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LOW TEMPERATURE ALUMINUM SOLDERING ANALYSIS

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LOW TEMPERATURE ALUMINUM SOLDERING ANALYSIS

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Prepared by W. G. Peterkort, D/862, under PDO 6984910

An investigation of low temperature aluminum soldering included the collection of spread factor and dihedral angle data for several solder alloys and a study of flux effects on aluminum. Selected solders were subjected to environmental tests and evaluated on the basis of tensile strength, joint resistance, visual appearance, and metallurgical analysis. A production line method for determining adequate flux removal was developed.

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SUMMARY

Low temperature (up to 266°C) aluminum soldering was investigated as a suitable means for connecting aluminum conductors to connector hardware. Solder alloys were evaluated on the basis of wettability tests and environmental exposure. The effects of flux on the aluminum conductors and the detection of flux residue were also studied.

Spread factor and dihedral angle measurements combined with previous processing information¹ indicate that the four best solders are 80 percent lead, 17 percent bismuth, 2 percent silver, and 1 percent tin (80Pb-17Bi-2Ag-1Sn); 91 percent tin and 9 percent zinc (91Sn-9Zn); 96 percent tin and 4 percent silver (96Sn-4Ag); and 82.5 percent cadmium and 17.5 percent zinc (82.5Cd-17.5Zn). However, 80Pb-17Bi-2Ag-1Sn was found to be superior when samples were cross sectioned and evaluated metallurgically. The flux used in soldering aluminum was found to deposit a layer of tin and zinc on the aluminum surface, and intergranular penetration of this deposit into the aluminum was observed.

Five solders were selected to undergo environmental testing:

- 80Pb-17Bi-2Ag-1Sn,
- 63Sn-37Pb on 91Sn-9Zn,
- 96Sn-4Ag,
- 91Sn-9Zn, and
- 82.5Cd-17.5Zn.

Environmental test samples consisted of a 0.13 mm (0.005 in.) thick by 6.35 mm (0.250 in.) wide 1100 aluminum conductor soldered to a gold plated beryllium copper slotted pin. The test environments consisted of high humidity, thermal-shock, and high ambient temperature. Exposed and unexposed samples were given resistance, tensile, visual, and metallurgical tests.

The comparison of pre- and post-environmental solder joint resistance measurements indicated no correlation between joint resistance and joint quality. Tensile test failures occurred only after humidity and temperature shock exposure. All solders except the 80Pb-17Bi-2Ag-1Sn failed after humidity and only the 82.5Cd-17.5Zn solder failed after thermal-shock. After the humidity exposure test, lead carbonate hydroxide was found forming on the 80Pb-17Bi-2Ag-1Sn solder, and blistering, a result of

interface corrosion, occurred in all but one of the other solders. Solder separation from the aluminum was noted in the 82.5Cd-17.5Zn after thermal-shock. All solders were visually sound after the high ambient environment.

Metallurgical evaluation revealed some problems with all of the solders. The initial, or as soldered samples, except for the 80Pb-17Bi-2Ag-1Sn and the 96Sn-4Ag solders, displayed such defects as microcracks along the solder aluminum interface and solder separation from the aluminum. The primary damage discovered after high humidity exposure was corrosion of the solder or the solder-aluminum interface, resulting in tensile test failure. Intermetallic formation and/or internal cracking in the solder were predominant in those samples exposed to thermal-shock and high ambient environments.

The 80Pb-17Bi-2Ag-1Sn solder was judged to be generally superior to the others studied, but it exhibited the potential for joint failure under longer exposure to the environments used in this evaluation. Low temperature aluminum soldering with this solder would be adequate for applications requiring short term electrical connections to aluminum conductors.

A method applicable to production line use was developed to detect the presence of aluminum solder flux residue in areas where visual inspection is impossible.

DISCUSSION

SCOPE AND PURPOSE

Aluminum soldering was investigated as a means of joining aluminum conductors to connector hardware. Solder selection heretofore was based primarily upon processibility.¹ To guarantee long term solder joint integrity, selected solders were exposed to wetability and environmental testing. Flux was evaluated for detrimental effects on the aluminum conductor. A test was developed to detect corrosive flux residue in the solder joint area.

PRIOR WORK

Several solders and fluxes have been investigated from a processibility standpoint.¹ Solders were compared visually for wetting and flow characteristics. Iron, ultrasonic, induction, and resistance soldering processes were evaluated for applicability to aluminum soldering.

