Superior Flux & Mfg. Co.

Soldering Aluminum

William F. Avery and Philip A. Baskin

Superior Flux and Mfg. Co

Cleveland, OH, USA

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Abstract

Superior Flux manufactures fluxes for solder bonding solutions to diverse metals, including aluminum. Utilizing a Meniscograph Solderability Tester, the solderability of various aluminum base alloys (1145, 1350, 3003, and 6061) with different lead-free solders (conventional aluminum solder 91Sn/9Zn; 96.5Sn/3.5Ag, 96.5Sn/3.0Ag/0.5Cu SAC305 solder and Sn100C electronics solders) and a number of aluminum flux formulations were evaluated to provide an overall view of soldering efficiency. The conclusions from the tests point to the best system to employ when solder coating and tin dipping aluminum for the objective of improving aluminum alloy conventional surface solderability.

Introduction

The ability of metals to be soldered can be accurately measured by the wetting balance solderability test. In this test, the soldering conditions of the process are matched as closely as possible to compare the variables in soldering (metal, solder, and flux) to measure performance differences. The wetting balance results are most useful for evaluating how much solder wetting will occur (a measure of the quality of solder flow).

In this qualitative evaluation, the common chloride-free organic based flux for soldering aluminum, Superior 1260, a traditional "yellow" or "honey" flux used for aluminum soldering based upon the design of the Alcoa #64 chloride-free basic organic flux, is compared to variations of this flux designed to optimize its performance. The variations used additives that empirically have been found to apparently improve the performance of the 1260 flux in the lab. One of the main considerations was to reduce the overall thickness of the 1260 flux which creates handling and dispensing problems for customers. Along those lines of concern, a dispensable flux paste variation of the 1260 has been created to ease the concerns about flux application. This form of flux was also included in this study.

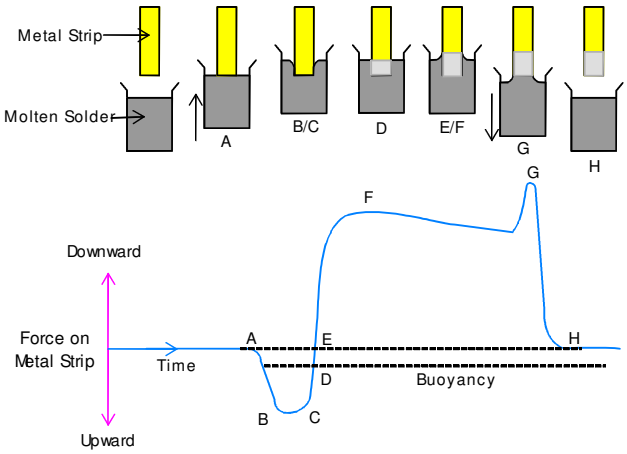
Since various aluminum alloys have widely varying degrees of solderability[1], a number of aluminum alloys that are commonly used in applications that would possibly need a soldered connection were evaluated. Aluminum alloy 1145 was used since it is very similar to construction materials used for heat sinks. 1350 aluminum was used because of its popularity as a replacement for copper in electrical wire. For many aluminum constructions, a popular alloy is 3003 aluminum. Finally, the 6061 aluminum is commonly used because of its excellent extrusion and machining properties.

In terms of what solder to use, a diverse sampling of lead-free solder alloys were used based on the common solders used for soldering aluminum while also considering what popular lead-free solders are seen in the market today. The most often suggested alloy for aluminum alloy soldering is 91/9 tin-zinc which is suggested because of the excellent intermetallic bond it creates with aluminum. Another common alloy suggested for aluminum is 96.5/3.5 tin-silver which also creates a good intermetallic bond with aluminum[2]. In the electronics industry, two other solder alloys are seen as popular lead-free replacements, SAC305, which is 96.5/3.0/0.5 tin-silver-copper, and Nihon Superior's SN100C which is a tin-copper solder with small additions of nickel and germanium.

SOLDERABILITY TESTER

The solderability tester measures the interfacial force between molten solder and the specimen being soldered, in essence, measuring the ability of the solder to flow on a surface. A common definition of solderability is "the ability of a metal to be wetted by molten solder"[3]. The solderability test is unique in that it permits the simultaneous evaluation of base metal, solder, and flux to determine the effect of these factors in the soldering process. Two of the factors are held constant while the third is the variable.

In the test, a fluxed metal strip specimen is held above the molten solder and connected to a load cell. The solder pot is raised to immerse the specimen to a preset depth below the solder for a set period of time. The load cell measures the weight change as solder draws up the test specimen. The weight difference is converted to wetting force by an on-line computer analysis. The solder pot then is lowered at the end of the immersion cycle, pulling the specimen out of the solder. To evaluate the results, the height of the curve within the immersion time of the solderability test dip is measured in terms of wetting force. The wetting force is a measure of the extent of solder flow. Greater solder flow will result in better soldering.



SOLDERABILITY TEST MATERIAL

- **Fluxes:**
  - *Superior 1260:* Traditional "yellow" or "honey" flux used for aluminum soldering based upon the design of the Alcoa #64 chloride-free basic organic flux
  - *Superior 1260A:* Variation of the 1260 flux with an performance enhancing additive
  - *Superior 1260B:* Variation of the 1260 flux with water added to reduce viscosity
  - *Superior 1260C:* Variation of the 1260 flux with water and another performance enhancing additive.
  - *Superior 1260D:* The 1260 flux put into a dispensable flux paste form.
  - *Superior 1260E:* Variation of the 1260 flux with all of the performance enchantments (versions A,B,C) above.

- **Lead-Free Solders:**
  - *91/9 Tin-Zinc:* Zinc bearing solder which is prone to corrosion, usually recommended for soldering aluminum4. Eutectic alloy melting point (m.p.) 199°C.
  - *96.5/3.5 Tin-Silver:* One of the oldest and most reliable lead-free alloys with a long history of soldering electrical connections. Eutectic alloy m.p. 221°C.
  - *Nihon Superior SN100C*: A modification of 99.3/0.7 Tin-Copper with trace amounts of nickel and germanium for electronics. Eutectic alloy m.p. 227°C.
  - SAC 305 Popular 96.5/3.0/0.5 Tin-Silver-Copper solder for electronics. Melting point 218-220°C.

