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BUREAU OF STANDARDS

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SOLDERS FOR ALUMINUM

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The question is frequently raised in connection with the use of aluminum and its alloys whether they can be satisfactorily soldered; and if so, by what method and with what metals or alloys. Aluminum, and to a lesser extent its alloys, can be welded quite satisfactorily by the oxygen-gas process, but often it is not desirable to heat the parts to be joined to the relatively high temperature necessary to weld them in this manner, owing to the resultant distortion of the parts, and a means of joining at lower temperatures is sought.

There are many special solder compositions for aluminum patented and sold to-day, with which it is claimed that soldering can be readily and satisfactorily accomplished, and the general interest in the utilization of this method is evidenced by the inquiries which are received by this Bureau relating to it and to the many commercial solders. It is in response to these inquiries that the following discussion of solders for aluminum has been prepared, based upon special tests made at this Bureau as well as upon current experience and the results and tests of previous investigation.[1]

[1] W. S. Bates, paper read before Am. Chem. Soc., March 1898: J. W. Richards, Method of Soldering Aluminum, J. Frank. Inst., 137, p. 160, 1894; C. F. Burgess and C. Hambuechen, Some Laboratory Observations on Aluminum, Journ. Soc. Chem. Ind., 22, p. 1135, 1903, and Electrochem. Ind., 1903.

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1. APPLICATION AND ADHESION

Whether aluminum can satisfactorily be soldered resolves itself into the questions: (1) Whether the solder can be applied and made to adhere to the aluminum, and (2) whether the joint thus made is stable and does not deteriorate. The choice of a solder composition is determined also by other factors, such as strength, ductility, etc., discussed below.

Aluminum solders, consisting usually of mixtures in various proportions, of zinc, tin, and aluminum, are usually applied in the following manner: The surfaces to be soldered are carefully cleaned with a file or with emery, and are then "tinned" or coated with a layer of the solder by heating the surface and rubbing the solder into it. The joint between the "tinned" surfaces may then be made in the usual manner with a soldering iron and the solders. A flux is not used. Evidently the efficiency of the joint depends upon the adhesion between the aluminum and the initial layer of solder.

A flux is sometimes recommended for use with commercial solders, consisting of stearic acid, rosin, zinc chloride, soap, sugar, or mixtures of these. Tests made at this Bureau have not shown any advantages in the use of such fluxes, either in the case of application ("tinning") or in the resultant adhesion of such fluxed metal.

Table 1 contains the results of certain special tests on commercial compositions of solders as well as upon compositions made up at the Bureau. From this table it will be noticed that the range of temperatures within which melting takes place in solders is usually large. Solders such as Sterling and Zn–1 are not very fluid until nearly at the upper temperature limit given, while the others become fluid within the lower ranges.

Strips of aluminum alloy and aluminum sheet were carefully cleaned and coated with the different compositions. This was accomplished quite readily in all cases. The resultant layer of solder, without exception, appeared to have "wetted" and joined quite thoroughly with the aluminum. The tinned strips were immersed in water for various periods of time and the effect of this treatment noted. Within 48 hours blisters, varying from one-half to 2 or 3 mm in diameter, appeared in the soldered layer of all specimens, as shown in Figs. 1–6. Upon breaking those blisters it was noted that the aluminum immediately below had never been alloyed with the solder. Within from 7 to 14 days

