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SOLDERS FOR ALUMINUM

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SOLDERS FOR ALUMINUM.

ABSTRACT.

In this revision of Circular on Solders for Aluminum, have been added the results of recent tests of several new solders and also a selected bibliography.

CONTENTS.

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] See Bibliography.

30152°—23

1. APPLICATION AND ADHESION.

Whether aluminum can satisfactorily be soldered resolves itself into the questions: (1) Can the solder be applied and made to adhere to the aluminum, and (2) is the joint thus made stable and not subject to deterioration. 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 generally 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, paraffin, or mixtures of these. Tests made at this bureau have not shown any advantages in the use of such fluxes, either in the ease 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 wide. Solders such as Sterling, Allen Alumi-solder, and Zn-1 are not very fluid until nearly at the upper temperature limit given, while the others become fluid within the lower ranges.

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

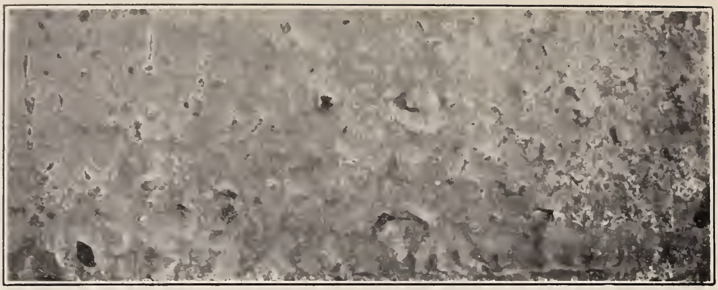

FIG. 4.—*Zn-1 solder; 7 days in tap water.* ×1

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 lines.* ×1

TABLE 1.—Compositions and Properties of some Aluminum Solders.

Name of solder.	Tin.	Zinc.	Lead.	Alumi-num.	Copper.	Other metals.	Melting range.	Tensile properties.			
								Tensile strength.	Yield point.	Elonga-tion in 2 inches.	Reduc-tion 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 [a]	62	15	8	11	3	1 (Sb)	228–503	[b] 13,000		1.6	1.3
Roesch [c]	49	50		.1	.2	0.7 (Sb)	195–360	11,900	10,300	13.4	25.4
Crowne [d]	63	18	1	13	3	2 (Sb)		14,500		[e] 1.9	1.5
So-Luminum [f]	55	33		11	1			[g] 9,860		1.6	1.5
Seifert [h]	73	21	5			1 (phosphor-tin)		6,045	5,430	6.5	11.0
Richards [i]	62	37		1				8,010		9.0	17.9
Bureau of Standards:											
Sn-1 [j]	78	8		9		5 (Cd)	194–508	14,300		18	41
Sn-3 [j]	81	9		5		5 (phosphor-tin)	200–460	11,200	9,400	8	41
Sn-4 [j]	87	8		5			200–434	12,200	9,100	41	81
Zn-1 [j]		75		5		20 (Cd)	264–375	28,000		0	1.9
Pb-1	35.2	30.2	34.6					6,730		13.8	12.3
Alumin-Knit						Fused zinc chloride					
Al-Solder [k]											
Grinlenton & Overend aluminum solder: [l]											
[m]	[n] 54	45.5	.3			Iron trace	198–354				
[o]	89		Trace.		Trace.	Cadmium, 10.8; iron trace	211.4				
Alumi-solder [p]	11.9	87.7	.28			Iron trace	195–392	3,415			
Wolframine [q]	72.3	22.5	.5		1.0	Silver, 3.5; antimony, 0.2	191–434				
Stagneol [r]	69.2	30.4	.14		.26	Iron less than 0.05	198–322				

[a] Manufactured by the Sterling Aluminum Solder Co., Brooklyn, N. Y.
[b] An average of 4 tests, varying from 6,000 to 23,000 lbs./in.²
[c] Manufactured by G. E. Roesch, Aurora, Ill.
[d] Manufactured by Crown Aluminum Solder Co., New York, N. Y.
[e] In 1 inch.
[f] Manufactured by the So-Luminum Manufacturing & Engineering Co., New York, N. Y.
[g] Average of 5 tests, varying from 4,120 to 17,500 lbs./in.²
[h] Manufactured by Seifert Superior Aluminum Solder Co.
[i] Manufactured by Janney-Steinmetz & Co., Philadelphia, Pa.
[j] Specimens were chill cast in a metal mold, one-fourth inch square, with rounded edges.
[k] See Bibliography. Manufactured by Rohde Laboratory Supply Co., New York, N. Y.
[l] Manufactured by Overend & Grinlenton, North Sydney, N. S. W.
[m] Tinning compound.
[n] Also a tool to be used in applying tinning compound composed of commercial zinc.
[o] Solder.
[p] Manufactured by L. B. Allen (Inc.), Chicago, Ill.
[q] French solder handled by Electrical, New York, N. Y.
[r] Solder manufactured in France and Italy.