- **Aluminum Base Metals:**
  - *1145 Aluminum:* Highly solderable aluminum alloy used in making soldered parts like heat sink fins.
  - *1350 Aluminum:* Alloy with particular electrical passing properties, widely used for electrical wire.
  - *3003 Aluminum:* Manganese-containing aluminum used for general sheet metal, drawn parts, and chem. storage.
  - *6061Aluminum:* Low cost aluminum alloy with excellent extrusion and machining properties.

SOLDERABILITY EQUIPMENT

- 50 ml beakers
- Meniscograph Solderability Tester
- Bascom-Turner Model 4120T Digital Chart Recorder / Computer

SOLDERABILITY TEST PROCEDURE [5]

1. Stabilize the solderability tester pot at the desired temperature to within ± 1°C. Use the following parameters for the solderability tester:
   - Pot Temperature : 280°C
   - Immersion Speed : 20 mm/sec
   - Immersion Depth : 2 mm
   - Immersion Time : 5 seconds
2. Attach the test part to solderability tester holder. Dip test part in the flux for 5 seconds.
3. Put the holder on the solderability tester's load cell connection above the molten solder. Wipe the solder surface clean of any dross. Activate the solderability tester and observe the dipped sample and the curve created by the chart recorder. Save the curve to the chart recorder disk drive.
4. Repeat steps 2-3 five times.
5. Change flux to be used then repeat steps 2-4.
6. Do the same procedure (2-4) with the aluminum alloy as the changing variable.
7. Do the same procedure (1-6) with the solder alloy as the changing variable.
8. Transfer the data to the computer to get numeric and graphic information.

SOLDERABILITY TEST TERMS

Time to Cross Axis (TCA) - Time, in seconds, needed to achieve positive solder wetting. This is the measure of how fast the solder will start to spread on a surface. This is used to predict how long a given soldering system will take to begin to solder. Factors such as the mass of the material can affect this value (caused by the delay to heat up the mass); therefore the best values are obtained when thin material is used.

Solder Wetting (in µN/mm) at given Times - Wetting force expressed in micronewtons / millimeter (µN/mm) at the time indicated in the solderability curve. This is a measurement of the wetting at different times to get a numerical expression as to how fast soldering is occurring at different stages of the soldering.

Maximum Wetting (MW) - Maximum force; expressed in micronewtons/millimeter (µN/mm), in the positive solder wetting region of the solderability curve. This is a measure of how far the solder will spread on a surface. Traditionally, the maximum wetting was viewed as the expression of how well soldering occurred. However, using the maximum wetting without understanding how long it takes to get maximum wetting can distort the truth as to how efficient a soldering system might be.

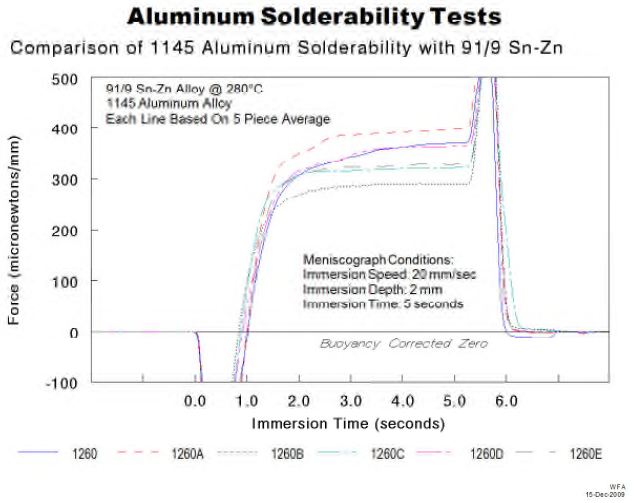
Integrated Area under the Curve (IA) – This is the area between the curve and the x-axis during the entire immersion cycle. The area is recorded in units of micronewtons/millimeter-seconds (µN/mm-sec). This is a measure, which combines the effects of both maximum wetting and time to cross axis to give a single performance value. This measurement was developed to get a more complete image (beyond just maximum wetting) as to what was going on during the soldering reaction. The integrated area under the curve serves as a work function, the higher the value the more positive "work" has gone into promoting soldering.

SOLDERABILITY RESULTS

In presenting these results, the flux is the variable in the test while the solder used and the aluminum alloy are held as constants.

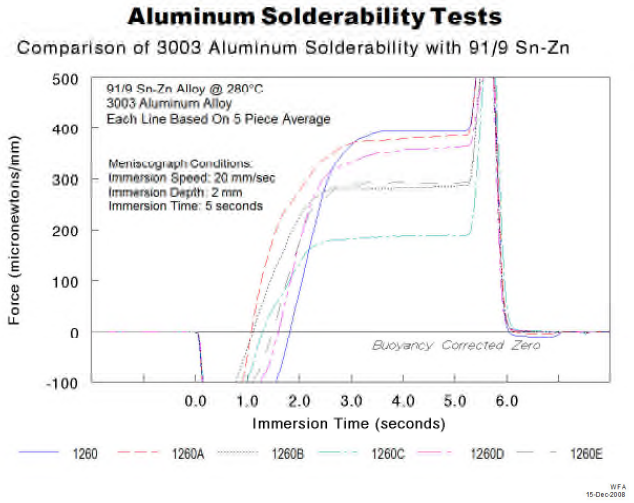
91/9 Sn-Zn Solder @ 280°C, 1145 Aluminum Alloy

Solder Wetting (in µN/mm) at given Times									
Flux	**TCA**	**0.70s**	**1.00s**	**2.00s**	**3.00s**	**4.00s**	**5.00s**	**MW**	**IA**
1260	1.02	-210	-11	307	344	362	371	371	1092
1260A	1.02	-230	-8	349	386	392	397	397	1238
1260B	0.84	-115	96	270	286	289	289	290	958
1260C	0.88	-156	84	307	315	319	321	321	1067
1260D	0.92	-157	48	314	346	362	364	364	1138
1260E	1.00	-220	0	305	323	326	327	328	1026