FIG. 1.—*Sn-1 solder; 7 days in tap water.* ×1

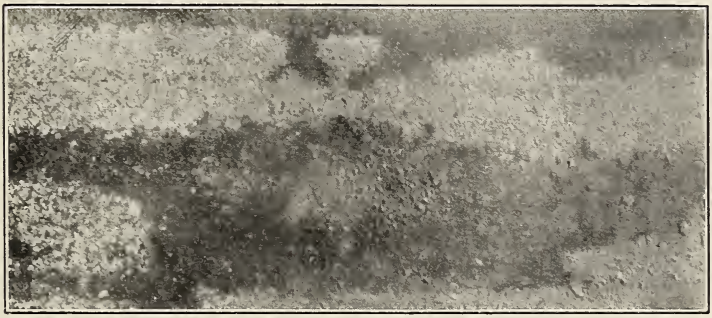

FIG. 2.—*Sn-2 solder; 7 days in tap water* ×1

FIG. 3.—*Sn-4 solder; 7 days in tap water.* ×1

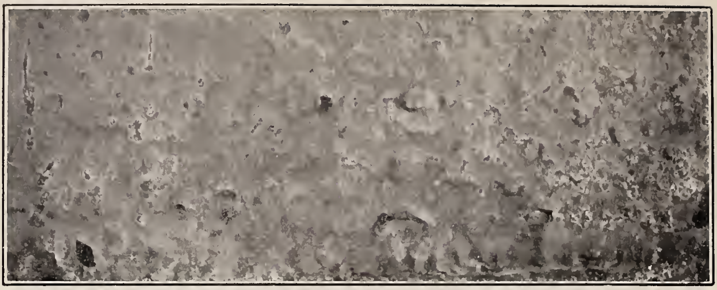

FIG. 4.—*Zn-1 solder; 7 days in tap water.* ×1

FIG. 5.—*Sterling solder; 7 days in tap water.* ×1

FIG. 6.—*Roesch solder; 7 days in tap water.* ×1

FIG. 7.—*Sterling solder joint; photographed wet, showing $Al(OH)_3$ deposit [redacted] lines.* ×1

TABLE 1.—Compositions and Properties of Some Aluminum Solders

Name of solder	Tin	Zinc	Lead	Aluminum	Copper	Other metals	Melting range	Cost per pound [a]	Tensile properties			
									Tensile strength	Yield point	Elongation in 2 inches	Reduction of area
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	°C		Lbs./in.²	Lbs./in.²	Per cent	Per cent
Sterling [c]	62	15	8	11	3	1 (Sb)	228–503	$0.62	[c] 13 000	...	1.6	1.3
Roesch [d]	49	50	1	0.1	0.2	...	195–360	.48	11 900	10 300	13.4	25.4
Crown [e]	63	18	1	13	3	2 (Sb)	...	.64	14 500	...	[f] 1.9	1.5
So-Luminum [g]	55	33	...	11	1	...	...	.56	[h] 9860	...	1.6	1.5
Seifert [i]	73	21	5	...	...	1 (phosphor-tin)	...	.69	6045	5430	6.5	11.0
Richards [j]	63	37	...	1	...	...	...	.60	8010	...	9.0	17.9
Bureau of Standards:												
Sn-1 [k]	78	8	...	9	...	5 (Cd)	194–508	.86	14 300	...	18	41
Sn-3 [k]	84	9	...	5	...	5 (phosphor-tin)	200–460	.80	11 200	9400	8	41
Sn-4 [k]	86	9	...	5	...	...	200–434	.85	12 200	9100	41	81
Zn-1 [k]	...	75	...	5	...	20 (Cd)	264–375	.47	28 000	...	0	1.9

[a] On the basis of following base-metal prices: Tin, $0.90; zinc, $0.07; cadmium, $1.50; aluminum, $0.32; lead, $0.08; copper, $0.23.5; antimony, $0.14.5; and phosphorus, $1.00.
[b] Manufactured by the Sterling Aluminum Solder Co., Brooklyn, N. Y.
[c] An average of 4 tests, varying from 6000 to 23 000 pounds per square inch.
[d] Manufactured by G. E. Roesch, Aurora, Ill.
[e] Manufactured by Crown Aluminum Solder Co., New York, N. Y.
[f] In 1 inch.
[g] Manufactured by the So-Luminum Manufacturing & Engineering Co., New York, N. Y.
[h] Average of 5 tests, varying from 4120 to 17 500 pounds per square inch.
[i] Manufactured by Scifert Superior Aluminum Solder Co.
[j] Manufactured by Janney-Steinmetz & Co., Philadelphia, Pa.
[k] Specimens were chill cast in a metal mold, one-fourth inch square, with rounded edges.