ACTIVITY

Preliminary Solder Alloy Evaluation

Several low temperature solder alloys were evaluated for possible use on aluminum. The areas of study included solderability, a metallurgical evaluation of the solder-aluminum interface on test coupons, and the effects of flux.

Wetability

The ability of nine alloys (Table 1) to wet aluminum was determined by a spread test. Samples for this test consisted of aluminum (1100 alloy) coupons measuring 25.4 by 38.1 by 3.18 mm (1.0 by 1.5 by 0.125 inches). These samples were vapor degreased in trichloroethylene just before use.

Preforms of these solders having a known volume were placed in the center of the coupons (one preform per coupon) and three drops of 150 flux, a proprietary aluminum soldering flux, were applied. Each sample was then lowered into a pot of molten solder and allowed to float for 5 seconds after the preform began to melt. The test temperature was 38°C above the liquidus temperature of the solder being evaluated. The coupons were then raised from the solder pot and allowed to cool. A warm water wash was used to remove the excess flux.

Table 1. Wetability Data

Solder Alloy	Liquidus/Test Temperatures (°C)	Percent Spread Factor			Dihedral Angle (Degrees)		
		High	Low	Average	High	Low	Average
80Pb-17Bi-2Ag-1Sn	232/288	97.3	93.4	95.5	59.0	6.0	26.3
96Sn-4Ag	221/277	95.5	88.5	93.04	2.5	1.0	1.8
63Sn-37Pb	183/238	92.4	90.8	92.1	26.0	20.5	23.3
82.5Cd-17.5Zn	266/321	93.2	91.0	91.8	11.5	6.0	8.5
91Sn-9Zn	199/254	94.0	86.8	91.3	8.5	1.5	4.1
50Pb-50In	209/264	88.1	82.9	85.2	16.0	3.0	11.0
62Sn-36Pb-2Ag	188/243	88.2	82.2	85.1	18.0	10.5	14.5
99In-1Cu	153/208	75.8	71.9	74.76	20.0	2.0	9.6
80In-15Sn-5Ag	157/213	74.1	70.9	72.4	73.0	34.0	48.8

Wetability of the nine alloys was determined from these coupons by two methods--spread factor and dihedral angle of wetting. The spread factor is a measure of the ability of the solder in question to wet and flow over the surface of a substrate material and is calculated from the following equation.

$$\text{Spread Factor (Percent)} = \frac{D-H}{D} \times 100$$

where:

D = Theoretical diameter of a sphere having the same volume as the preform used, and

H = Height of the solder above the coupon surface after the solder has flowed.

A large spread factor indicates good wetting.

This technique is empirical in the sense that the spread factor cannot be directly correlated to the physics of wetting. The dihedral angle, on the other hand, is a direct measurement of the wetting angle of the solder; that is, the angle between the solder-base metal interface and the solder-flux interface at the edge of the solder meniscus. A small angle is an indication of good wetting.

The results from both methods are given in Table 1. A review of the data reveals that a separate ranking of the solders on the basis of spread factor and dihedral angle results in two different lists. Of these two, the ranking obtained from spread factor data is probably the more reliable since the range in data from high to low is much smaller than that for the dihedral angle data.

Any of the first seven alloys in Table 1 would, from a solderability viewpoint, be adequate for use with aluminum conductors. Previous experimentation has shown that 63Sn-37Pb does not easily solder aluminum. However, it has a spread factor in excess of 90 percent (considered excellent). This is because the amount of heat available during solderability testing is much greater than a soldering iron provides. The temperature drop of the 100 pound solder pot heat source would be negligible compared to the soldering iron. Solderability tests assess the potential for an alloy to wet base materials--a necessary starting point. Actual performance, however, can be evaluated only in a working situation.

Metallurgy

Four of the nine alloys were chosen for further consideration as a result of previous study¹: 80Pb-17Bi-2Ag-1Sn, 96Sn-4Ag,

91Sn-9Zn, and 82.5Cd-17.5Zn. The solderability test coupons for these alloys were cross-sectioned and metallographically prepared. Optical examination of the aluminum-solder interfaces provided limited information about alloying. For this reason the scanning electron microscope was used to gather the information.

80Pb-17Bi-2Ag-1Sn. This alloy solidifies with such a fine structure that a good microstructural study was difficult to achieve. Examination of the interface revealed no intermetallic layers or excessive alloying with aluminum.

The scanning electron micrograph in Figure 1 is a 300X overall view of the aluminum-solder interface. The dark areas inside the solder are aluminum. These are not aluminum grains removed by the solder but merely machining chips entrapped during solderability testing. The small geometrical regions contain silicon carbide particles which were imbedded during metallographic preparation. There is no intergranular attack of the aluminum.