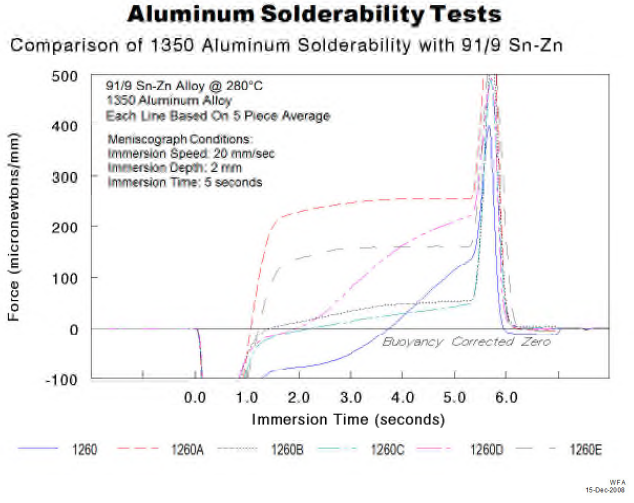
91/9 Sn-Zn Solder @ 280°C, 3003 Aluminum Alloy

Solder Wetting (in µN/mm) at given Times									
Flux	**TCA**	**0.70s**	**1.00s**	**2.00s**	**3.00s**	**4.00s**	**5.00s**	**MW**	**IA**
1260	1.82	-181	-153	78	367	394	394	394	788
1260A	1.08	-210	-47	277	370	379	385	385	1085
1260B	1.10	-127	-33	225	283	283	286	286	802
1260C	1.30	-169	-95	133	182	188	189	189	420
1260D	1.60	-218	-133	175	331	357	363	363	804
1260E	1.50	-209	-115	175	290	293	292	293	682



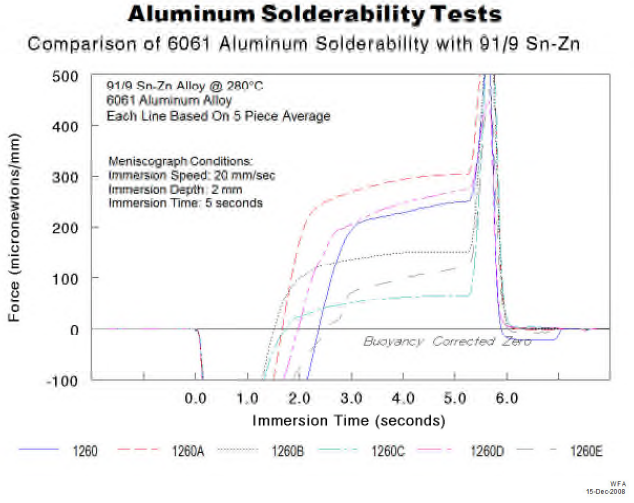
91/9 Sn-Zn Solder @ 280°C, 1350 Aluminum Alloy

Solder Wetting (in µN/mm) at given Times									
Flux	**TCA**	**0.70s**	**1.00s**	**2.00s**	**3.00s**	**4.00s**	**5.00s**	**MW**	**IA**
1260	3.74	-231	-162	-77	-50	23	113	113	-302
1260A	1.08	-227	-52	228	246	253	253	254	725
1260B	1.48	-191	-54	12	33	46	51	51	-54
1260C	2.24	-216	-82	-4	12	28	41	41	-138
1260D	1.96	-179	-57	2	80	163	210	210	173
1260E	1.24	-232	-103	138	158	161	161	162	354



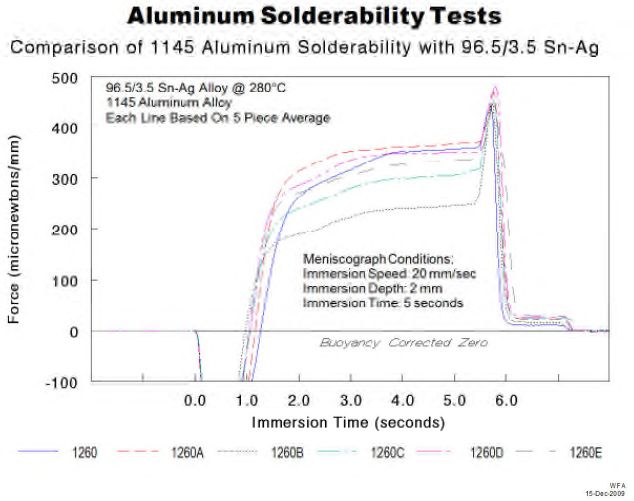
91/9 Sn-Zn Solder @ 280°C, 6061 Aluminum Alloy

Solder Wetting (in µN/mm) at given Times									
Flux	**TCA**	**0.70s**	**1.00s**	**2.00s**	**3.00s**	**4.00s**	**5.00s**	**MW**	**IA**
1260	2.38	-233	-233	-164	193	228	248	248	73
1260A	1.68	-233	-233	171	269	294	303	304	546
1260B	1.52	-233	-210	99	137	150	150	151	193
1260C	1.74	-233	-213	23	50	62	66	66	-100
1260D	1.98	-233	-233	9	204	246	271	271	282
1260E	2.52	-233	-233	-77	71	99	118	118	-178



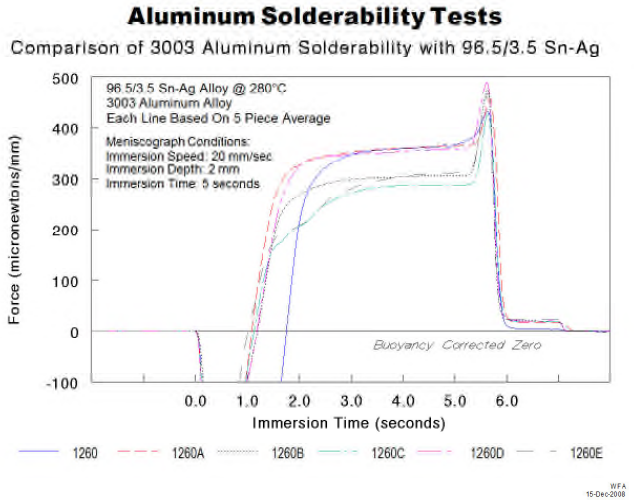
96.5/3.5 Sn-Ag Solder @ 280°C, 1145 Aluminum Alloy

