Solders for Thick Gold Plating

Consideration of solder characteristics, joint shear strength, and soldering conditions determines the choice of a solder-flux system

BY DAVID H. BREWER

ABSTRACT. A study was made to find a solder more suitable than 63Sn-37Pb for use with thick gold plating. Conclusions were based upon the results of wettability and shear-strength tests. The test methods used provided results that are reproducible with equipment that is uncomplicated.

Eutectic 63Sn-37Pb solder is satisfactory for use with thick gold plating only if soldering time and temperature are closely controlled to prevent excessive alloying of tin and gold. Used under conditions that produce excessive alloying, 90In-10Ag has a higher shear strength than that of 63Sn-37Pb. Although high in shear strength, 80Au-20Sn solder is restricted in use because of its high soldering temperature.

A study of the wettability and shear-strength test results presented in this paper will aid in the choice of a solder-flux system for almost any intended use involving thick gold plating.

Introduction

Technological advancement in the electronics industry has led to increasing use of gold-plated components. Gold plating may be used to minimize the resistance of a conductor, decrease contact resistance, prevent corrosion, or, in thin deposits, to increase solderability. Difficulty is often encountered in soldering, however, when design considerations dictate that a thick gold plating be used.

The pins of a miniature connector block are a typical example of a thick gold-plating application. While it would be desirable to have a thin plating on the end of the pin that is soldered to the conductor, repeated abrasion of the opposite end by the mating connector demands that a thick plating be used. The small size of the pins makes it impractical to use two different plating thicknesses.

Excessive alloying of tin-lead solder with gold has long been known to produce joints that appear "cold" and are extremely weak. Certain other high-temperature solders that are better adapted for use with gold plating often cannot be used because of the required use of rosin fluxes or the presence of organic insulating materials.

This investigation was made to find a solder more suitable for use with thick gold plating than 63Sn-37Pb. Thick gold plating was considered to be a deposit of 0.3 mil or greater. The investigation was made in two phases:

1. A study of the wettability of gold plating by the various solders.
2. A determination of the shear strength of the solders after they were alloyed with gold.

All of the solders used in the investigation are commercially available.

Background

An earlier study of gold-plating for solderability by Harding and Pressly* presents the following six conclusions:

"1. Thin, pure gold plating of approximately 0.05 mil and less and very thin, alloy gold plating of approximately 0.01 mil and less dissolve readily in tin-lead solder and have no measurable detrimental effects on the structure or strength of the solder joints.

"2. Thick gold plating of approximately 0.05 mil and greater dissolves readily in tin-lead solder at normal soldering temperatures. The gold-tin-lead alloy formed is significantly weaker than eutectic tin-lead solder, its strength varying inversely with the gold content. Thus, any factor that will increase the amount of gold in the solder will produce weaker solder joints; that is, increased gold thickness, increased soldering temperature, and increased soldering time. The gold-tin-lead alloy formed is weaker than the eutectic tin-lead solder because of the formation of large, brittle, acicular crystals of $AuSn_4$ in the solder. These large crystals give the solidified solder a crystalline appearance that can be confused with a 'cold solder joint.'

"3. Except for very thin deposits of approximately 0.01 mil and less, alloy golds containing small quantities of nickel, cobalt, or silver cause considerably weaker solder joints than do pure golds of comparable thicknesses. The weak solder joints are due primarily to a dewetting condition. The solder initially wets the gold surfaces and then draws back to leave ridges of solder connecting the joint.

"4. Pure golds and alloy golds containing nickel, cobalt, or silver are significantly, although not markedly, more readily wetted by tin-lead solders than is bare copper.

"5. Pure golds are only slightly more readily wetted than alloy golds.

"6. Thinner golds of both pure and alloy types are slightly more readily wetted than thicker golds."

In the same report, Harding and Pressly make the following recommendations:

"Thin gold plating (approximately 10 millionths) is definitely a soldering aid and has no detrimental effects on the structure or strength of solder joints.

"Thick gold plating (approximately 50 millionths and greater) should be avoided when strength is important.

"In those applications where thick gold plating is required for other reasons, as thin a gold as can be tolerated should be used; pure gold deposits should be chosen; and the soldering operation should be precisely controlled to minimize soldering temperature and soldering time."

