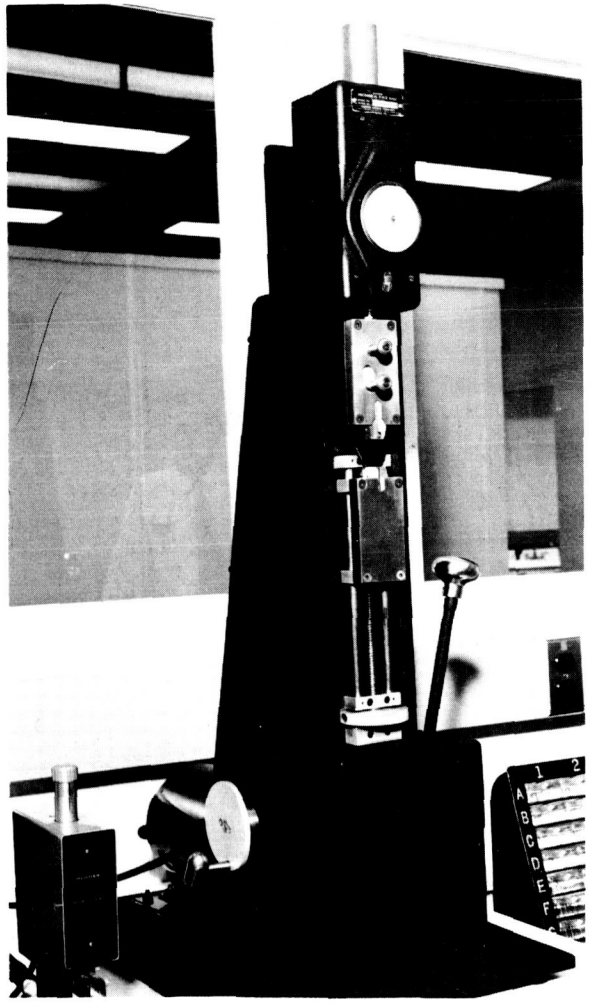


Figure 59. Constant Rate Tensile Test Machine

Recorder – Visicorder manufactured by Minneapolis-Honeywell. This instrument was used to record load strain curves and to record magnitude and duration of current pulse (Figure 60).

Binocular Microscope (Figure 60) – American Optical Range of magnification to 40X.

Bosch and Lomb Balphot Metallograph Model No. A-2000 equipped with polaroid camera attachment, binocular eye piece and magnaviewer observation 1000X magnification maximum (Figure 61).

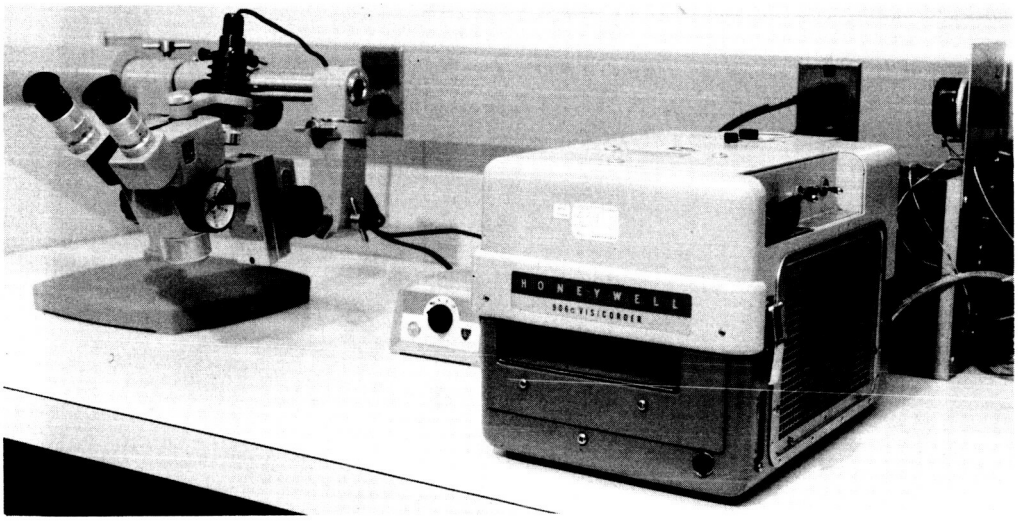


Figure 60. Viscorder and Binocular Microscope (40X)