Solder Wetting (in µN/mm) at given Times									
Flux	**TCA**	**0.70s**	**1.00s**	**2.00s**	**3.00s**	**4.00s**	**5.00s**	**MW**	**IA**
1260	1.26	-217	-146	263	316	350	357	357	903
1260A	1.16	-233	-126	314	353	361	368	368	1043
1260B	0.98	-198	16	189	223	238	245	245	670
1260C	1.06	-210	-39	240	281	299	305	305	850
1260D	1.06	-225	-45	286	336	348	351	351	1028
1260E	1.04	-229	-34	271	306	325	336	336	948



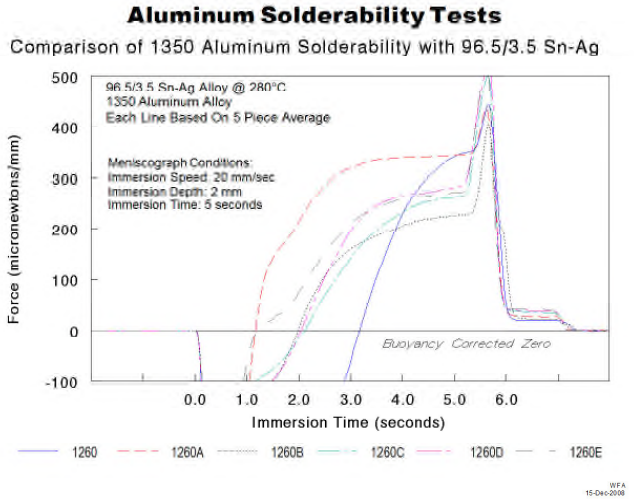
96.5/3.5 Sn-Ag Solder @ 280°C, 3003 Aluminum Alloy

Solder Wetting (in µN/mm) at given Times									
Flux	**TCA**	**0.70s**	**1.00s**	**2.00s**	**3.00s**	**4.00s**	**5.00s**	**MW**	**IA**
1260	1.76	-233	-233	214	348	359	367	367	711
1260A	1.08	-233	-69	326	353	360	365	365	1084
1260B	1.18	-218	-100	268	299	303	306	306	858
1260C	1.12	-232	-78	206	272	286	288	288	751
1260D	1.18	-210	-94	325	349	353	358	358	1032
1260E	1.02	-206	-7	208	281	302	311	311	832



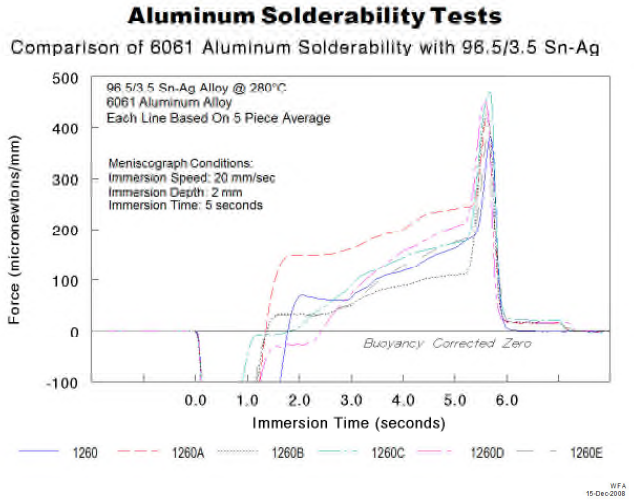
96.5/3.5 Sn-Ag Solder @ 280°C, 1350 Aluminum Alloy

Solder Wetting (in µN/mm) at given Times									
Flux	**TCA**	**0.70s**	**1.00s**	**2.00s**	**3.00s**	**4.00s**	**5.00s**	**MW**	**IA**
1260	3.18	-233	-233	-233	-60	228	342	342	-216
1260A	1.16	-233	-137	214	319	339	344	344	867
1260B	1.98	-233	-184	5	161	206	226	226	209
1260C	2.12	-233	-140	-17	143	232	262	262	249
1260D	2.04	-233	-145	-9	196	259	278	278	327
1260E	.22	-232	-63	75	209	257	271	271	496



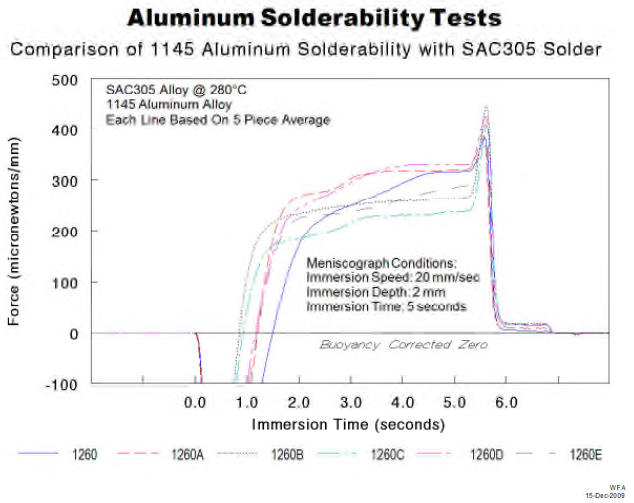
96.5/3.5 Sn-Ag Solder @ 280°C, 6061 Aluminum Alloy

Solder Wetting (in µN/mm) at given Times									
Flux	**TCA**	**0.70s**	**1.00s**	**2.00s**	**3.00s**	**4.00s**	**5.00s**	**MW**	**IA**
1260	1.78	-233	-233	69	66	118	163	163	-33
1260A	1.36	-233	-231	149	162	200	240	240	383
1260B	1.38	-233	-213	33	51	89	110	110	-13
1260C	1.36	-229	-48	8	90	144	172	172	147
1260D	1.78	-233	-215	-28	73	156	205	205	42
1260E	1.38	-233	-191	32	54	128	174	174	69