Emphasis is placed on the fact these conclusions and recommendations are for tin-lead solders, and the use of gold plating, to enhance solderability.

Solder Selection

The choice of solders to be included in this investigation was based upon several factors. Table 1 lists the solder

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DAVID H. BREWER is with the Kansas City Division, Bendix Aerospace-Electronics Co., Kansas City, Mo.

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*Harding, W. B., and Pressly, H. B., "Soldering to Gold Plating," *Technical Proceedings*, 1963, American Electroplaters' Society, pp. 90-106.

Table 1—Properties of Solders Considered for Investigation

Solder composition, %	Eutectic (E) or liquidus (L) melt temperature, °F	Comments
63Sn-37Pb	361 E	Common, general-purpose solder for electrical connections.
80In-15Pb-5Ag	315 E	Indium-base solders are weaker without tin, but
90In-10Ag	446 L	gold-indium intermetallics may not be as brittle.
96.5In-3.5Bi[a]	304 L	Recommended by manufacturer "for soldering thin films of gold without appreciable gold scavenging."
97.5Pb-1.5Ag-1.0Sn	588 E	
68Sn-32Cd	349 E	Alloys containing cadmium are used for solder-
83Pb-17Cd	478 E	ing in the jewelry industry.
80Au-20Sn	536 E	Gold-base alloys recommended by manufacturer for soldering "because of their excellent
88Au-12Ge	673 E	wettability, good thermal conductivity, high strength, resistance to many etchants, and
94Au-6Si	698 E	low melting point." Alloys with melting points higher than that of 80Au-20Sn were found in-
27Au-73T1	268 E	capable of being fluxed by rosin fluxes. Most of them are quite brittle. The 27Au-73T1 alloy was so brittle that it could not be rolled into preforms needed for the shear specimens.
56.5Bi-43.5Pb	255 E	

[a] Composition determined by laboratory analysis.

compositions that were initially considered, together with the preliminary data obtained in preparation for the study. Except for 63Sn-37Pb, solders containing a high percentage of tin were avoided because of the brittleness of the gold-tin intermetallic compounds that would be formed. The 63Sn-32Cd composition was included because of its reported use in the jewelry industry.

In general, gold- and indium-base solders were considered to be the most promising. It was reasoned that the gold-base solders would pick up additional gold from the plating, thereby decreasing the percentage of intermetallics, and probably increasing the ductility. It was also thought that indium-gold intermetallics would be less brittle than those formed from tin and gold, despite their frosty appearance.

High melting temperatures excluded 88Au-12Ge and 94Au-6Si solders from the investigation because of the presence of organic insulating and potting materials in the components to be soldered, and the required use of rosin-alcohol and rosin-terpene fluxes.

Of the original twelve solders considered, the following nine were chosen for study:

1. 63Sn-37Pb.
2. 80In-15Pb-5Ag.
3. 96.5In-3.5Bi
4. 68Sn-32Cd.
5. 90In-10Ag.
6. 83Pb-17Cd.
7. 80Au-20Sn.
8. 97.5Pb-1.5Ag-1.0Sn.
9. 56.5Bi-43.5Pb.

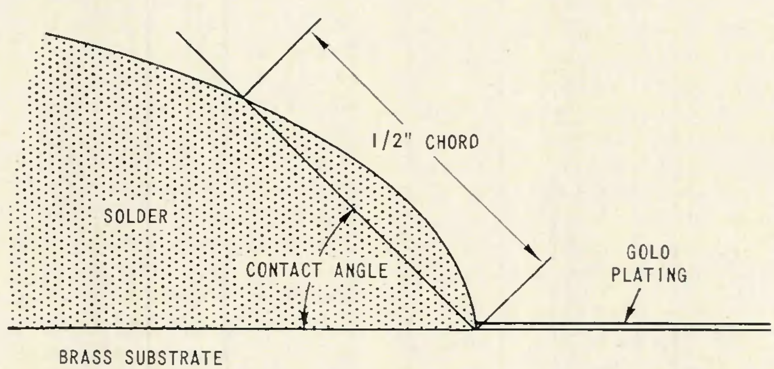

Fig. 1—Method of determining contact angle on 50X photomicrograph

Wettability Study

Method

Wettability of the solders chosen for study was determined by melting a specific quantity of each solder on a circular specimen punched from a gold-plated panel. After cooling, the outline of the wetted area was traced on translucent paper cross-ruled in 0.1 in. squares (each unit having an area of 0.01 sq in.). The included squares were counted, and fractional parts were estimated to the nearest tenth of a unit.