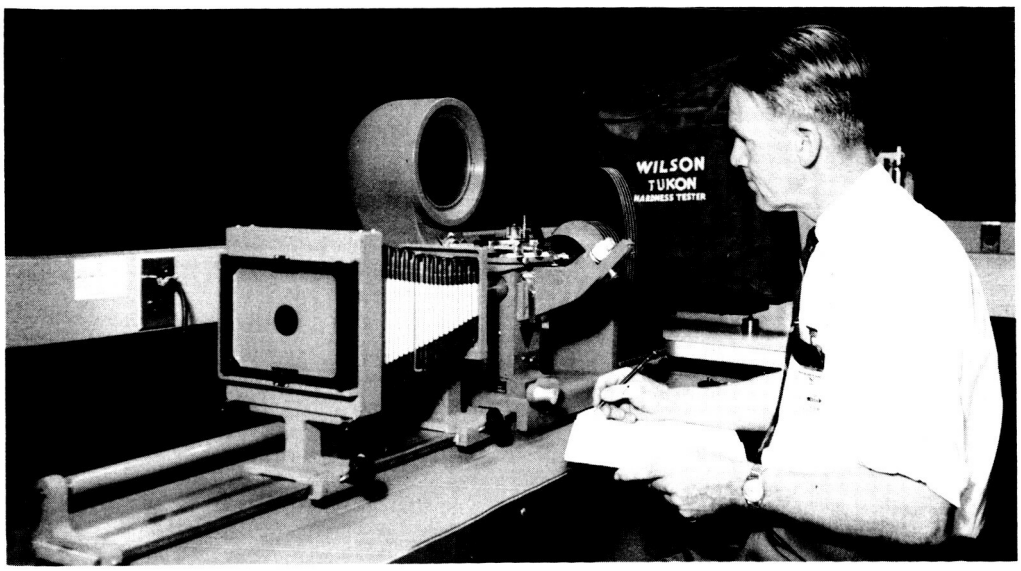


Figure 61. Metallograph Model No. A-2000

APPENDIX E

SOLDERABILITY METHODS

The Meniscus Test (Signal Corps) and Edge-Dip Test as directed by the members of the Solderability Committee and Board of Directors of the Institute of Printed Circuits at the March 1964 annual meeting in New York City.

The solderability of Terminals and Aging, Contract No. DA-36-039-AMC-0008(E) Task 702, 1963 for U.S. Army Electronics Material Support Agency, Fort Monmouth, New Jersey, by General Electric.

The Solderability and Component Lead Aging Methods recommended by the International Electrotechnical Commission, held May 21st and 22nd, 1963, at Aix-Les-Bains, France (Ten-Duis method and Autonetics, Downey, California).

Solderability of Printed Circuits, Contract DA-36-039-AMC-0008(E) Task 703, by Joel Fabish, General Electric Company.

MIL-STD-202 Method 208.

EIA Standard RS-178A.

The solder wire wrap or Pessel method.

Peel test per MSFC-STD-154.

Spread Test

Tin Research Institute of England and Columbus, Ohio.
RCA
Martin Company
Alpha Metals

Hair Pin Tension specimen by Battelle Memorial Institute, Columbus, Ohio.

Projection Viewer by Battelle Memorial Institute, Columbus, Ohio.

The methods listed below are of unknown origin:

Wire Twist at 1/2 inch pitch (2 wires).

Coiled wire (spring) under tension.

A comparison of permanent electrical connections, by G. W. Mills (The Bell System Technical Journal, Vol XLIII No. 3, May 1964).

Three Fundamental Types of Wetting Adhesion Tension as the Measure of Degree of Wetting, by H. J. Osterhof and F. E. Bartell, Journal of Physical Chemistry, Vol 34, 1930.

Tinplate Testing Chemical and Physical Methods, by W. E. Horace, DSc, FIM, S. C. Britton, MA, FRIC, FIM, Tin Research Institute.

APPENDIX F

PERSONS AND COMPANIES CONTACTED

A. R. McCown
Boeing
P.O. Box 37017
Seattle 24, Washington

Dresser Electronics
HST Division
555 5th Street
Garland, Texas

Engineering and Electronics
Devices, Incorporated
1024 North McCadden Place
Los Angeles, California 90038

Mr. Jack Mervin
37 Abbott
Morristown, New Jersey

Weston Instruments
Weston, New Jersey

Homer G. Thomson
Chief Engineer
Resistor Laboratory
Allen-Bradley
222 West Greenfield Avenue
Milwaukee, Wisconsin 53204

ARMCO Sale Division
ARMCO Steel Corporation
Department A-2474,
P.O. Box 600
Middletown, Ohio 45042

Harold Shapiro, Chief Chemist
Central Systems Manufacturing
Plant
Sylvania Electronics
Buffalo, New York

Camden Wire
Wire Fabrication
Camden, New York

D. N. Kirkpatrick
Manager of Engineering
Electronics Division
Stackpole Carbon Company
Carbon Products Division
St. Marys, Pennsylvania

Sprague Electric Company
307 Marshall Street
North Adams, Massachusetts

Motorola
Semiconductor Products,
Incorporated
Box 955,
Phoenix, Arizona 85001

G. C. VanTilburg
U.S. Metal Climax Incorporated
1270 Avenue of the Americas
Rockefeller Center
New York 20, New York 10020