Figure 2 is a 3000X view of the bulk solder adjacent to the wetting interface. Energy dispersive X-ray analysis (EDAX) of the circled dark region (A) indicated the major constituent to be lead. This area also contained silver, aluminum, and a trace of bismuth. The light region (B) consisted mainly of lead with only a trace of aluminum and bismuth. Additional spot analysis of the bulk solder gave roughly similar results. Aluminum apparently is dissolved in the solder, but the amount is relatively small.

This solder appears to be adequate in forming a metallurgical bond to aluminum. There were no reaction layers observed, and the dissolution of aluminum is minimal.

91Sn-9Zn. This alloy is a eutectic composition that melts at 198°C. In actuality, the material used was found to be an off-eutectic alloy, as evidenced by the presence of zinc dendrites in the fine eutectic microstructure. These dendrites were generally found to nucleate at surface irregularities on the aluminum (Figure 3). EDAX analyses of the bulk solder near the wetting surface indicated the presence of aluminum in both the dendritic and eutectic structures.

As shown in Figure 3, the solder has separated from the aluminum. This was noted several times during the evaluation of this solder, but no reaction layers were found at the aluminum-solder boundary which might produce this type of failure. The bulk solder was found to be cracked at several locations, generally along the dendrites, which suggests that the interface separation may result from a lack of solder ductility. Eliminating the dendritic structure by using a perfectly eutectic alloy could reduce the

Figure 1. SEM of Aluminum (Left) Interface With 80Pb-17Bi-2Ag-1Sn Solder

Figure 2. Microstructure of 80Pb-17Bi-2Ag-1Sn Solder; EDAX Spot Analysis Areas Are Circled

Figure 3. SEM of Aluminum (Left) Interface
With 91Sn-9Zn Solder

cracking (dendrites can act as stress risers), but obtaining this control on commercially purchased material is a problem.

96Sn-4Ag. Examination of the wetting surface of this alloy revealed a compound layer in the solder next to the interface (Figure 4). Closer examination of this region revealed at least two, and possibly three, layers (Figure 5). Immediately adjacent to the aluminum is a layer of tin followed by a layer of silver-aluminum (probably Ag_3Al). A third layer may exist, but it was not possible to discern the elements contained.

A considerable amount of cracking was also observed in the aluminum next to the wetting interface and the compound layers (Figure 5). EDAX analyses of the cracked regions indicated the presence of tin and silver in the aluminum. There is obviously some embrittlement occurring, but its nature is not known.

82.5CD-17.5Zn. This alloy was previously investigated for intergranular penetration. Confirmation of this liquid metal embrittlement (LME) in the aluminum center conductor of a development unit is shown in Figure 6.

Intergranular penetration of the aluminum was not observed during this investigation. However, the aluminum wetting surface was found to be rough and uneven, indicating rapid alloying

Figure 4. SEM of Aluminum (Left) Interface With 96Sn-4Ag Solder

Figure 5. SEM of Compound Layers and Cracking at Interface of Aluminum (Left) and 96Sn-4Ag Solder

Figure 6. SEM Showing Intergranular Penetration Into a Center Conductor (Top) and EDAX of the Area of Penetration

(Figure 7) and increasing the potential for LME, particularly on thin aluminum foil. The lack of LME on these samples may result from the short length of time the solder was molten. Reworking of solder joints with this alloy would promote LME.

The microstructure consists of an eutectic mixture of cadmium rich (light areas) and zinc rich (dark areas) phases. Some aluminum was detected throughout the solder. No compound layers were observed at the aluminum-solder interface.

Flux Effects

The flux used during this study consisted of an organic carrier of triethanol amine containing salts of tin and zinc. This flux deposits a layer of these metals on the aluminum surface¹. This raised the question of possible LME by the tin-zinc deposit.

Additional solderability coupons were processed, but only flux was applied to the aluminum surface. These samples were then metallographically prepared and examined. Figures 8 and 9 present the results. The deposited layer of tin and zinc was 1.27 to 2.54 mm (50 to 100 μ in.) thick. There was a significant amount of intergranular penetration by the deposit, which is molten at soldering temperatures.

The lack of LME in the coupons having solder is probably the result of almost immediate dispersion of this layer within the bulk solder. Those areas of the joint which are fluxed but are not soldered (at the end of the solder fillet, for example) are potential sites for LME. This was confirmed by subsequent re-examination of the wetting coupons. Those areas which were beyond the meniscus exhibited intergranular penetration.