A supplementary method of expressing solder wettability was used—Fig. 1. This method consists of determining the angle between the surface of the solder (at its leading edge) and the surface of the base metal on which the gold is plated. For this purpose, a representative cross section of the specimen is photomicrographed at 50X. A $^1/_2$ in. chord is drawn on the photomicrograph from the leading edge of the solder to its top surface. The included angle is termed the "contact angle."

Results from the two methods of expressing solder wettability were correlated, and acceptable limits were defined for each method.

Specimen Preparation

Test panels for the wettability study consisted of two $10^1/_2$ by 12 in. sheets of 0.020 in., 70-30 half-hard brass. Preparation before plating, primarily done to remove tarnish, consisted of vapor degreasing, cleaning anodically in an alkaline cleaner (Oakite 191), and rinsing. For economy, and to prevent edge build-up of plating, the back and edges of each panel were masked with platers' tape to leave an exposed area of $8^1/_2$ by 10 in. The panels were then dipped in a 2 lb/gal solution of ammonium persulfate at room temperature for 2 min, rinsed, dipped in 10% sulfuric acid at room temperature for 20 sec, rinsed, and copper-plated in a sulfate bath for 4 min at 15 asf (amp/sq. ft.) to obtain a maximum deposit thickness of 0.1 mil.

Following the copper plating, the panels were rinsed, dipped again in 10% sulfuric acid, rinsed, dipped in sodium cyanide at room temperature for 30 sec, and gold-plated in a proprietary pure-gold plating solution (Sel-Rex BDT 200) for 42 min at 3 asf. This was calculated to produce a gold deposit ranging in thickness from 0.3 to 0.4 mil.

A formed anode was used in the plating tank in an attempt to obtain a uniform deposit. After the first panel was plated and checked for plating

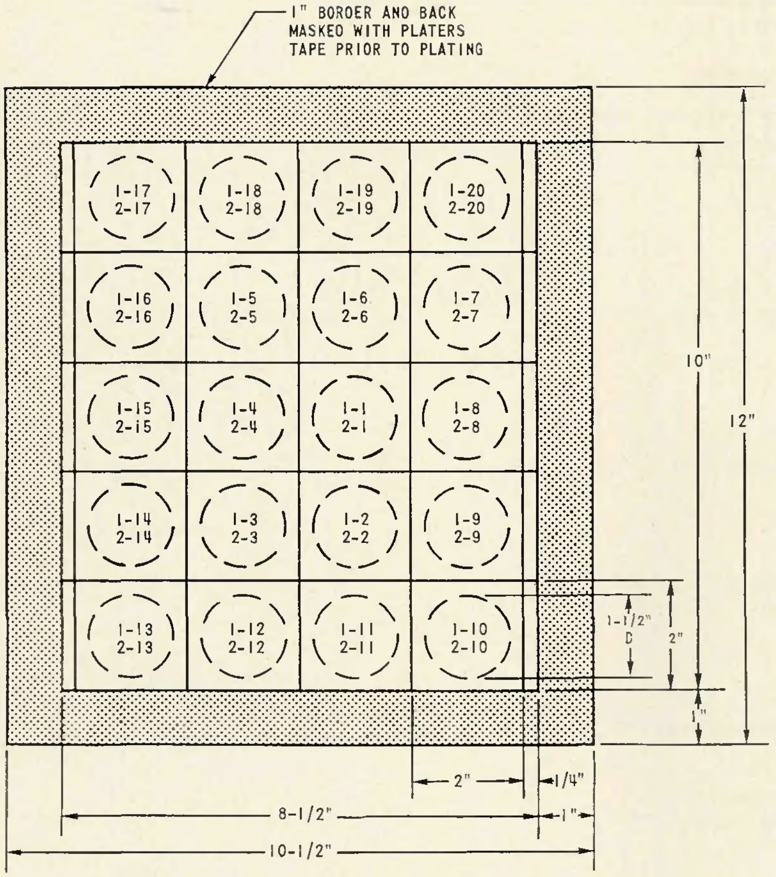

Fig. 2—Location of wettability specimens on plated panels

Table 2—Beta Backscatter Thickness Values for Gold Plating on Wettability Specimens