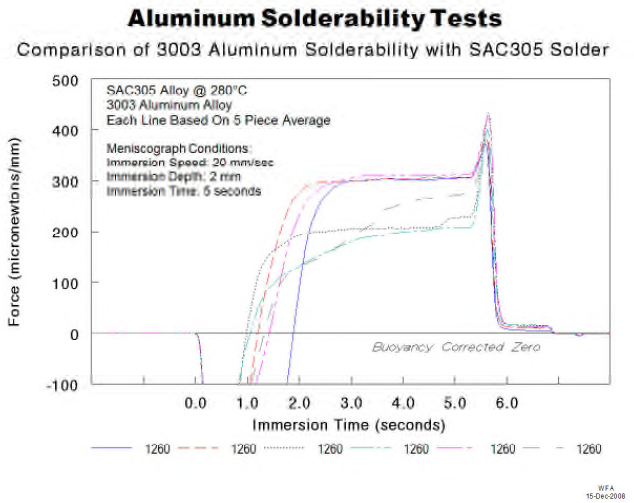
SAC305 Sn-Ag-Cu Solder @ 280°C, 1145 Aluminum Alloy

Solder Wetting (in µN/mm) at given Times									
Flux	**TCA**	**0.70s**	**1.00s**	**2.00s**	**3.00s**	**4.00s**	**5.00s**	**MW**	**IA**
1260	1.50	-209	-205	172	249	294	316	316	614
1260A	1.20	-209	-160	268	302	317	319	319	865
1260B	0.86	-157	108	233	250	258	264	264	844
1260C	0.92	-173	44	185	216	231	238	238	677
1260D	1.16	-209	-99	244	294	327	330	331	872
1260E	1.20	-209	-127	225	237	262	285	285	689



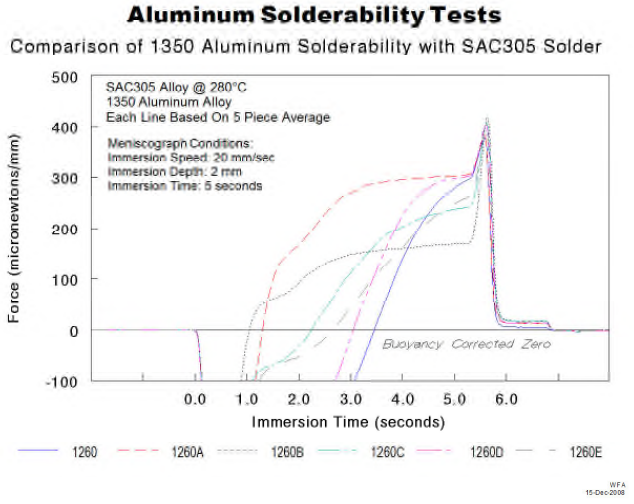
SAC305 Sn-Ag-Cu Solder @ 280°C, 3003 Aluminum Alloy

Solder Wetting (in µN/mm) at given Times									
Flux	**TCA**	**0.70s**	**1.00s**	**2.00s**	**3.00s**	**4.00s**	**5.00s**	**MW**	**IA**
1260	1.88	-209	-209	91	300	302	304	304	524
1260A	1.20	-209	-128	277	300	304	306	306	857
1260B	0.98	-207	10	191	205	207	227	227	615
1260C	1.06	-171	-19	132	179	199	208	208	493
1260D	1.42	-206	-130	232	305	309	312	312	781
1260E	1.34	-209	-138	132	189	255	272	272	511



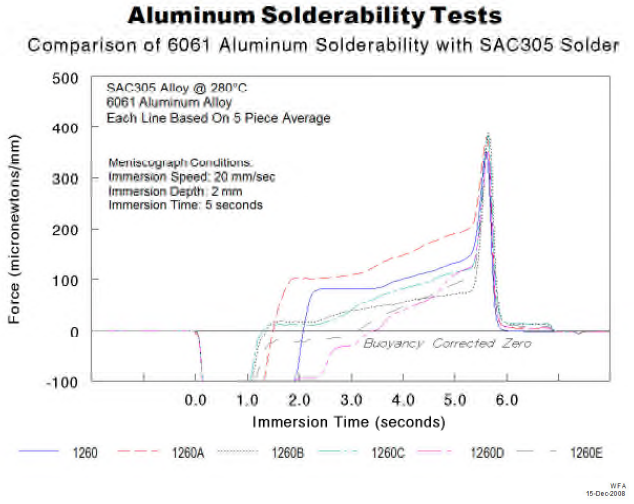
SAC305 Sn-Ag-Cu Solder @ 280°C, 1350 Aluminum Alloy

Solder Wetting (in µN/mm) at given Times									
Flux	**TCA**	**0.70s**	**1.00s**	**2.00s**	**3.00s**	**4.00s**	**5.00s**	**MW**	**IA**
1260	3.46	-209	-209	-209	-114	139	278	278	-335
1260A	1.30	-209	-180	167	270	295	303	303	682
1260B	1.04	-209	-21	92	148	160	169	169	345
1260C	2.24	-209	-126	-31	112	203	237	237	187
1260D	3.06	-209	-205	-177	-15	225	297	297	-106
1260E	2.66	-209	-190	-53	44	161	247	247	39



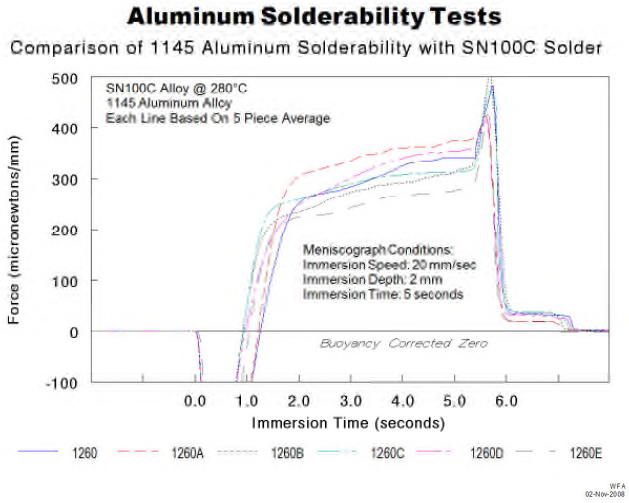
SAC305 Sn-Ag-Cu Solder @ 280°C, 6061 Aluminum Alloy