Environmental Exposure

Environmental testing was conducted on joints made with five solders showing positive processing characteristics¹ and on which preliminary evaluation was completed:

- 80Pb-17Bi-2Ag-1Sn plus 150 flux,
- 63Sn-37Pb soldered with rosin flux to ultrasonically tinned aluminum using 91Sn-9Zn solder,
- 96Sn-4Ag plus 150 flux,
- 91Sn-9Zn plus 150 flux, and
- 82.5Cd-17.5Zn plus 150 flux.

3000X

Figure 7. SEM of Interface of Aluminum
(Left) and 82.5Cd-17.5Zn Solder

The 80Pb-17Bi-2Ag-1Sn solder indicated promising metallurgical and wettability data. The use of 63Sn-37Pb solder would allow aluminum solder joints to be made without using a potentially corrosive soldering flux. The other three solders were included because they are alloys used in industry.

Configuration and Tests

Each sample was manufactured by soldering a 6.35 mm (0.250 in.) wide by 76.20 mm (3.00 in.) long strip of 0.127 mm (0.005 in.) thick 1100 aluminum to the contact pin shown in Figure 10.

The contact pins were ultrasonically cleaned in trichloroethylene followed by an alcohol rinse. The aluminum strips were wiped with trichloroethylene before soldering. All solder joints were post cleaned with hot water followed by an alcohol rinse except for the 63Sn-37Pb which was spray cleaned with trichloroethylene. Flux 150 was used except on the 63Sn-37Pb where 4705010 rosin base flux was used.

Samples were manufactured for the tests and assigned numbers as in Table 2. Eight samples of each solder were produced for each test.

Figure 8. Photomicrograph of Flux Deposited Metallic Layer and Intergranular Penetration Into Aluminum

Figure 9. SEM of Flux Deposited Metallic Layer and Intergranular Penetration Into Aluminum

Figure 10. Contact Pin Used on Solder Samples

The initial samples were produced for reference in comparing environmental exposure versus non-exposure. The parameters specified for these environments were as follows:

- Humidity steady state (MIL-STD-202E, Method 103B) for consecutive periods of 24, 48, 96, 192, 384, and 768 hours, checking samples for corrosion at the end of each time step;
- Thermal shock (MIL-STD-202E, Method 107D, condition F-1); exposure time at each temperature level was a minimum of 30 minutes;
- High ambient temperature (MIL-STD-202E, Method 108A) at 150°C for 250 hours; and

Each sample was visually inspected at 10 to 30X and each joint's resistance was measured before and after environmental testing; two cross sections and six pull tests were made on the initial samples as well as on those environmentally tested.

Table 2. Solder Sample Identification

Solder	Initial	Humidity Steady State	Thermal Shock	High Ambient
80Pb-17Bi-2Ag-1Sn	A1-A8	A9-A16	A17-A24	A25-A32
63Sn-37Pb (91Sn-9Zn)	B1-B8	B9-B16	B17-B24	B25-B32
96Sn-4Ag	C1-C8	C9-C16	C17-C24	C25-C32
91Sn-9Zn	D1-D8	D9-D16	D17-D24	D25-D32
82.5Cd-17.5Zn	E1-E8	E9-E16	D17-E24	E25-E32

Test Results

Resistance Measurements

The resistance of the solder joints remained essentially constant before and after environmental testing (Table 3). No correlation between solder joint quality and its resistance was observed. The variations between pre- and post-environmental resistance measurements can be explained by inconsistent contact resistance.

Tensile Strength

Each of the samples listed in Table 4 was pull tested along an axis parallel to and along the center of the part length. Ten unsoldered aluminum strips were pulled and had an average tensile strength of 68.84 N.

All solder joints except the A Series failed after humidity testing and there were three failures in the E Series after temperature shock. The typical mode of failure is shown in Figure 11; the solder has separated from the aluminum in each case. The A Series had no joint failures and displayed a higher average tensile strength than any of the other samples exposed to the same environment (excluding initial).