International Wire Products
Corporation
Midland and Greenwood Avenue
Midland Park, New Jersey

Wilbur B. Driver Company
160 Riverside Drive
Newark 4, New Jersey

Copperweld Steel Company
39 Tiefeld Street
Glassport, Pennsylvania

Driver Harris
Harrison 23, New Jersey

Metz Refining Company
371 Mulberry Street
Newark, New Jersey

Phelps Dodge Copper Products
Corporation
300 Park Avenue
New York City, New York

Little Falls Alloys, Incorporated
185 Caldwell Avenue
Paterson 1, New Jersey

Hudson Wire Company
Ossining Division
Ossining, New York

Cannon Electric Company
Humboldt and Avenue 33
Los Angeles, California

Consolidated Wire Associated
Companies
1637 South Clinton Street
Chicago 16, Illinois

Henry L. Cornell
Carborundum
Electronics Division
Latrobe Plant
P. O. Box 311
Latrobe, Pennsylvania

Workman Electronic Products
Incorporated
Sarasota, Florida

Belden Manufacturing Company
415 South Kilpatrick
Chicago 24, Illinois

Lyle R. Smith
General Sales Manager
West – CAP
San Fernando Electric
Manufacturing Company
1509 First Street
San Fernando, California

John Mac Williams
Sales Engineer
Philadelphia Division
International Resistance Company
401 North Broad Street
Philadelphia 8, Pennsylvania

F. G. Wehler, Sales Manager
Speer Carbon Company
Speer Resistor Division
Bradford, Pennsylvania

Mr. R. W. Movat
Marketing Section
General Electric Company
21800 Tungsten Road
Cleveland 17, Ohio

W. G. Bader
Bell Telephone Laboratories
Murry Hill, New Jersey

Mr. W. P. Bowling
Quality Assurance Engineer
Apparatus Division
Texas Instrument Incorporated
6000 Lemmon Avenue
Dallas, Texas

Mr. R. A. Kay, Dept 7632
Western Electric Corporation
Hawthorne Station
Chicago 23, Illinois

Mr. D. A. Popham, Supv
Certification Control Center
Aerojet-General Corporation
6352 North Irwindale Avenue
Azusa, California

Mr. Howard F. Valentine
Instrument Division
Lear Siegler, Incorporated
4247 Eastern Avenue
Grand Rapids 8, Michigan

Mr. Philip G. VanBrocklin
Minneapolis Honeywell
Regulator Company
600 Second Street, North
Hopkins, Minnesota

Westinghouse Electric
Corporation
P.O. Box 868
Pittsburgh, Pennsylvania

C. H. Hack
National Lead Company
Heighstown, New Jersey

Sperry Gyroscope
Great Neck, New York
MS 1A 36

V. S. Gittens
Philco Corporation
Tioga and "C" Streets
Philadelphia 34, Pennsylvania

Ward Leonard Electronic Company
Mount Vernon, New York

Microelectron Incorporated
Santa Monica, California

The Electric Auto Lite Company
Port Huron, Michigan
Mr. Howard Borgman

Fan Steel
Chicago, Illinois

Fairchild
545 Wisman Road
Mountain View, California

APPENDIX G

TYPICAL SURVEY LETTER

MARTIN COMPANY

ORLANDO
DIVISION
Orlando,
Florida

Gentlemen:

The Orlando Division of Martin Company is engaged in a study program to investigate the solderability and weldability of materials used for electronic component leads. The purpose of this study is to establish material standards specifications which will result in the improved reliability of electronic equipment.

It would be appreciated if you would name an individual in sales, engineering, or both, within your organization, which we may contact regarding this subject. A sample form is provided which will indicate to some degree the questions which will be asked.

Any contribution you wish to make to this program will be appreciated. Results of this survey will be furnished to the contracting government agency.

Very truly yours,

L G Hall

L. G. Hall, Mfg. Engineer
Advanced Mfg. Technology
Mail No. 150

CC: G. W. MacFarlane
Procurement Dept.
Advanced Program

LGH:es
Attachments

THE AEROSPACE
DIVISION OF
MARTIN
MARIETTA

APPENDIX H

COMPONENT AND WIRE MANUFACTURERS

OFHC Brand Copper News June 1962 American Metal Climax, Incorporated

Standardization of Component Lead Materials by S. D. Ebneter, Chrysler Corporation, Space Division, Huntsville Operation

International Resistance Company

Stackpole Resistor, St. Marys, Pennsylvania

Common Component Lead Materials as listed by the Martin Company

Speer Carbon Company, Bradford, Pennsylvania

International Wire Products Corporation, Midland Park, New Jersey

Camden Wire Company (Heavy tinned copper wire for electrical conductors) L. A. Kent and J. F. Mahon and other materials.