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 3 mm in diameter, appeared in the soldered layer of all specimens, as shown in Figure 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 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 $Al_2O_3 \cdot 3H_2O$ being formed, as shown in Figure 7. In the case of the specimens soldered with zinc-base solders (Zn–1, Allen Alumi-solder, and Roesch), the solder also was attacked, whereas the tin-base solder was not itself corroded.

2. STRENGTH AND DUCTILITY OF SOLDERS.

Table 1 gives 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.

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.^{2}	Lbs./in.^{2}	Per cent.	Per cent.	
1	2-inch round aluminum bar	Butt	4,100	4,100	2	2	Coarsely crystalline through solder.
2	do	do	4,500	4,540	1	1.7	Do.
3	20-gage aluminum sheet	do	7,900	7,900	6	2	Through solder.
4	do	do	7,600	7,600	4	4	⅔ through solder; ⅓ through bond.
5	do	Special butt[b]	4,800	14,300	2	6	Through solder.
6	do	do	4,100	14,400	4	7	⅓ through solder; ⅔ through solid metal.
7[c]	do	do	3,100	9,500	5	2	Through solder.
8[c]	do	do	3,100	10,200	5	2	Do.
9	20-gage aluminum alloy metal	do	1,400	5,200	0	6	At bond.
10	do	do	1,800	5,500	0	0	Do.
11[c]	do	do	2,100	7,100	0	0	Through solder.
12[c]	do	do	1,500	3,500	0	0	At bond.
13[d]	½ by 2 inch aluminum bar	Butt	1,300	....	....	....	Through bond.
14[d]	do	do	2,600	....	....	....	Do.
15[d]	do	do	1,700	....	....	....	Do.
16	Pb-1, ⅛″ aluminum sheeting	do	4,000	6,730	....	....	Through solder.
17	Alumin Knit, ⅛″ aluminum sheeting	Lap[e]	[f] 6,400	....	....	....	Partially through solder.
18	Grinlenton & Overend, ⅛″ aluminum sheeting	do.[e]	[f] 1,670	....	....	....	Do.
19	Allen Alumi-solder, ⅛″ aluminum sheeting	do.[e]	[f] 1,870	....	....	....	Do.
20	Stagneol, ⅛″ aluminum sheeting	do.[e]	[f] 2,640	....	....	....	Do.
21	Wolframine, ⅛″ aluminum sheeting	do.[e]	[f] 2,640	....	....	....	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.
[e] Lapped area approximately ½ sq. in.
[f] Shear stress through solder at fracture lbs./in.

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 electropositive [2] 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, 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:

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 electropositive to aluminum. Electrolytically they act as positive galvanic poles, accelerating the corrosion of the aluminum. The zinc-base solders, in addition, are themselves rapidly attacked.

It was thought, magnesium being electronegative to aluminum, that it might be used advantageously in an aluminum solder. Experiments to this effect were tried at the bureau; but due to the

[2] This designation is in conformance to the usage which has been officially adopted by the American Electrochemical Society (Trans., 36, pp. 3–15; 1919) and adopted by the Bureau of Standards editorial committee.

rapid corrosion of magnesium by moisture, the solders containing magnesium were found to disintegrate rapidly.

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 Tables 3 and 4. 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.

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	20.29	21.74	10.14				1.44 Bi; 14.49 Hg; 21.74 brass.
1907	Fr. 379211		85	4.3		10.7			
1907	Brit. 13689	78.68	19.67	1.31				.33	
1907	Brit. 13689	61.07	34.13	4.55				.25	
1907	Brit. 26932	75	15	10					
1907	Fr. 380952	54.05	40.54			5.40			
1907	Fr. 381878	14.28	7.14				7.14		71.43 MgCl.
1908	U. S. 900810	54.05	40.54			5.40			
1908	U. S. 906383	47.5			47.5				5 Ca.
1908	U. S. 906367	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	48.53					2.19		48.53 Zn spelter, 0.74 salicylic acid.
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 or Pt; 2.75 Mg.
1909	Brit. 9654		80	15			5		
1911	U. S. 989573	65.77	12.23	.65	17.42	3.10		.29	0.55 phosphorus.
1912	Brit. 27835	85		10					5 P-Sn.[a]
1912	Brit. 27835	85.71	7.14	3.57					1.78 P-Sn; [a] 1.78 soft solder.
1912	Brit. 29239	61.54	38.46						
1912	Brit. 29239	59.25	40.74						
1913	U. S. 1052693	38	30						32 P-Sn.[a]
1913	U. S. 1067016	45.45	45.45	4.54	4.54				
1913	U. S. 1078114	86							14 Bi.
1913	U. S. 1083828		99.35		.18	.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	47.32	24.92	24.92		.49	1.74		0.49 Bi; 0.12 soft solder.
1914	U. S. 1145307	62.5	12.5	6.25	12.5				6.25 P.
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				
1916	Aust. 71088	5	30						65 Cd.
1917	U. S. 1222158	69.07	1.44		28.77			.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	.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			
1917	Fr. 483293	55	45						2.5 parts stearin.
1917	Fr. 485344	66.67	4.44	4.44	13.33	4.44	2.22		4.44 Cd.
1918	U. S. 1273146	20–30	40–50	7–11	12–15	6–8			
1918	U. S. 1256285	33.3	66.7						
1919	Brit. 124715	33	37.5–36.5	28		1.5–2.5			
1919	U. S. 1301633	61	36					1–2	
1919	Brit. 131299	63	(b)		(b)	(b)		(b)	Small amounts Cd and Bi.
1919	Brit. 132724	a c 60 55–65	c 30 26–35	c 10 7–15					
1919	Brit. 152486	57.14	19.04	14.28	7.14				2.38 alloy of Cu 50 Al 50.
1919	Brit. 139402	69	26.2	2.4					2.4 P.
1919	Brit. 141280	60	35	.15		4			Mn 0.85.
1919	Can. 193926	96.6	2.3	.4					0.4 Bi, 0.4 phosphor Sn.