Solder Wetting (in µN/mm) at given Times									
Flux	**TCA**	**0.70s**	**1.00s**	**2.00s**	**3.00s**	**4.00s**	**5.00s**	**MW**	**IA**
1260	2.08	-209	-209	-53	81	100	133	133	-97
1260A	1.50	-209	-209	101	108	148	190	190	193
1260B	1.36	-209	-160	17	39	55	72	72	-54
1260C	1.30	-209	-133	11	40	82	114	114	-3
1260D	2.20	-209	-200	-96	-30	38	109	109	-325
1260E	1.58	-209	-178	-22	-8	47	91	91	-155



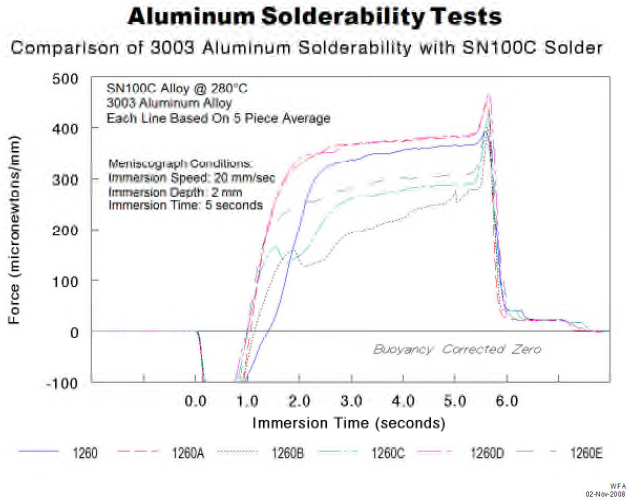
SN100C Solder @ 280°C, 1145 Aluminum Alloy

Solder Wetting (in µN/mm) at given Times									
Flux	**TCA**	**0.70s**	**1.00s**	**2.00s**	**3.00s**	**4.00s**	**5.00s**	**MW**	**IA**
1260	1.26	-230	-149	251	284	325	343	343	813
1260A	1.22	-230	-157	304	336	360	374	374	982
1260B	0.92	-172	49	234	274	292	313	313	886
1260C	0.94	-176	49	259	290	307	313	313	951
1260D	0.98	-163	13	248	301	341	354	354	967
1260E	1.04	-204	-33	224	242	268	277	277	766



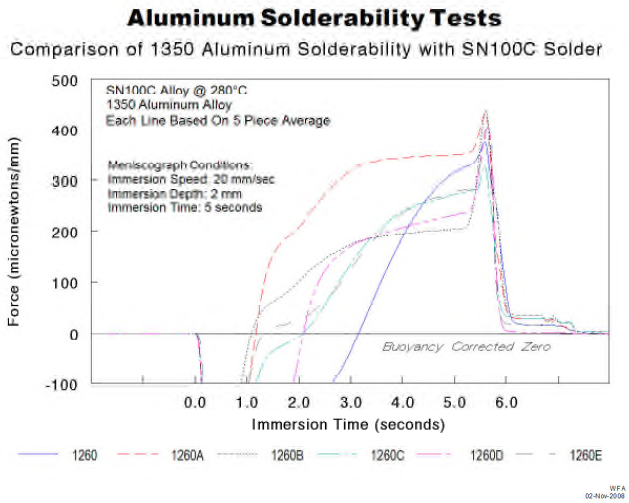
SN100C Solder @ 280°C, 3003 Aluminum Alloy

Solder Wetting (in µN/mm) at given Times									
Flux	**TCA**	**0.70s**	**1.00s**	**2.00s**	**3.00s**	**4.00s**	**5.00s**	**MW**	**IA**
1260	1.40	-143	-88	205	338	352	365	365	933
1260A	1.06	-199	-42	327	367	374	380	380	1153
1260B	1.14	-151	-59	141	192	216	250	250	562
1260C	1.02	-124	-3	148	260	274	287	287	786
1260D	1.00	-127	4	340	367	374	383	383	1189
1260E	1.00	-204	5	248	281	298	305	305	889



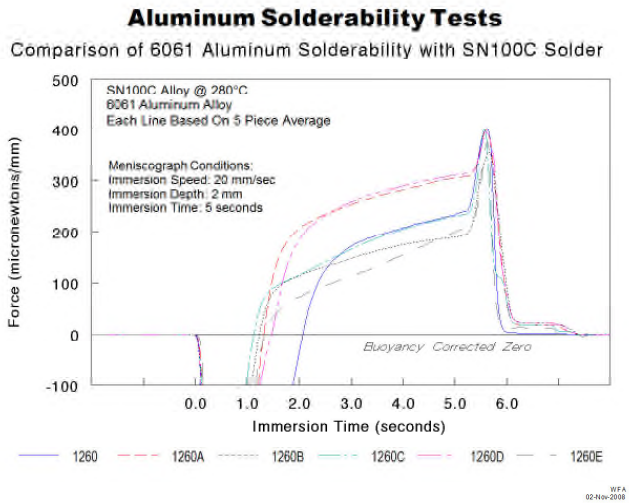
SN100C Solder @ 280°C, 1350 Aluminum Alloy

Solder Wetting (in µN/mm) at given Times									
Flux	**TCA**	**0.70s**	**1.00s**	**2.00s**	**3.00s**	**4.00s**	**5.00s**	**MW**	**IA**
1260	3.16	-230	-228	-151	-35	188	315	315	-150
1260A	1.18	-230	-128	208	318	345	352	352	875
1260B	1.08	-222	-36	101	174	195	204	204	417
1260C	2.08	-230	-175	-7	136	239	275	275	265
1260D	2.08	-233	-233	-45	170	207	232	232	118
1260E	1.34	-209	-117	25	126	235	277	277	343