the blisters grew in number and area until quite a large proportion of the "tinned" layer could be stripped off. In these tests it was noted that with solders such as "Sterling," which remained semisolid up to high temperatures, finer blisters were produced. This is to be attributed to the fact that in order to apply such a solder a higher temperature was necessary to melt the solder, and that alloying of the layer with the aluminum beneath thus took place more completely.

Besides the blistering, extensive corrosion took place during these tests. In all specimens the aluminum was rapidly attacked immediately adjacent to the "tinned" layer, gelatinous Al_2O_3 being formed, as shown in Fig. 7. In the case of the specimens soldered with zinc-base solders (Zn–1 and Roesch), the solder also was attacked, whereas the tin-base solder was not itself corroded.

2. STRENGTH AND DUCTILITY OF SOLDERS

The Table 1 gives a data of mechanical tests made on cast specimens of the various solders. There is not much variation in the strength of the solders tested, but there is considerable variation in their ductility. Small one-fourth-inch bars of solder such as Zn–1 and Sterling could not be bent more than a few degrees, whereas Sn–1 could be bent double and flattened out. It is highly desirable to have a ductile solder, and the presence of copper or antimony or of excess of aluminum, producing brittleness, is therefore to be avoided, as there is no other necessity for it.

Some tests were made to ascertain the strength of soldered joints of sheet, the results being shown in Table 2.

The strength of the solder in these joints was rarely equal even to its strength in the cast form. (See Table 1.) Failure occurred apparently both through the solder and at the bond.

3. ELECTROLYTIC BEHAVIOR OF SOLDERS

The most common solders consist of tin as a base with addition of zinc, aluminum, and sometimes lead in moderate proportions. Tin, zinc, and lead are all electrolytically electronegative to aluminum. In contact with aluminum, and in the presence of moisture, each of these metals causes a galvanic action by which the aluminum is attacked. These elements form simple eutectic binary alloys (except zinc-aluminum, aluminum-lead, and zinc-lead) with each other, such that a solder containing tin, zinc, lead,

TABLE 2.—Tests of Soldered Joints [a]

No.[a]	Material of specimen	Type of joint	Tensile test				Fracture
			Tensile stress through solder at fracture	Tensile stress through metal at fracture	Elongation in 4 inches	Reduction of area	
			Lbs./in.	Lbs./in.	Per cent	Per cent	
1	2-inch round aluminum bar	Butt	4100	4100	2	2	Coarsely crystalline through solder.
2	do	do	4500	4540	1	1.7	Do.
3	20-gage aluminum sheet	do	7900	7900	6	2	Through solder.
4	do	do	7600	7600	4	4	2/3 through solder; 1/3 through bond.
5	do	Special butt [b]	4800	14 300	2	6	Through solder.
6	do	do	4100	14 400	4	7	1/3 through solder; 2/3 through solid metal.
7 [c]	do	do	3100	9500	5	2	Through solder.
8 [c]	do	do	3100	10 200	5	2	Do.
9	20-gage aluminum alloy metal	do	1400	5200	0	6	At bond.
10	do	do	1800	5500	0	0	Do.
11 [c]	do	do	2100	7100	0	0	Through solder.
12 [c]	do	do	1500	3500	0	0	At bond.
13 [d]	1/2 by 2 inch aluminum bar	Butt	1300	....	....	....	Through bond.
14 [d]	do	do	2600	....	....	....	Do.
15 [d]	do	do	1700	....	....	....	Do.