Visual Examination

The samples were compared visually before and after environmental exposure (Figures 12 to 15). The samples are A, B, C, D, and E from left to right in these photographs. The quality of the

Table 3. Solder Joint Resistance Data

Milliohms			Milliohms		
Sample	Before	After	Sample	Before	After
A9	2.49	3.03	B9	3.00	2.59
A10	3.01	3.00	B10	3.03	2.59
A11	3.03	3.00	B11	3.05	2.99
A12	3.01	2.39	B12	3.03	3.00
A13	2.99	3.00	B13	3.03	3.00
A14	3.00	2.79	B14	3.05	3.00
A15	2.79	2.59	B15	2.69	3.00
A16	3.02	3.00	B16	2.79	2.59
A17	3.05	2.19	B17	2.99	3.00
A18	3.04	3.00	B18	3.03	2.39
A19	3.03	3.00	B19	3.03	2.39
A20	2.79	2.29	B20	3.39	2.39
A21	3.02	2.39	B21	3.07	2.39
A22	3.01	3.00	B22	3.07	2.39
A23	3.01	3.00	B23	2.79	2.19
A24	3.02	3.00	B24	3.03	3.00
A25	2.90	2.39	B25	2.79	2.39
A26	2.59	3.00	B26	2.99	2.39
A27	3.03	2.99	B27	3.00	2.59
A28	3.03	2.19	B28	3.00	2.05
A29	2.90	2.79	B29	3.03	2.19
A30	3.01	2.39	B30	3.00	2.59
A31	3.03	2.79	B31	3.05	3.00
A32	3.03	2.59	B32	3.03	3.00
C9	3.05	3.00	D9	3.05	2.79
C10	3.03	3.00	D10	3.03	2.59
C11	3.03	2.79	D11	3.05	3.00
C12	3.03	2.79	D12	3.00	3.99
C13	3.03	2.79	D13	3.03	2.59
C14	3.03	2.59	D14	3.03	2.59
C15	3.03	3.00	D15	3.01	2.39
C16	3.19	3.00	D16	3.03	3.00
C17	3.03	2.19	D17	2.99	2.19
C18	3.03	2.39	D18	3.03	2.39
C19	2.39	2.59	D19	3.03	3.00
C20	2.39	2.39	D20	3.03	2.19
C21	2.39	2.01	D21	2.79	2.19
C22	3.00	2.39	D22	3.03	2.19
C23	3.01	2.39	D23	3.03	2.39

Table 3 Continued. Solder Joint Resistance Data

Milliohms			Milliohms		
Sample	Before	After	Sample	Before	After
C24	2.59	2.29	D24	3.03	3.00
C25	2.99	2.39	D25	2.79	2.39
C26	3.05	2.39	D26	2.59	2.19
C27	3.05	2.19	D27	3.03	3.00
C28	3.07	2.39	D28	2.59	2.39
C29	2.99	2.19	D29	2.39	2.19
C30	3.09	2.19	D30	2.59	2.39
C31	3.05	2.39	D31	2.39	2.19
C32	3.19	2.39	D32	2.39	2.39
E9	3.00		E24	3.03	
E10	3.03		E25	2.79	
E11	3.05		E26	2.79	
E12	3.05		E27	3.03	
E13	3.03		E28	2.39	
E14	3.05		E29	2.59	
E15	3.03		E30	2.39	
E16	3.19		E31	2.39	
E17	3.01		E32	2.39	
E18	3.03				
E19	3.03				
E20	3.05				
E21	3.05				
E22	3.05				
E23	3.03				

solder joints before testing as determined by visual inspection for voids, good contact angle with the aluminum, and the amount of solder flow into the contact slot was, from best to worst, B, E, A, C, and D.

After exposure to high humidity (Figure 13), Sample A developed a layer of white crystals on the solder surface. This material was identified by X-ray diffraction analysis as lead carbonate hydroxide $Pb_3(CO_3)_2(OH)_2$. A few scattered blisters were found on Samples D and E; however, Sample B displayed severe blistering on each part. The problem is probably a result of hydrogen gas given off during the corrosion reaction at the solder aluminum interface.

Table 4. Tensile Strength Data

Initial Testing		Humidity Testing	
Sample	Strength (Newtons)	Sample	Strength (Newtons)
A1	48.05	A9	64.53
A2	52.47	A10	51.58
A3	44.91	A11	54.72
A4	50.31	A12	48.94
A5	52.47	A13	42.66
A8	41.38	A14	56.49
Standard			
Deviation	4.41		7.35
Average	48.25		53.15
B1	53.35	B9*	53.84
B2	52.47	B10*	39.13
B3	55.11	B11*	45.80
B4	59.62	B12*	37.85
B5	50.31	B13*	43.64
B6	47.56	B14*	50.31
Standard			
Deviation	4.12		6.28
Average	53.05		45.11
C1	49.82	C9*	37.85
C2	49.33	C10*	34.23
C3	44.03	C11	41.37
C4	50.70	C12*	37.85
C5	45.40	C13*	38.25
C6	50.70	C14*	33.34
Standard			
Deviation	2.84		2.89
Average	48.35		37.14
D1	47.56	D9*	35.14
D2	53.35	D10*	49.37
D3	49.33	D11*	40.48
D4	50.70	D12*	49.82
D5	53.35	D14*	40.92
D6	50.70	D15*	41.37
Standard			
Deviation	2.26		5.69
Average	50.90		42.85