Unitek Weldmatic Division, 950 Royal Oaks Drive, Monrovia, California

Hitemp Wire Company, Westbury Plant, Westbury, Long Island, New York

The Hudson Wire Company (Mr. R. Cashman) Ossining, New York

Allen-Bradley Company, Milwaukee, Wisconsin

General Electric, 21800 Tungsten Road, Cleveland, Ohio 44117

Sylvania, Woburn Semiconductors, Woburn, Massachusetts

Evaluation of Solderability of Electroplated Coatings, James Thompson and Leo K. Bjelland.

Precious Metal Plating and Solderability. A Preliminary Report by A. Korbelsk and R. Duva, Sel-Rex Corporation

Gold in Printed Circuitry, A. Korbelak, Sel-Rex Corporation, Nutley 10, New Jersey

Texas Instrument, 6000 Lemmon Avenue, Dallas, Texas, (Arnie Walkon)

Electra Precision Products, Manufacturing Company, Independence, Kansas

Phelps Dodge, 300 Park Avenue, New York City, New York

San Fernando Electric Manufacturing Company, Perrott Associates, 501 Park Avenue, North, Suite 23, Winter Park, Florida

Sprague Electric Company, North Adams, Massachusetts

Copperweld Steel Company, Glassport, Pennsylvania

Fansteel, Number One Tantalum Place, North Chicago, Illinois

Alpha Metals, 56 Water Street, Jersey City, New Jersey. Howard Manko, Solders and Soldering.

Materials and Techniques for Electron Tubes, by Walter H. Kohl

Soldering Manual, prepared by AWS Committee on Brazing and Soldering.

Ward Leonard Electric Company, Metal Film Division, Hagerstown, Maryland

Lear Siegler, Incorporated, Instrument Division, 4247 Eastern Avenue, Grand Rapids 8, Michigan.

Driver-Harris Company, Harrison, New Jersey

Prestolite (Formerly Division of the Electric Autolite Company), Port Huron, Michigan

Soldering in the Space Age, by Alvin B. Kaufman, Arnoux Corporation

Cannon Electric Company, 3208 Humbolt Street, Box 3765, Los Angeles 54, California

Dearborn Electronic Laboratories, Incorporated, Box 3431, Orlando, Florida

Assured Reliability in Soldering Connections Solderability as Parameter of Assurance, Dr. L. Pessel, RCA, IEEE Transaction of Product Engineering and Production, January 1963

APPENDIX I

PLATING AND SURFACE PREPARATION ARTICLES

Gold Plating to Tight Tolerances, Product Finishing Magazine, December 1963. (Electronic and Missile Specs).

Plating for the Electronics Industry, Panel Discussion. Product Finishing October 1964

Evaluating the properties - plated finishes, Product Finishing, October 1964

Electrical Terminations, Machine Design Magazine, 21 May 1964

Choosing Electrical Connections, Machine Design Magazine, 30 July 1964

Welded Connections, Product Engineering Magazine, 5 August 1963

Thickness and Hardness Measurements on Gold Deposits

Working Instructions for bright tin plating by the Tribrite (Aldehyde-Amine) Process, May 1962. Tin Research Institute, Frasek Road, Perivale, Greenford, Middlesex, England.

Tin-Nickel-Alloy Plating, R. M. Angles, The International Nickel Company, (MOND) Limited.

APPENDIX J

Rough Screening Outline Plan

Basis Material	Surface Preparation			Hot Dip			Plating Electro					Schedule	
	OP-98	As Received	Other	60/40	10/90	Tin	Tin	Ag	Ni	Au/Ni	Au/Ag/Ni	Board	Row
Copper													
OFHC (Soft)		X										A	2
ASTM B-170-59	X		Steel wool scrub		X							25	1
	X			X								12	4
	X					X						11	2
	X		Ajax Scrub	X								17	3
	X					X						18	4
			Degrease									26	1
			P-31041F				X(1)					7	1
				X			X(2)					19	2
						X	X					19	3
			P-85030 + HCL										
			30 second rinse	X								22	2
			Air dry			X						22	3
			P-31041F				X(2)					19	1
			P-31001F Grade III					X		(3)		16	3
ASTM B1 Hard		X										A	3
	X		Steel wool scrub	X								13	3
	X		Ajax scrub	X								18	1
	X					X						10	3
			P-31041F				X(4)					8	2
			P-31041F				X(1)					7	3
QQ-W-343		X										A	3
Type S	X											A	4
Soft	X	X	Ajax scrub	X								13	4
	X					X						10	2
			P-31041F				X(4)					7	2
DLP 1/2 Hard		X										22	4
			P-31041F				X(1)					25	3
			P-31041F				X(5)					25	2
Copper Weld		X										5	1
QQ-W-345	X		Steel wool scrub	X								14	2
30 percent Conductivity	X					X						10	1
			P-31041F				X(4)					8	4
	X		Ajax scrub	X								17	1
	X					X						18	2
Dumet		X											
MIL-STD-12764 Type D	X		Ajax scrub	X								17	4
(except unplated and	X					X						17	2
unborated)			P-31041F				X(4)					22	1
			P-31041F				X					19	4