[a] Numbers 1–12, inclusive, soldered with Sterling solder.
[b] Flanged and abutted to give greater section.
[c] Immersed in water seven days before testing.
[d] Soldered with So-luminum solder.

and aluminum actually contains each of these elements, practically pure. The electrolytic emfs of these metals to aluminum in a normal solution of their salts are given below:

	Volts
Magnesium	+0. 20
Aluminum	± .00
Zinc	− .52
Cadmium	− .88
Tin	−1. 12
Lead	−1. 13
Copper	−1. 56

Measurements made of the electrolytic emf of solders to aluminum gave the following results:

	Volts [2]
In 0.1 per cent H_2SO_4:	
Sterling	−0. 364
Sn-1	− .445
Zn-1	− .391
In 0.001 n $(Al)_2(SO_4)_3$ solution:	
Sterling	−0. 300
Sn-1	− .269
Zn-1	− .310
In {0.005 n HCl, 0.001 n $Al_2(SO_4)_3$}:	
Sterling	−0. 312
Sn-1	− .321
Zn-1	− .346

Thus there is little difference between the different solders in this respect. They are all electronegative to aluminum. Electrolytically they act as negative galvanic poles, accelerating the corrosion of the aluminum. The zinc-base solders, in addition, are themselves rapidly attacked.

4. COMPOSITION OF SOLDERS

An idea of the energy which has been devoted to the discovery of special compositions of solders for aluminum is given by Table 3. For many of these solders extravagant claims are made for ease of application and for permanence. The first of these is generally justified, since solders within fairly wide limits of composition can readily be applied when due care is exercised, but the second is not, since without exception joints soldered with such compositions when exposed to water or moist air are rapidly corroded and disintegrated.

[2] The sign (−) indicates that this solder was negative to the aluminum; i. e., the current flowed from the aluminum to the solder in the solution.

TABLE 3.—Compositions of Patented or Commercial Solders

Year	Patent No.	Sn	Zn	Al	Pb	Cu	Sb	Ag	Miscellaneous
		Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	
1904	Brit. 17031	66.66	31.23	1.04	1.04				
1905	Fr. 355761	25		70		5			
1906	Ger. 197510	60	25	2		10			3 Cd.
1907	Brit. 14157	72.72	24.24					3.04	
1907	Fr. 374750	50	16.66		33.33				
1907	Fr. 376383	10.14	20.28	21.74	10.14				1.14 Bi; 14.49 Hg; 21.74 brass.
1907	Fr. 379211		85	4.3		10.7			
1907	Brit. 13689	78.68	19.67	1.31				0.33	
1907	Brit. 13689	70.60	24.94	4.15				0.21	
1907	Fr. 381878	13.33	13.33				6.6		66.66 MgCl.
1908	U. S. 906383	47.5			47.5				5 Ca.
1908	U. S. 900367	68	29				2		1.0 phosphorus.
1908	Fr. 394115	75.94	20.27	2.53				1.26	
1908	Fr. 394115	69.38	24.49	4.08				2.04	
1908	Fr. 396345	19.76	59.29	15.80				4.74	0.39 phosphorus.
1909	U. S. 931523		95.26				3.54		
1909	U. S. 938423	80		17					0.7 Ni; 2.3 Mg.
1909	U. S. 939494	49.05	20.31		26.06	1.10	3.43		
1909	U. S. 941835	76.10	21.8			2.10			
1909	U. S. 968203	85.1		10.8					1.35 Cd; 2.75 Mg or 1.0 Pt.
1909	Brit. 9654		80	15			5		
1911	U. S. 989573	65.77	12.22	0.65	17.42	3.09		0.28	0.53 phosphorus.
1912	Brit. 27835	85		10					5 P-Sn.[a]
1912	Brit. 27835	85.68	7.14	3.51					1.78 P-Sn;[a] 1.78 soft solder.
1912	Brit. 29239	61.54	38.46						
1912	Brit. 29239	59.26	40.76						
1913	U. S. 1052693	38	30						32 P-Sn.[a]
1913	U. S. 1067016	45.45	45.45		4.54				
1913	U. S. 1078114	86							14 Bi.