Table 4 Continued. Tensile Strength Data

Initial Testing		Humidity Testing	
Sample	Strength (Newtons)	Sample	Strength (Newtons)
E1	47.56	E9*	43.64
E2	36.87	E10*	38.74
E3	48.44	E11*	34.72
E4	45.40	E13*	38.74
E6	42.66	E14*	39.13
E7	40.01	E15*	36.48
Standard			
Deviation	4.51		3.04
Average	43.54		38.54
T-Shock Testing		High Ambient Testing	
Sample	Strength (Newtons)	Sample	Strength (Newtons)
A17	56.98	A25	46.68
A18	35.60	A26	54.72
A19	62.27	A27	59.13
A20	48.94	A28	42.66
A21	63.15	A29	60.90
A22	58.25	A30	55.60
Standard			
Deviation	10.40		7.16
Average	54.13		53.35
B17	45.40	B15	47.56
B18	49.82	B26	48.94
B19	47.17	B27	47.56
B20	47.56	B28	44.03
B21	52.07	B29	49.82
B22	46.68	B30	51.58
Standard			
Deviation	2.35		2.55
Average	48.15		48.25

Table 4 Continued. Tensile Strength Data

T-Shock Testing		High Ambient Testing	
Sample	Strength (Newtons)	Sample	Strength (Newtons)
C17	38.74	C25	48.05
C18	52.47	C26	46.29
C19	58.74	C27	47.17
C20	47.17	C28	49.33
C21	39.62	C29	46.68
C22	41.38	C30	49.33
Standard			
Deviation	8.04		1.37
Average	46.39		47.86
D17	50.70	D25	44.03
D18	48.44	D26	46.68
D19	49.82	D27	52.07
D20	52.96	D28	53.35
D21	48.05	D29	48.05
D22	46.29	D30	45.80
Standard			
Deviation	2.35		3.63
Average	49.33		48.35
E17*	22.24	E25	42.66
E18	50.26	E26	24.42
E19*	19.13	E28	34.23
E20	32.47	E30	37.36
E21*	28.02	E31	35.99
E24	55.60	E32	39.13
Standard			
Deviation	14.99		6.18
Average	34.61		35.70

*Indicates solder joint failed

All samples except E looked satisfactory after T-Shock and high ambient testing. In a few samples of this alloy, the solder was beginning to separate and lift from the aluminum. Sample C had the fewest external defects after environmental testing but only the A samples were able to maintain satisfactory tensile strength after exposure to high humidity. Visual examination alone cannot be relied upon in selecting an acceptable aluminum solder joint.

SAMPLE C9 AFTER HUMIDITY EXPOSURE

SAMPLE E17 AFTER THERMAL SHOCK TESTING

Figure 11. Typical Tensile Test Failures

Metallurgical Analysis

80Pb-17Bi-2Ag-1Sn Plus 150 Flux. In the initial state (Figure 16), the solder displayed no problems with the aluminum solder bond. The samples exposed to high humidity (Figure 17) developed corrosion of both the solder and aluminum. The aluminum corroded along the solder aluminum interface. The T-shock samples (Figure 18) disclosed cracking of the solder along grain boundaries. A gold-aluminum intermetallic, identified by SEM analysis, was found at the aluminum-solder interface in the samples exposed to high ambient temperature (Figure 19). The gold plating from the sample pin is going into solution in the solder during the soldering operation and alloying with the aluminum during the high ambient exposure.

63Sn-37Pb Soldered With Rosin Flux to Aluminum 91Sn-9Zn. A sample of this alloy which was not environmentally tested is shown in Figure 20. Good solder flow is evident but the solder bond is questionable because of microcracks at various places along the solder aluminum interface. The result of this poor bond is evident in Figures 21 and 22 which are cross sections of a sample after humidity exposure. Figure 21 shows a solder bubble and the corrosion of the aluminum underneath. An external view of this phenomena was shown in Figure 13. It was found only in those solders displaying a questionable bond to the aluminum. The poor initial bond allowed moisture to penetrate the aluminum solder