Basis Material	Surface Preparation			Hot Dip			Plating Electro					Schedule	
	OP-98	As Received	Other	60/40	10/90	Tin	Tin	Au	Ni	Au/Ni	Au/Ag/Ni	Board	Row
Dumet Continued													
MIL-STD-1276A ±		X	MIL-G-45204							X		5	3
Type D			QQ-N-290	X						X		14	3
MIL-STD-1276A Type D (Unplated and borated)		X										5	4
Alloy 180		X										6	2
	X		Ajax scrub	X								13	1
	X					X						10	4
			P-31041F Class I				X(4)					7	4
Alloy 152		X							X(6)			6	3
												16	1
Alloy 90		X										6	4
	X		Ajax scrub	X								13	2
	X					X						11	1
			P-31041F Class I				X(4)					8	1
Nickel "A"		X								X		16	4
Kovar		X										4	1
MIL-STD-1276	X	Ajax scrub		X								15	1
Except no plating	X					X						15	4
			Paragraph B and C-4 Appendix K				X(2)					25	4
Rodar		X										6	1
MIL-STD-1276			Degreased					X				14	1
Au Plated			MIL-STD-45204	X		X		X				15	3
Brass		X										4	3
	X		Ajax scrub	X								12	2
	X					X						11	4
			P-31041F Class I				X(4)					9	2
			QQ-S-365 Type 3 Grade B					X				16	2
Phosphor Bronze		X										4	4
				X								12	3
	X					X						11	3
	X						X(4)					9	1
			Appendix K, B, C, 1, 2, and 3							X(7)		23	3
Tantalum		X										5	2
Silver		X										4	1
MIL-STD-19424			Ajax scrub			X						14	4
Grade "A" Fine			Vapor degrease									15	2
Class II, 1/2 Hard													

Remarks: Dimension size mm
(1) 0.0051 to 0.0102
(2) 0.00457 to 0.00559
(3) 0.00127 to 0.00178
(4) 0.0025 to 0.0051
(5) 0.0076 to 0.0127
(6) Ni 0.00381 to 0.0127
(7) Cu 0.0051, Ni 0.00127 to 0.00254, Au 0.00127 to 0.00178

APPENDIX K

Plating Processes

SHIPLEY COPPER DEPOSITION PROCESS

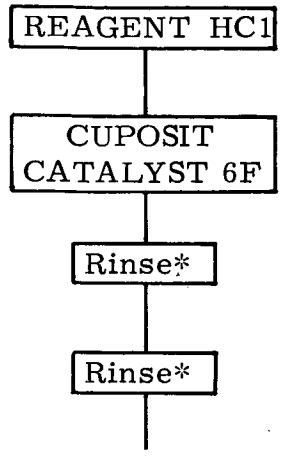
For metallizing non-conductors

The Shipley Copper Deposition Process is basically a 2-step process for metallizing non-conductive and semi-conductive materials. The CUPOSIT COPPER MIX solutions chemically reduce copper onto surfaces which have been immersed in CUPOSIT CATALYST 6F.

Deposited copper bonds to many materials, including:

Abraded Plastics	Ceramics
Cellulose Acetate Butyrate	Mylar
Copper-Clad Plastic Laminates	Teflon

The copper deposits are of fine-grain structure, and so dense as to appear non-porous. The deposition rate ranges from 1/2 to 1 millionth of an inch per minute. Since copper is deposited by auto-catalytic means, greater thicknesses are achieved by longer deposition time.



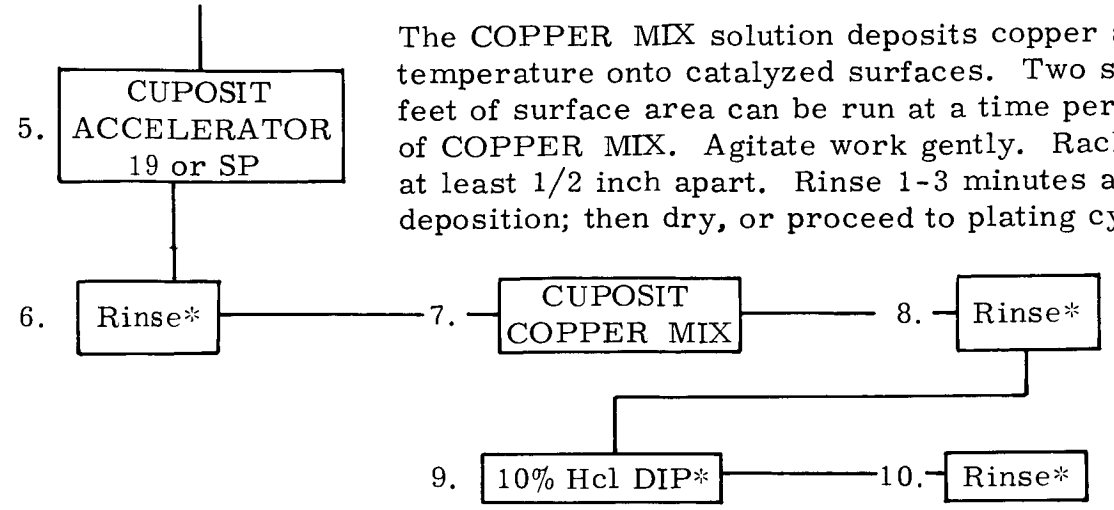
Use reagent hydrochloric acid (25 percent by volume) to protect CATALYST from drag-in contamination.