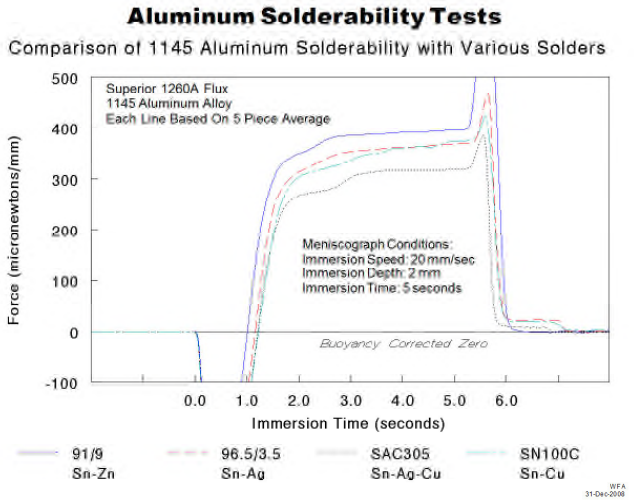
Sn100C Solder @ 280°C, 6061 Aluminum Alloy

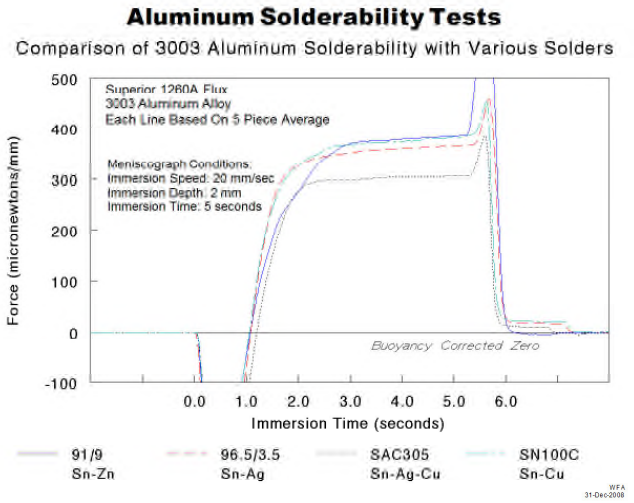
Solder Wetting (in µN/mm) at given Times									
Flux	**TCA**	**0.70s**	**1.00s**	**2.00s**	**3.00s**	**4.00s**	**5.00s**	**MW**	**IA**
1260	2.06	-233	-233	-34	172	207	233	233	122
1260A	1.32	-233	-218	207	252	282	306	306	654
1260B	1.24	-233	-143	114	148	175	189	189	326
1260C	1.12	-232	-82	115	166	205	231	231	430
1260D	1.48	-227	-179	185	257	290	311	311	624
1260E	1.34	-209	-172	72	112	155	200	200	235

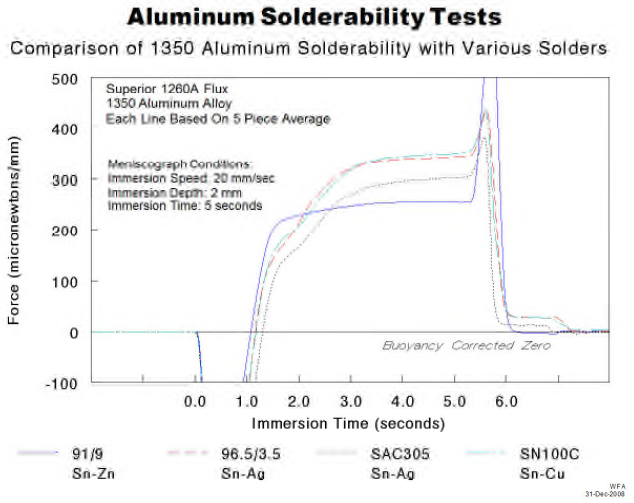


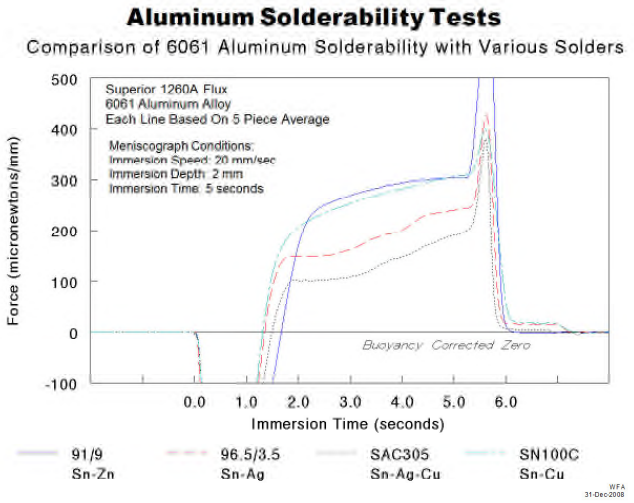
Solder Comparisons

Solder alloy solderability is shown below with the aluminum alloy and the Superior 1260A flux held as controls in the test.