Figure 12. Initial Solder Samples

Figure 13. Solder Samples Exposed to Humidity

Figure 14. Solder Samples Exposed to Thermal Shock

Figure 15. Solder Samples Exposed to High Ambient Temperature

500X

Figure 16. Sample A6 (80Pb-17Bi-2Ag-1Sn)
Initial

500X

Figure 17. Sample A15 (80Pb-17Bi-2Ag-1Sn)
After Humidity Exposure

Figure 18. Sample A24 (80Pb-17Bi-2Ag-1Sn)
After Thermal Shock

Figure 19. Sample A31 (80Pb-17Bi-2Ag-1Sn)
After High Ambient Temperature

236X

Figure 20. Sample B8 (63Sn-37Pb) Initial

236X

Figure 21. Sample B16 (63Sn-37Pb) Bubbling After Humidity Exposure

interface and the products of the resulting corrosion reaction then sealed off the potential escape path for any gas produced during the process.

The line parallel to and a short distance from the aluminum conductor in Figures 23 through 25 is probably caused by the alloying of the two solders and is possibly an intermetallic formation. The line is more pronounced after high ambient exposure (Figures 24 and 25). The growth of the lead-rich areas (dark regions) is normal after exposure to elevated temperatures.

The advantage of being able to solder this alloy without using an aluminum soldering flux is offset by its poor bonding ability to aluminum and the unknown alloying effects between the two solders.

96Sn-4Ag Plus 150 Flux. The as-soldered sample in Figure 26 shows no metallurgical problems and good solder bond to the aluminum conductor. Intermetallic layers have formed along the aluminum solder interface after each of the three environmental tests (Figures 27, 28, and 30). These intermetallic formations were previously discussed and are very evident here. Note the cracking of the solder as a result of T-shock and high ambient exposure (Figures 29 and 30).

This solder is metallurgically unsound for use in the test environments it was exposed to because of the intermetallic formations and solder cracking.

91Sn-9Zn Plus 150 Flux. The solder-aluminum interface separation of an initial solder sample (Figure 31) shows an example of the poor metallurgical bond which often occurs in this alloy.

The result of this solder's exposure to high humidity conditions is the solder separation and grain boundary corrosion evident in Figure 32.

The alloy held up well to thermal shock and high ambient tests (Figures 33 and 34). The growth of zinc-rich (dark) areas (Figure 34), is normal at elevated temperatures. These areas, however, appear to be aligning themselves into a dendritic structure as was observed in Figure 3. The significant disadvantage of this alloy is its inconsistency in making a good metallurgical bond with the aluminum. This was found to be true both with ultrasonic and iron soldering techniques.

82.5Cd-17.5Zn Plus 150 Flux. Solder separation from the aluminum was evident in the initial samples of this alloy (Figure 35).

236X

Figure 22. Sample B16 (63Sn-37Pb) Poor Bonding After Humidity Exposure

236X

Figure 23. Sample B24 (63Sn-37Pb) After Thermal Shock

236X

Figure 24. Sample B31 (63Sn-37Pb) After
High Ambient Temperature

462X

Figure 25. Sample B31 (63Sn-37Pb) After
High Ambient Temperature

236X

Figure 26. Sample C7 (96Sn-4Ag) Initial

236X

Figure 27. Sample C16 (96Sn-4Ag) After
Humidity Exposure

462X

Figure 28. Sample C23 (96Sn-4Ag) Intermetallic Formations After Thermal Shock

462X

Figure 29. Sample C23 (96Sn-4Ag) Cracking After Thermal Shock

462X

Figure 30. Sample C31 (96Sn-4Ag) After
High Ambient Temperature

236X

Figure 31. Sample D8 (91Sn-9Zn) Initial

236X

Figure 32. Sample D13 (91Sn-9Zn) After Humidity Exposure

462X

Figure 33. Sample D23 (91Sn-9Zn) After Thermal Shock

236X

Figure 34. Sample D32 (91Sn-9Zn) After
High Ambient Temperature

236X

Figure 35. Sample E8 (82.5Cd-17.5Zn) Initial

Intergranular penetration was found in samples after humidity and after high ambient exposure (Figures 36 and 39). The problem is typical of this alloy and is probably not a direct result of these environments.

Note the aluminum corrosion and solder separation (Figure 36). Three samples (50 percent) failed tensile testing after T-shock exposure, and the reason is evident in Figure 37. Severe solder-aluminum separation is responsible. Some solder separation was noted in the samples exposed to high ambient tests (Figure 38). The isolated dark areas are rich in zinc.

This solder is easy to use and wets and flows on the aluminum well. But metallurgical data indicates this solder to be a poor choice, especially if used on thin foils in which intergranular penetration is a serious threat to joint integrity.