CATALYST 6F imparts a charge to non-conductors. Smooth surfaces are catalyzed, even if not wet.

Vigorous rinsing is important. Use clean water.

Use of an ACCELERATOR speeds the initial cover; also protects COPPER MIX from CATALYST drag-in.

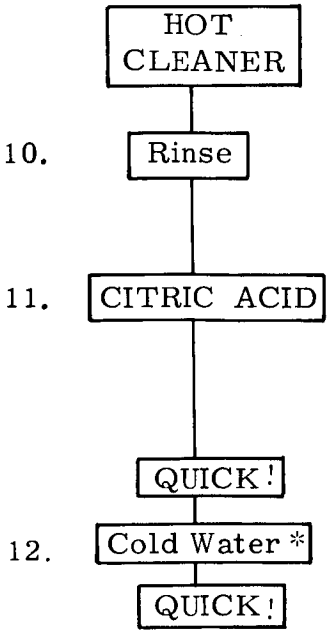
*Deionized H_2O.



The COPPER MIX solution deposits copper at room temperature onto catalyzed surfaces. Two square feet of surface area can be run at a time per gallon of COPPER MIX. Agitate work gently. Rack parts at least 1/2 inch apart. Rinse 1-3 minutes after deposition; then dry, or proceed to plating cycle.

How to Prepare Nickel for EL-221 Gold Deposition

Nickel surfaces must be active upon entering EL-221 GOLD solution. When the surfaces are properly activated, the EL-221 GOLD deposits should withstand nitric acid for at least 20 minutes. However, if the surfaces are passive, the gold is apt to deposit on the nickel with a poor bond. In general, nickel activation treatments which have proved to be effective for electroplating on nickel should be satisfactory for EL-221 GOLD deposition on nickel. The following process is known to give good results over electroplated nickel:



Vapor degrease to remove heavy organic soil. Then soak parts in AL-CHELATE or NEUTRA-CLEAN 7 for 3-5 minutes at 180°F. Be sure surfaces are wet. These steps may be omitted for parts that have just been plated.

Boiling sulfuric acid activates nickel plate. Make sure that nickel gasses before removing. Make-up: 1 quart 66° Baume acid, 5 gallons water. Citric acid standard. Citric acid treatment before any gold plating of copper, 2 pounds per gallon of water.

Quickly enter cold water rinse; agitate work vigorously. Then quickly enter EL-221 GOLD. In some areas deionized water should be used.

13.	EL-221 GOLD 160-175°F 30 mins	Agitate work upon entering EL-221 GOLD bath. Gold should coat the metal within 20 seconds; a slow cover indicates passive nickel. Do not process at one time more than 1 square ft metal surface area per gallon of solution. Maintain level with ammonium hydroxide (10 percent by volume). Bath turns green or blue on use. See Page 4.
14.	Rinse	+ 15 Dry

Operation of EL-221 Gold Solution

Make-up

Use EL-221 GOLD as supplied. Do not dilute with water.

Operating Temperature

Operate at 160 to 175°F. Higher temperatures increase deposition rate, but square ft yield is less. At lower temperatures deposition is not so fast nor so reliable.

Deposition Time Limits

30 minutes deposition time at 160°F is recommended for obtaining good corrosion protection. Longer deposition time increases gold thickness to some extent, but after about 120 minutes the plating stops. Shorter times may be suitable for some applications; test before using.

Operation Suggestions

Do not process at one time more than 1 square ft of metal surface area per gallon of EL-221 GOLD solution. While more area can be safely processed at a time, deposition time has to be increased from 30 minutes to 45 minutes.

Do not use metal tongs or clips for handling the metal, either in EL-221 GOLD bath or during the pre-cleaning.

For scrubbing, use pumice or SCRUB CLEANER No. 11. Unlike household cleaners, these do not leave a film on metal.

Agitation

Continuous agitation of work and/or bath is beneficial, especially for treatment of parts having deep recesses.