Panel 1 specimen No.	Thickness, microin.	Panel 2 specimen No.	Thickness, microin.
1–1	235	2–1	230
1–2	242	2–2	245
1–3	230	2–3	235
1–4	225	2–4	215
1–5	235	2–5	225
1–6	242	2–6	240
1–7	305	2–7	295
1–8	305	2–8	295
1–9	293	2–9	305
1–10	355	2–10	330
1–11	297	2–11	290
1–12	290	2–12	300
1–13	280	2–13	265
1–14	230	2–14	225
1–15	212	2–15	215
1–16	230	2–16	225
1–17	265	2–17	260
1–18	280	2–18	265
1–19	300	2–19	285
1–20	285	2–20	330
Avg	267	Avg	264

Table 3—A Comparison of Beta Backscatter and Microscopic Measurements of Gold Plating

Specimen reference	Microderm thickness, microin.	Microscope thickness,[a] microin.
1–1	235	233
1–20	285	496
2–1	230	248
2–20	330	448

[a] Measured near the indicated specimen.

thickness and uniformity, a modification was made in the shape of the anode before plating the second panel.

Following removal of the masking tape, each panel was scribe-marked into 20 two-inch squares. A $1^1/_2$ in. diameter specimen was punched from the center of each square and identified according to the plot shown in Fig. 2. The specimens were then vapor degreased and individually stored in tarnish-inhibiting paper.

The thickness of the gold plating was measured at the center of each specimen with a nondestructive beta backscatter thickness-measuring instrument. The values obtained are shown in Table 2. The plating-thickness measurements of Panel 1 ranged from 212 to 355 microin., with an average of 267; those from Panel 2, 215 to 330 microin., with an average of 264.

In addition, two microscopic measurements were made from the remaining portion of each panel for comparison with the beta backscatter reading of the nearest specimen. The locations of the microscopic measurements corresponded on the two panels and were near specimens 1-1, 1-20, 2-1, and 2-20.

A comparison of the beta backscatter and microscopic plating-thickness measurements may be obtained from Table 3. The marked increase in thickness shown by the microscopic measurements made near specimens 1-20 and 2-20 may be attributed to the location being near the edge of the panels. Analysis of the data in Tables 2 and 3 indicates that the plating thickness of Panel 2 averaged slightly less, but was more uniform, than that of Panel 1. Although the thickness on most of the specimens was less than had been desired, it was considered adequate for the wettability study.

The 63Sn-37Pb test solder used in the investigation consisted of 0.062 in. diameter wire. All of the others were obtained in the form of foil that measured 0.500 by 0.375 by 0.005 in. The amount of wire and of foil required to provide a volume of 0.002 cu. in. (equivalent to a $^1/_8$ in. cube) was calculated. Foils for each solder specimen were stacked and folded twice, and the wire solder was rolled into small spheres, to produce small, compact masses.

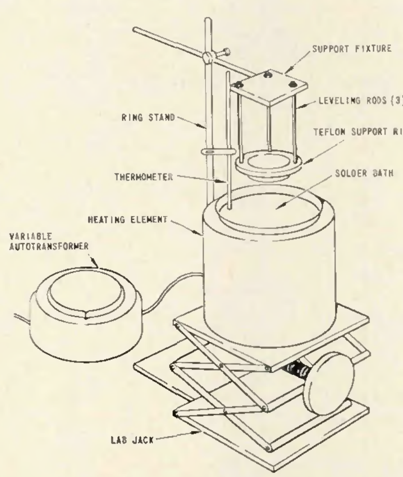

Fig. 3—Wettability test apparatus

The apparatus with which the specimens were prepared is illustrated in Fig. 3. A solder bath of eutectic tin-lead solder served as the heat source for melting the test solder. A variable autotransformer was used to control the temperature.

Each specimen was secured in the Teflon support ring, and three drops of an activated rosin flux in alcohol (Kester 1544) were spread over its entire bottom surface with a small brush. The support ring was then screwed onto the three leveling rods, and leveling was accomplished by adjusting the rods while observing a small bubble level that had been placed on the gold-plated surface of the specimen. Specimens were selected for use in the order of decreasing plating-thickness.