Flux Detection

A method was developed which is applicable for use on the production line to monitor the removal of aluminum soldering flux. The procedure involved rinsing the area containing the flux sequentially with distilled water in 200 milliliter allotments and then measuring the conductivity of the rinse solutions and comparing it with fresh distilled water.

An experiment was conducted by heating four rectangles of 1100 aluminum 38.10 by 25.4 by 3.18 mm (1.5 by 1 by 0.125 in.) to 260°C and applying varying amounts of flux to each piece. The flux was baked on the metal for 1 minute and then allowed to cool. The data in Table 5 indicates the decrease in conductivity of the rinse water as the sample becomes cleaner and shows that after the third rinse it approaches that of clean distilled water. The samples were found visually clean after the third rinse.

This test is an indirect test only and will give only an indication of the water soluble ions in the rinse water. The water must have access to the flux residue and the residue must be water soluble. Fortunately, that portion of the residue which is not water soluble is not normally corrosive.

ACCOMPLISHMENTS

Wetability data, spread factor and dihedral angle information was collected on nine solder alloys with 80Pb-17Bi-2Ag-1Sn, 96Sn-4Ag, 91Sn-9Zn, and 82.5Cd-17.5Zn selected for further evaluation. Metallurgical evaluation of the solderability samples revealed 80Pb-17Bi-2Ag-1Sn to be superior.

236X

Figure 36. Sample E12 (82.5Cd-17.5Zn) After Humidity Exposure

236X

Figure 37. Sample E23 (82.5Cd-17.5Zn) After Thermal Shock

236X

Figure 38. Sample E29 (82.5Cd-17.5Zn) Solder
Separation After High Ambient Temperature

462X

Figure 39. Sample E29 (82.5Cd-17.5Zn) Intergranular
Penetration After High Ambient Temperature

Table 5. Conductivity Test Data

Sample	Weight of Flux Residue (mg)*	Conductivity (in Micromhos)			
		First Rinse	Second Rinse	Third Rinse	Distilled Water
1	19.6	47.1	3.18	3.09	3.12
2	37.5	66.1	5.74	3.32	3.26
3	46.7	94.5	3.31	3.10	3.11
4	66.2	112.0	3.38	3.30	3.28

*Indicates the weight of the flux remaining on the aluminum sample after heating for 1 minute.

The flux used in soldering aluminum deposits a layer of tin and zinc or compounds of these elements on the aluminum surface. Metallurgical examination revealed this layer to be intergranularly penetrating the aluminum up to 0.009 mm (350 μ in.). This could have a detrimental effect on thin aluminum conductors.

Environmental testing of five solders,

- 80Pb-17Bi-2Ag-1Sn,
- 63Sn-37Pb on 91Sn-9Zn,
- 96Sn-4Ag,
- 91Sn-9Zn, and
- 82.5Cd-17.5Zn,

was conducted and the results evaluated by resistance, tensile, visual, and metallurgical tests.

No information pertaining to solder joint quality was obtained by comparing solder joint resistance before and after environmental testing. Tensile test failures occurred after high humidity and T-shock exposure. Only the 80Pb-17Bi-2Ag-1Sn solder passed tensile testing after humidity exposure and only the 82.5Cd-17.5Zn solder failed after T-shock exposure. Visual defects were found in some of the solders after high humidity and T-shock exposure. The high humidity environment was the most severe on the solder joints, causing lead carbonate hydroxide to form on the 80Pb-17Bi-2Ag-1Sn solder, deteriorating it. Blistering occurred in all the

other solders except the 96Sn-4Ag. The only solder to indicate visual damage after T-shock was the 82.5Cd-17.5Zn which showed the solder separating from the aluminum.

Metallurgical evaluation after environmental testing revealed some problems with all solders. The most severe defect, specifically solder separation from the aluminum caused by corrosion of the solder aluminum interface, occurred primarily after humidity exposure. Internal cracking along grain boundaries, and the presence of intermetallics at the interface, was noted after T-shock and high ambient exposure.

The 80Pb-17Bi-2Ag-1Sn solder is considered to be the best of those studied on the basis of the information gathered. However, it still cannot be considered reliable over long periods of time in the environments to which it was exposed. It could easily be used to make short term electrical connections to aluminum when other means are not feasible or economical.

A method was developed to detect the presence of water soluble flux residue in a production part. The test involves measuring the conductivity of distilled water used to rinse the part and comparing that result with the conductivity of fresh distilled water.

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