Filtration

Not needed. Never carbon treat, as it spoils the bath.

pH Control

Maintain the bath level by frequency additions of dilute ammonium hydroxide; this controls the pH. Do not allow the bath to evaporate below 90 percent of its original volume. When plating onto copper, add a mixture of 3 parts

C.P. grade ammonium hydroxide to 7 parts of distilled water. DO NOT USE TAP WATER. When plating on other metal, add a mixture of part ammonium hydroxide, 9 parts water.

Maintenance Suggestions	Cover bath when not in use; a floating cover is best. During bath operation a loose-fitting cover lessens the evaporation losses, also helps to maintain temperature.
Equipment	Use vessel of pyrex, high-temperature plastic, or metal coated with a plastic which resists hot dilute ammonium hydroxide. DO NOT USE METAL. To minimize evaporation use a deep tank, not a shallow tray. A water jacket is preferred for temperature control. Continuous agitation should be provided when a hot plate or quartz immersion heater is used. Operate the solution in a vented hood.
Safety Precautions	EL-221 GOLD contains no free cyanide, but does contain complexed cyanide. Keep away from strong mineral acids. Avoid prolonged contact with skin. In case of contact with eyes, flush with large amounts of water. If taken internally, induce vomiting at once. Call a physician .

Establishments of Standards for Compatability of Printed Circuits and Component Lead Materials

Base Material	Plating System: Top-Plate	Plating System: Underplate(s)
Welding		
Copper weld Alloy No. 180[3] Alloy No. 152 Alloy No. 90 Brass Phosphor Bronze Dumet	Gold Plate[1] 50-70 millionths	Nickel plate[4]: 50-100 millionths See Note (3) Copper flash 100-200 millionths Nickel plate 50-100 millionths Copper flash 100-200 millionths Nickel plate 50-100 millionths Nickel plate 50-100 millionths Nickel plate 50-100 millionths Nickel plate 50-100 millionths
Copper OFHC Nickel A Dumet Kovar Tantalum	Tin Plate[2] 300-500 millionths	No underplates
Tantalum	Cleaning treatment[5] only: no electroplating	
Alloy No. 152 Kovar Copper OFHC	Cleaning Study: Gold Plate[1]: 50-70 millionths	
Soldering		
Phosphor Bronze Copper Coupons Tantalum Copper, DLP Nickel A	Gold Plate[1]: 50-70 millionths	Nickel plate 50-100 millionths No underplate
Copper OFHC Nickel A Kovar Tantalum Copper, DLP Nickel A	Tin Plate[2]: 300-500 millionths	Nickel plate 50-100 millionths No underplates
	Cleaning - Activation Study	See Engineering Notebook No. 7573, page 44 or Lester Hall, AMT

NOTES:

(1) Gold Plate
Gov't Specs: MIL-G-45204 "Gold Plating"
MIL-C-14550 (Ord) "Copper Plating"
QQ-N-290 "Nickel Plating"
Martin Process: P31001 "Plating, Gold, Alkaline"
P31004 "Plating, Copper, Alkaline"
P31037 "Plating, Nickel, Gray"

(2) Tin Plate
Gov't Specs: MIL-T-10727 (Ord) "Tin Plating, Electrodeposited"
Martin Process: P31041 "Plating, Tin, Alkaline, Matte, Electrodeposited"

(3) Alloy No. 182,

Run No. 1 dated:	11-11-64	Cu flash 100-200 millionths Nickel plate 50-100 millionths Gold plate 50-70 millionths
Run No. 2 dated:	11-19-64	Nickel plate 50-100 millionths Gold plate 50-70 millionths
Run No. 3 dated:	11-23-64	Woods Nickel Strike Nickel plate 50-100 millionths Gold plate 50-70 millionths
Run No. 4		Bare wire: See W. Hutch

(4) Nickel Plating
Gov't Specs: QQ-N-290 "Nickel Plating (Electrodeposited)"
Martin Process: P31037 "Plating, Nickel, Gray (Electrodeposited)"

(5) Tantalum Cleaning: See Engineering Notebook No. 7573 page 28, 30.

(6) Cleaning Study:
Phase I: Wire process with no interruption between cleaning and plating sequence.
Phase II: Wire processed with 48 to 60 hour delay (running water storage medium) between cleaning and plating sequence.
Phase III: Wire processed with refinements (to determine critical time delay) between cleaning and plating sequence.