[a] 5 per cent phosphor-tin.

TABLE 3.—Compositions of Patented or Commercial Solders—Continued

Year	Patent No.	Sn	Zn	Al	Pb	Cu	Sb	Ag	Miscellaneous
		Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	
1913	U. S. 1083828		99.35		0.18	0.30			0.17 Fe.
1913	U. S. 1092340	30	52	17.5					0.5 Ni.
1913	Fr. 464716	60		30			10		
1913	Brit. 23077	58.6	23.4		17.6				
1914	U. S. 1093403	50	25		25				
1914	U. S. 1107082	47.35	24.92	24.92		0.49	1.74		0.49 Bi; 0.12 soft solder.
1914	Brit. 7928	5	30						65 Cd.
1915	U. S. 1161612	75.29		5.89	18.82				
1916	U. S. 1194101	25	25	12.5	12.5		12.5		12.5 Bi.
1916	U. S. 1195955	25	50		25				
1917	U. S. 1222158	69.07	1.44		28.77			0.72	
1917	U. S. 1224491	36	20		44				
1917	U. S. 1239854	53.84	15.38	7.69	23.07				
1917	U. S. 1239785	65.39	32.69			1.86	0.06		
	A. G. Le Chatelier		20						80 Cd.
	Do		15						85 Cd.
	Do		30						70 Cd.
	Wuest		50	30		20			
	Do		65	20		15			
	Do		80	12		8			
	Do		85	9					6 Hg.
	Do		88	7					5 Hg.
	Do		90	6					4 Hg.
	Do		94	4		2			
	Do	97.08						1.92	0.97 Ni.
	Burgess and Hambuechen	76	21	3					
	E. Hirsch	93.75	3.12					1.56	1.5 spurious gold leaf.
	Do	91.5	3.92					2.61	1.96 spurious gold leaf.
	Ferman		90	6		4			

5. GENERAL CONCLUSIONS CONCERNING ALUMINUM SOLDERS

1. All metals or combinations of metals used for aluminum soldering are electrolytically electronegative to aluminum. A soldered joint is therefore rapidly attacked when exposed to moisture and disintegrated. There is no solder for aluminum of which this is not true.

2. Joints should therefore never be made by soldering unless they are to be protected against corrosion by a paint or varnish, or unless they are quite heavy, such as repairs in castings, where corrosion and disintegration of the joint near the exposed surface would be of little consequence.

3. Solders are best applied without a flux, after preliminary cleaning and tinning of the surfaces to be soldered. The composition of the solder may be varied within wide limits. It should consist of a tin base with addition of zinc or of both zinc and aluminum, the chief function of which is to produce a semifluid mixture within the range of soldering temperatures

SUGGESTED RANGES OF COMPOSITION

Tin-zinc solders:	
Tin	Remainder
Zinc, per cent	15–50
Tin-zinc-aluminum solders:	
Tin	Remainder
Zinc, per cent	8–15
Aluminum, per cent	5–12

4. The higher the temperature at which the "tinning" is done, the better the adhesion of the tinned layer. By using the higher values of the recommended zinc and aluminum percentages given above, the solder will be too stiff at lower temperature to solder readily and the workman will be obliged to use a higher temperature, thus securing a better joint. A perfect union between solder and aluminum is very difficult to obtain.

5. The joint between previously tinned surfaces may be made by ordinary methods and with ordinary soft solder. Only the "tinning" mixture need be special for aluminum.

6. There is no reason why a good solder for aluminum need be brittle as several commercial varieties are, and it is very undesirable that it should be.

7. The tensile strength of a good aluminum solder is about 7000 pounds per square inch. The strength of a joint depends upon the type and upon the workmanship. Much dependence should not be placed on the strength of a joint.

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