The test solder was placed in the center of each specimen in such a manner that a minimum area of the gold-plated surface was contacted. The solder was then covered with two drops of the specified flux. Rosin fluxes using alcohol as the solvent were used at temperatures below 500° F. Because of its lower volatility, a flux using terpene as the solvent was used at temperatures of 500° F and above.

After the dross had been skimmed from its top, the solder bath was raised by means of the laboratory jack to contact the bottom surface of the specimen. The bath was kept in contact with the specimen for 5 sec after melting the test solder. The test solder was allowed to solidify undisturbed, after which the specimen was removed from the leveling rods and support ring and immersed in trichloroethylene to remove the excess flux.

Results

The wetted area of each specimen was measured, as previously described, and the results recorded. The specimen nearest the mean value of each solder-flux group measured was then chosen for determination of the contact angle. The results obtained from both methods of denoting wettability are shown in Table 4, in the order of decreasing wetted area. As might be expected, an analysis of the data shows an inverse correlation between the wetted area and the contact angle of the test solder.

Based upon an examination of the specimens and a study of the data obtained, the following guidelines were established as criteria for judging solder wettability:

1. Solder-flux systems producing wetted areas smaller than 0.050 sq in. for 0.002 cu. in. of solder, or contact angles of 65 deg or more, do not wet sufficiently.

2. Solder-flux systems producing wetted areas larger than 0.100 sq in. for 0.002 cu. in. of solder, or contact angles of 25 deg or less wet sufficiently to flow. A solder meeting this definition is termed, "suitable for general use."

3. Solder-flux systems producing wetted areas ranging between these two sets of conditions should be used only when the solder can be preplaced and will not be required to flow to form a good joint.

Table 5 shows the solder-flux systems that are considered suitable for general use with thick gold plating, based upon the average wetted areas determined from the wettability study.

Table 4—Spread Area and Contact Angle of Wettability Specimens

Solder-flux system[a]	Solder Bath temperature,[b] °F	Panel no.	Wetted area, sq in.	Contact angle, deg
63Sn-37Pb Kester 1544[c]	410 ± 5	1–8	0.195	16
		1–7	0.205	
		1–15	0.175	
			Avg 0.191	
90In-10Ag Kester 1015[d]	500 ± 5	2–6	0.130	
		1–2	0.145	
		1–6	0.130	20
			Avg 0.135	
80Au-20Sn Kester 1015	586 ± 5	1–3	0.115	
		1–14	0.121	22
		2–1	0.121	
			Avg 0.119	
63Sn-37Pb Alpha 100–30[e]	410 ± 5	1–10	0.115	
		2–10	0.093	
		2–20	0.108	18
			Avg 0.105	
97.5Pb-1.5Ag-1.0Sn	638 ± 5	2–15	0.110	—
		2–5	Ruined	
56.5Bi-43.5Pb Kester 1544	370 + 5 − 0	2–14	0.100	—
		1–16	0.095	
			Avg 0.098	
96.5In-3.5Bi Kester 1544	370 + 5 − 0	2–11	0.078	
		1–12	0.088	31
		1–9	0.107	
			Avg 0.091	
80In-15Pb-5Ag Kester 1544	370 + 5 − 0	1–11	0.090	36
		1–19	0.090	
		2–9	0,090	
			Avg 0.090	

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Table 5—Solder-Flux Systems Suitable for General Use With Thick Gold Plating, as Determined From Wettability Study

Solder-flux system	Use temperature, °F	Average wetted area, sq in.
63Sn-37Pb Kester 1544	410 ± 5	0.191
90In-10Ag Kester 1015	500 ± 5	0.135
80Au-20Sn Kester 1015	586 ± 5	0.119
63Sn-37Pb Alpha 100–30	410 ± 5	0.105

Lap Shear-Strength Study

Method

Application of the criteria established for determining acceptable wettability characteristics eliminated 83Pb-17Cd solder from the shear-strength investigation. Six lap shear-strength specimens were made from each of the other solders used in the wettability study. Of each group, three specimens were made at 50° F above, and three at 150° F above the eutectic or liquidus temperature. The object of the higher-temperature study was to determine the effect upon shear strength of additional gold being alloyed with the solder.