Plating Process Procedure

A. Basic Information:
(1) Areas: Plating rack plus wire (approx 40 feet) 0.27 ft^2
(2) Current Density - Current data:

Copper Strike (Acid)	20 asf → 5.0 amps
Copper Plate Cyanide)	20 asf → 5.0 amps
Nickel Plate (Low Stress Watts)	30 asf → 7.5 amps
Gold Plate (Cyanide)	4 asf → 1.1 amps
Tin Plate (Alk Stainate)	50 asf → 13.0 amps
Nickel Strike (Acid)	60 asf → 16.0 amps

B. Cleaning Procedure: (Does not apply to Tantalum):
(1) Electroclean, cathodic, 5 amps, 2 minutes
(2) Warm water rinse, agitation, 15 sec min
(3) CWR (Cold Water Rinse)
(4) Hydrochloric acid rinse (50 percent min by volume) 15 to 25 sec
(5) CWR
(6) Nitric acid dip (20 percent min by volume) 5 to 10 sec (Omit this step for Dumet and Copper weld)
(7) CWR
(8) Repeat step (4)
(9) Hydrochloric Acid rinse (20 percent min by volume) 5 to 10 sec
(10) FAST cold water rinse (3 to 5 sec vigorous agitation)
(11) Electroplate immediately.

C. Plating Procedure (Does not apply to Tantalum)
(1) Copper flash (100-200 millionths):
(a) Copper strike in acid bath, 5 amps, 30 seconds
(b) CWR
(c) Cyanide dip (KCN 6 oz/gal), 3 to 5 sec
(d) Copper plate in cyanide bath, 5 amps, 4 to 5 minutes
(e) CWR
(f) Hydrochloric acid (20 percent) rinse, 5 to 10 sec
(g) Nickel plate
(2) Nickel Plate (50-100 millionths):

Times-Deposition
15 sec gives approx 10 millionths
2½ minutes approx 50 millionths
6 minutes approx 100 millionths

(a) Nickel plate at 7.5 amps for desired time
(b) Activate nickel electroplate for cyanide gold plating: Cathodic treatment (NiCN Activation Sel-Rex Trademark "Nickel Sol-U-Salts) for 30 to 45 seconds
(c) CWR 5 to 10 seconds, distilled water rinse, then immediately gold strike and gold plate
(3) Gold Plate (50-70 millionths)
4½ minutes gives approx 50 millionths
10 minutes gives approx 100 millionths
(a) Gold strike at 2.5 volts for 15 to 30 seconds
(b) CWR
(c) Distilled water rinse (do not use the same distilled water used in Step (2) (c))
(d) Gold plate, 1.1 amps for necessary deposit time (usually 5½ minutes for 60 millionths)
(e) CWR
(f) Acetic acid (5 to 10 percent by volume) rinse, 30 sec (with agitation) minimum
(g) CWR
(h) Dry, clean compressed air or equivalent
(4) Tin Plating (300 to 500 millionths)
9 minutes → 300 millionths
15 minutes → 500 millionths
(a) Clean per Paragraph B
(b) Tin plate, 13 amps, eleven minutes (≅ 400 millionths)
(c) CWR
(d) Dry, clean compressed air, or equivalent
(5) Plating, Miscellaneous:
Woods Nickel Strike:
(a) After cleaning per Paragraph B, Wood's Nickel Strike, 16 amps, 2 minutes (cathodic)
(b) CWR: 3 to 5 seconds with vigorous agitation
(c) Nickel plate immediately, Paragraph C, Step (2).

APPENDIX L

OIL DATA SHEET

ADM CHEMICALS | **TECHNICAL DATA** | HYDROFOL TIN FAT 50

ARCHER DANIELS MIDLAND COMPANY 733 MARQUETTE AVENUE MINNEAPOLIS, MINNESOTA 55440 DATE: January 1964

HIGH TEMPERATURE RANGE HEAT TRANSFER
AND TIN STRIPPING MEDIUM

DESCRIPTION: Hydrofol Tin Fat 50 was developed specifically for use in the manufacture of tin plate and also as a high temperature heat transfer medium. Being specifically designed for its excellent tin stripping properties, Tin Fat 50 results in a long life, clean and more economical product than palm oil or other natural fats.

SUGGESTED USES:

High Temperature Heat Transfer Medium
Continuous or Batch Tin Stripping Medium

PHYSICAL PROPERTIES: Tin Fat 50 is a wax-like, white solid at room temperature, possessing unusually high flash and fire point and a melting point which ranges from 49 - 55°C. Hydrofol Tin Fat 50 is particularly noted for its pleasant clean odor, and it give off less smoke and fumes than other products used. It is economical to use due to its long life, hence minimum of viscosity increase. The superior stripping characteristics of Tin Fat 50 results in more uniform and bright tin strip. It is a uniform product manufactured under consistent conditions and product specifications and performs equally well in batch or continuous tinning operation.

SPECIFICATIONS

Open Tube Melting Point °C	49 - 55°C (120 - 130°F)
Flash Point	570°F min
Fire Point	630°F min
FFA (Oleic)	1% max
Acid Value	2 max
Specific Gravity 100/25°C	0.854 av

AVAILABILITY: Hydrofol Tin Fat 50 is available from our Peoria, Illinois plant in tankcar quantities, also available in flake form packed in 50 pound Multiwall paper bags.

Code: (Until 12-31-63)	Form	(Effective 1-1-64)
171-088	Bulk	631-180
171-188	Flake	631-181