[a] 5 per cent phosphor-tin. [b] Small amount. [c] Preferred composition.

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.	
1919	U. S. 1321529	34.69	30.62		34.69				Stearic acid 50, mutton tallow 43.75, skunk oil 6.25.
1919	U. S. 1323520	96.6	2.3	.4					0.4 Bi, 0.4 phosphor Sn.
1920	U. S. 1326971	64.7	21.18	14.12					½ part NaCl.
1920	U. S. 1328694	37–41	37–41		15–19		1–4		White metal 1–5 per cent; white metal=Sn 80–90 per cent, Sb 5–15 per cent, Cu 3–10 per cent.
1920	U. S. 1332899	56.59	38.3	.14		4.14			Mn 0.83.
1920	U. S. 1333239	37–42	37–43		17–24				
1920	U. S. 1336081	34	30	2	34				
1920	U. S. 1341508	67.60	16.90	1.41					Bi 2.82, phosphor Sn. 11.27.
1920	U. S. 1344165	33	37.5–36.5	28		1.5–2.5			
1920	U. S. 1344566	40	49		10				1 per cent white metal; white metal=Sn 80–90 per cent, Sb 5–15 per cent, Cu 3–10 per cent.
1920	Brit. 164655	49	49			2			
1921	Brit. 156665	30–35	50–53	12–15		.5			
1921	Jap. 38783		.15	5.18					5.18 pine rosin, 10.36 NH_4Cl mixture, 51.81 Sn, 25.9 Zn.
1921	Can. 214193	34	30	2	34				
1922	U. S. 1402644	100							Linseed oil 231, olive oil 231, rosin 231, paraffin 231, solid fat 76 and solution of Ni, Sn, NH_4, and Na salts.

TABLE 4.—Compositions of Patented Soldering Processes.

Year.	Patent No.	Soldering processes.
1916	Fr. 481551......	Overend process. See U. S. 1233803.
1916	Brit. 104633.....	A flux of fatty acid, either animal or vegetable, is used with ordinary solder. Sn 12.5 per cent; Pb 87.5 per cent.
1916	Brit. 108916.....	Granulated Cu or brass turnings are mixed into molten solder, in which they are insoluble at the soldering temperature.
1916	Brit. 109645.....	Aluminum ends are tipped with Cu or brass by cementing or screwing on before solder is applied.
1917	U. S. 1233803...	Aluminum is treated with stearic acid, tinned with Sn-Zn alloy, using Zn tool and soldering with Sn-Cd alloy. Overend process.
1917	Swiss 74542....	Overend process. See U. S. 1233803.
1918	Brit. 134315.....	Aluminum is coated electrolytically with Fe, then soldered with ordinary tin solder.
1919	Brit. 130586.....	Coating aluminum parts to be soldered with Ni or Cu by electrodeposition.
1920	Brit. 156019.....	Soldering by scratching off O_2 and applying solder by a rubber consisting of a pad or roll of steel wool.
1921	U. S. 1387426...	Treating aluminum with HCl and electroplating with Cu.
1921	Brit. 159480.....	Cleansing liquid composed of linseed oil, resin, paraffin, and solid fat; also H_2O solution of nickel sulphate, NH_4Cl and $Na_4P_2O_7$ and H_2O solution $SnCl_2$ $Na_4P_2O_7$ and citric acid. The paste and 2 solutions are prepared separately. This liquid is applied before soldering Al with pure tin by means of a soldering iron.
1922	Brit. 176006.....	1 part solution of chloride, chlorate, borate, and sulphate of Na and $MgCl_2$ in H_2O and 60 parts of a paste of equal portions of paraffin and stearic acid. Solder is dipped into this mixture and then applied with blowpipe.

5. GENERAL CONCLUSIONS CONCERNING ALUMINUM SOLDERS.

1. All metals or combinations of metals used for aluminum soldering are electrolytically electropositive 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 or by using paraffin as 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 7,000 lbs./in.^{2}, those with higher tensile strength (Table 1) have, in general, their temperature of complete liquation too high for soldering purposes. 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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[3] Refers to reference 1 in text. [4] Refers to reference 2 in text.