All six of the 80Au-20Sn solder specimens were made at the lower temperature, since a temperature 150° F above the eutectic temperature was considered excessive. Prior to

Table 4—(Continued)

Solder-flux system[a]	Solder Bath temperature,[b] °F	Panel no.	Wetted area, sq in.	Contact angle, deg
56.5Bi-43.5Pb	370 + 5	1–4	0.070	—
Alpha 100–30	− 0	2–16	0.082	
			Avg 0.076	
68Sn-32Cd	400 ± 5	2–18	0.060	
Kester 1544		1–17	0.068	44
		1–18	0.070	
			Avg 0.066	
80In-15Pb-5Ag	370 + 5	2–12	0.063	
Alpha 100–30	− 0	2–8	0.050	
		2–7	0.057	64
			Avg 0.057	
96.5In-3.5Bi	370 + 5	1–13	0.055	59
Alpha 100–30	− 0	2–19	0.058	
		1–20	0.050	
			Avg 0.054	
83Pb-17Cd	530 ± 5	1–5	0.041	
Kester 1015		1–1	0.030	
		2–3	0.037	86
	576	2–4	0.040	
			Avg 0.037	
68Sn-32Cd	400 ± 5	2–2	0.025	
Alpha 100–30		2–17	0.037	69
		2–13	0.040	
			Avg 0.034	

[a] All solder volumes were 0.002 cu in.
[b] Temperature measurements made with ASTM glass-stem mercury thermometer
[c] Kester 1544 is an activated rosin flux in alcohol.
[d] Kester 1015 is an activated rosin flux in terpene solvent.
[e] Alpha 100–30 is a nonactivated rosin flux in alcohol.

the shear tests, three of the 80Au-20Sn specimens were subjected to thermal shock in accordance with Military Standard No. 202, Method 107, Test Condition B. Because 80Au-20Sn, as purchased, is quite brittle, it was thought the joints might prove to be sensitive to thermal shock.

Shear-strength tests were performed at room temperature, at a rate of 0.050 ipm, in a tensile-testing machine with two self-aligning grips. A grip-length of 0.625 in. was used on all specimens.

Specimen Preparation

The dimensions and assembly of the lap shear-strength specimens are illustrated in Fig. 4. The panels consisted of annealed copper, gold-plated in an acid citrate pure-gold bath to a thickness of from 0.3 to 0.4 mil. Preformed foils of the various solders, each measuring 0.500 by 0.375 by 0.005 in., were used between the lapped areas of the panels, and 0.004 in. diameter wire spacers were inserted to prevent excessive solder squeeze-out. Each assembly was held together with a steel binder clip.

Solder joints were formed by dipping the assemblies in animal fat which had been heated to the required temperature. Flux was not used, as the animal fat was considered sufficiently active.

To compensate for the slower heat transfer of animal fat (compared to that of liquid solder) and the increased mass of the lap shear specimens (compared to that of the wettability specimens), the animal fat was heated 5° F above the desired temperature for temperatures below 500° F, and 10° F above the desired temperature for temperatures of 500° F and above. Under these conditions, 50 sec were required for each specimen to reach its designated temperature. With an additional 5 sec allowed for formation of the joint, the total time in the bath was 55 sec.

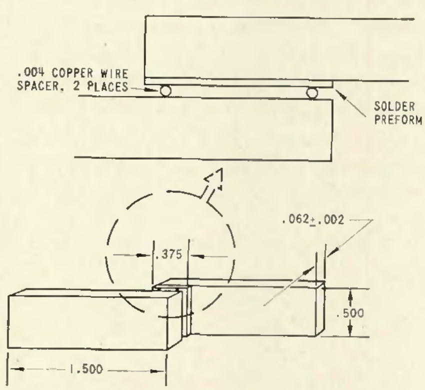

Fig. 4—Dimensions and assembly of lap shear-strength specimens

Results

Table 6 shows the results of the lap shear-strength tests. A comparison of column 3 with column 2 illustrates the effect on shear strength of additional gold being alloyed with the solder. While the average strength of some of the solders increased with the pick-up of additional gold, four of them showed a decrease. This is an important consideration in choosing a solder for a loosely controlled operation. A solder that gains strength as the gold content increases is more desirable than one that loses strength.

Microsections of the joint components, made after the shear tests were completed, showed that the entire thickness of the gold plating had been alloyed with solder at temperatures of about 500° F, and higher. This accounts for the similarity in the strength values obtained from the high-temperature solders.