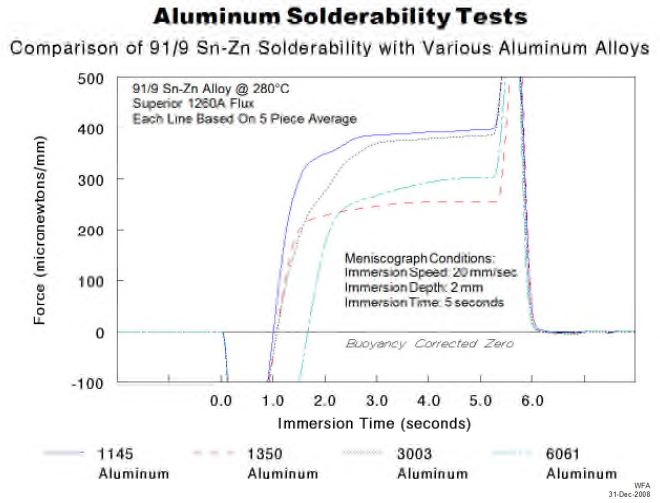


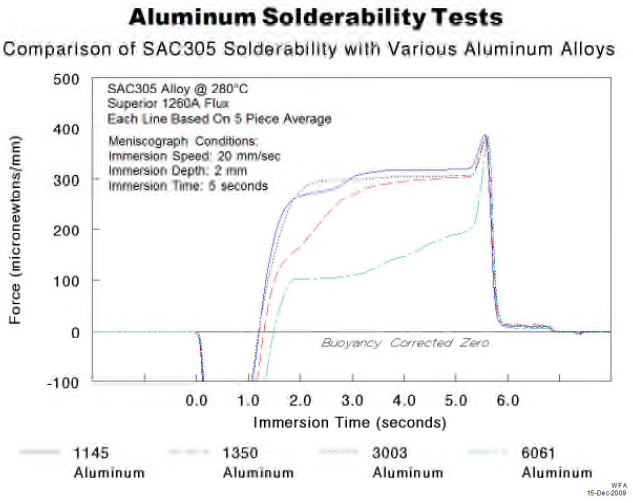


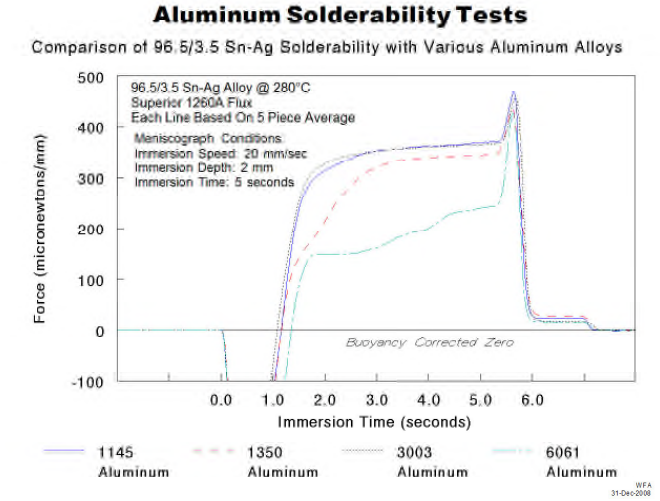


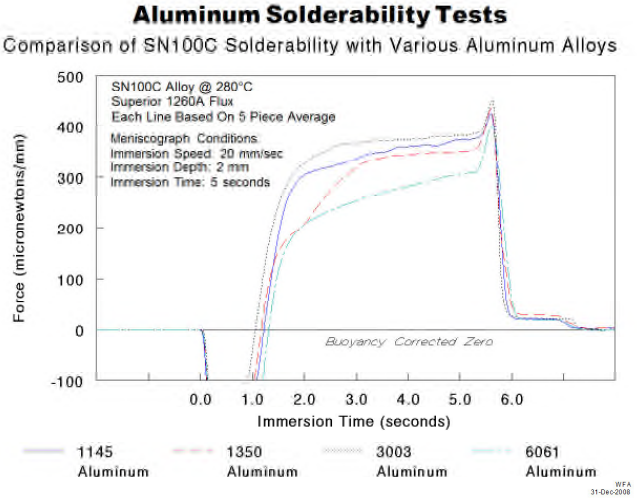
Aluminum Metal Comparisons

Aluminum alloy solderability is shown below with the solder alloy used and the Superior 1260A flux held as controls in the test.









Conclusions

Optimizing Flux

One of the goals of this test was to optimize the performance of the Superior 1260 flux on various aluminum surfaces.

- From the test results the best solderability occurs when we use the "1260A" variation of the 1260 flux in almost all of the cases studied. The enhancement scheme with this variation created a flux that had generally faster but more importantly much stronger wetting early in the soldering cycle.
- Another benefit seen was the strong performance of the "1260D" which is the Superior 1260 flux in a paste media.
- Not so promising were those formulations, 1260B, 1260C, and 1260E that had water dilution as a part of their formulation.

Selecting Best Solder

There were considerable variations in the quality of soldering due to the chemical composition of the solder.

- In the test the 91/9 tin-zinc alloy was one of the best or the best in all cases except for soldering 1350 alloy, in which case it was the worst.
- The 96.5/3.5 tin-silver solder also performed very well but was never the overall clear leader in soldering although it was strong in soldering the 1350 aluminum alloy. It did not perform very well on the 6061 alloy.
- The SAC305 solder did not excel on any of the aluminum alloys and was particularly poor on the 6061 aluminum alloy.
- The best overall performance was the SN100C solder which performed well on all of the alloys, matching the high performance of the 96.5/3.5 tin-silver on 1350 alloy and the 91/9 tin-zinc on the hard to solder 6061 alloy.

Using Proper Aluminum

The literature on aluminum alloy solderability[1], would strongly suggest using 1XXX series of aluminum for any operation to be soldered. This is the same advice that Superior Flux has traditionally given to customers who were seeking to solder aluminum.

- The solderability of the 1145 was strong with all of the solders used and was only out performed in some instances by the 3003 aluminum.
- The testing of the 1350 aluminum shows that with two different grades of aluminum even within a class of aluminum said to be "solderable" there can be widely varying degrees how well solder will flow on any given aluminum alloy. 1350 aluminum, which is widely used and recommended for electrical connection replacement of copper alloys, has some serious issues in terms of its ready solderability in comparison to aluminum of the same class like 1145 aluminum. Since 1350 aluminum solders so much slower than other aluminum alloys, it is not surprising that operators who expect a "just as fast as copper" solder dipping efficiency with electrical connections disappointed and have to modify their dipping techniques because of the slow solderability of this alloy.
- The 3003 aluminum shows a high degree of solderability comparable to the 1145 aluminum.
- The overall poor solderability with the commonly used 6061 aluminum again demands that conditions be optimized for the best soldering results when using this alloy.

References

[1] Soldering Alcoa Aluminum, Aluminum Company of America, 1965, Chapter 3, page 78;

[2] William F. Avery, "Heat Sink Thermal Interface", *Cooling Zone's 5th Annual International Symposium on Thermal Management*, Natick, MA, August 2005,page 31

[3] Manko, Howard H., Solders and Soldering: Materials, Design, Production, and Analysis for Reliable Bonding, 3rd Edition, McGraw-Hill, 1992, pages 465-467.

[4] Soldering Alcoa Aluminum, Aluminum Company of America, 1965, Chapter 3, page 32-33.

[5] GEC Meniscograph MK6B Solderability Tester, Operations Manual, The General Electric Company Research Laboratories, Hirst Research Centre, Wembley, Middlesex, England, 1986.