Table 6 also shows the disastrous results that occur from the use of tin-lead solder when soldering conditions are not controlled. By accident, three specimens were soldered with 63Sn-37Pb at 284° F above the eutectic temperature. A study of the data shows that the strength of the joints averaged about one-third that of the joints produced at 150° F above the eutectic temperature, and one-sixth that of the joints produced at 50° F above the eutectic temperature.

Data in Table 6 further indicate that thermal shock has no effect upon the strength of 80Au-20Sn solder. It may be noted that the highest strength was exhibited by a joint that had undergone thermal shock, and the lowest, by a joint that had not been so subjected.

Table 7 shows the average shear strengths, in decreasing order, of the three solders that are considered suitable for general use with thick gold plating. A study of Tables 5 and 7 will aid in choosing a solder-flux system for almost any intended use. Good results can be obtained from eutectic tin-lead solder if the soldering time and temperature are held to a minimum.

Table 6. Lap Shear Joint Strength

Solder	Shear strength (joint 50° F above eutectic or liquidus), psi		Shear strength (joint 150° F above eutectic or liquidus), psi
63Sn-37Pb	4270	510[a]	1970
	3550	750[a]	1730
	3590	650[a]	1820
	Avg 3800	Avg 640	Avg 1840
80In-15Pb-5Ag	1820		1900
	1674		1800
	1460		1840
	Avg 1650		Avg 1850
96.5In-3.5Bi	740		860
	310		1230
	720		1150
	Avg 590		Avg 1080
68Sn-32Cd	2280		3070
	2460		2800
	2610		3190
	Avg 2450		Avg 3020
90In-10Ag	1020		1010
	1090		1040
	1160		980
	Avg 1090		Avg 1010
80Au-20Sn[b]	7040	No thermal shock	—
	5490	No thermal shock	—
	7080	No thermal shock	—
	6980	Thermal shock	—
	7770	Thermal shock	—
	6450	Thermal shock	—
	Avg 6800		—
97.5Pb-1.5Ag-1.0Sn	3070		2130
	2880		4150
	3550		3120
	Avg 3170		Avg 3130
56.5Bi-43.5Pb	1560		1200
	1630		1520
	1990		1530
	Avg 1730		Avg 1420

[a] Joints formed at 645° F (284° F above eutectic temperature) by accident. Data included for comparison.
[b] Lap distance was decreased from 3/8 to 3/16 in. to cause break to occur in the joint.

Table 7—Average Shear Strength of Solders Suitable for General Use with Thick Gold Plating

Solder	Average shear strength (joints 50° F above eutectic or liquidus), psi	Average shear strength (joints 150° F above eutectic or liquidus), psi
80Au-20Sn	6800	—
63Sn-37Pb	3800	1840
90In-10Ag	1090	1010

Conclusions

Results of the wettability and lap shear-strength studies performed on various solders used with thick gold plating indicate the following conclusions:

1. If used with Kester 1544 flux, 63Sn-37Pb solder has greater wettability than any of the other solders tested. It also has the second-highest shear strength if joints are formed within 5 sec at 410° F. Its primary advantage is its low melting temperature (361° F). *Satisfactory results can be obtained only if soldering time and temperature are controlled at a minimum to prevent excessive alloying with gold. Ordinarily, soldering procedures do not provide such control.*

2. The 80Au-20Sn solder has the highest shear strength of all those tested and ranks third in wettability. Its use is restricted because of its high soldering temperature (586° F). Although it is somewhat brittle, its strength is not adversely affected by thermal-shock cycling.

3. The 90In-10Ag solder, used with Kester 1015 flux, ranks second in wettability. Its application temperature (500° F) is moderate. The shear strength is lower than that of either 63Sn-37Pb or 80Au-20Sn when joints are made within 5 sec at 50° F above the eutectic or liquidus temperature. Used under conditions that produce excessive alloying with gold, 90In-10Ag has a higher shear strength than that of eutectic tin-lead solder.

The findings of the study described in this paper show that either 90In-10Ag or 80Au-20Sn may be more suitable for use with thick gold plating than 63Sn-37Pb. The 63Sn-37Pb can be used effectively only when soldering time and temperature are controlled to minimize alloying of gold with tin.

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