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SOLDERS AND SOLDERING

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Many inquiries come to the National Bureau of Standards for information on solders and soldering. This letter circular has been prepared to give essential information on the subject in a condensed form in answer to such inquiries.

I. General considerations

The term "soldering" is generally understood to mean the joining of two metal surfaces by means of another metal which is applied in the molten condition. The metal which forms the joint is the solder. Pure metals may be used as solders, but practically all solders in common use are alloys.

To form a satisfactory soldered joint it is necessary to heat the metal at the joint at least to a temperature at which the solder is entirely molten. One of the distinctions between a soldered joint and a welded joint is that in the former the metals to be joined are not heated to their melting points. Consequently, one of the requisites for a solder is that its melting point must be lower than that of the metals being joined. It is generally believed that to obtain satisfactory adherence of the solder it is necessary that the solder form an alloy with the metals which it is to join. On the other hand, it has been claimed that satisfactory adherence can be obtained without actual alloying of solder and metal.

II. Classes of solders

The solders, in general use, may be divided into the following classes:-

1. Soft solders
2. Hard solders
   a. Silver solders
   b. Brazing solders
3. Aluminum solders

Recently a number of preparations designated "Liquid Solders" or "Cold Solders" have come into the market. These preparations are recommended for the joining of all sorts of materials without the use of heat. Most of these preparations are really cements or "glues" and are not solders in the generally accepted meaning of the term. Although they may make joints with satisfactory strength for some purposes, they do not form a metal-to-metal bond and cannot be used to make joints to conduct electric current.

III. Necessity for fluxes

The strength of a soldered joint depends largely on the adherence of the solder to the metal being joined. To secure good adherence it is necessary that the surface of the metal and of the solder be free of oxide, dirt, etc. Base metals are normally covered with a film or layer of oxide and the amount of oxide increases as the metal is heated to the soldering temperature. Hence, to enable the solder to "wet" the metal, it is necessary to employ a material which will remove the oxide film already present and also protect the surfaces of both metal and solder from the air while they are heated to the soldering temperature. Such a material is known as a soldering flux.

IV. Soft solders

(a) Composition and properties

The desirable properties of soft solders are that they have comparatively low melting points and will withstand a considerable amount of bending without fracture. They can be applied by simple means, and can be used for joining metals with low melting points. One of their chief disadvantages is that they have comparatively low strengths.

The metals almost universally used as soft solders are the lead-tin alloys. The alloy containing 63 percent tin and 37 percent lead melts at about 360°F (182°C). All the other lead-tin alloys begin to melt at this temperature but are completely molten at a higher temperature depending upon the relative amounts of lead and tin in the alloy.

The most widely used "all purpose" soft solder is the alloy containing 50 percent lead and 50 percent tin. The temperature at which this alloy is completely molten is variously given as 415°F to 440°F (212°C to 226°C). The alloy containing about 2 parts of lead to 1 part of tin is used in preference to the "half and half" alloy for making "wiped" joints, as it has a wider melting range and therefore can be molded during solidification. Most commercial soft solders contain small percentages of antimony which is claimed to increase the strength of the solder. There are other modifications of the lead-tin alloys for soft soldering purposes, the advantages or particular applications of which cannot be discussed here.

The ordinary lead-tin solders cannot be used for soldering pewter. The metals known as pewter consist largely of tin or lead, or both, and melt at approximately the same temperature as the lead-tin solders. The following alloys, which have sufficiently low melting points to be applied as solders on pewter, have been recommended for this purpose:-

Designating Number	Composition in Percent		
	Lead	Tin	Bismuth
1	25	25	50
2	50	37.5	12.5
3	25	50	25

An alloy of 95 percent tin with 5 percent antimony, melting at approximately 450°F (232°C) with a small melting range, has been recommended for use as a soft solder. Joints made with this alloy are claimed to have somewhat higher strength than when made with lead-tin solders.

For joints which are required to withstand temperatures close to or slightly above the melting temperature of lead-tin solders, soft soldering with an alloy of 95 percent cadmium with 5 percent silver has been recommended. This alloy begins to melt at approximately 640°F (338°C) and is completely molten at approximately 740°F (393°C).

(b) Fluxes

The fluxes ordinarily used for soft soldering are solutions or pastes that contain zinc chloride or mixtures of zinc and ammonium chlorides as the active fluxing agents. The solvent or other medium holding the flux material is evaporated by the heat of the soldering operation, leaving a layer of the solid flux on the work. At the soldering temperature the flux is melted and partially decomposed with the liberation of hydrochloric acid. It is this acid reaction when heated which enables the flux to dissolve the oxides from the surfaces of the solder and the work. The fused flux also forms a protective film that prevents further oxidation from taking place. Thus, the two-fold function of a flux is fulfilled. It is claimed that a flux containing zinc and ammonium chlorides in their eutectic proportion (71 percent by weight of zinc chloride to 29 percent by weight of ammonium chloride) is the most satisfactory flux for soft soldering.

Because zinc chloride fluxes have a corrosive action, it is sometimes necessary to employ a non-corrosive flux for certain types of work where the last traces of the flux cannot be removed after the soldering is completed. Rosin is the most commonly used flux of this type. Soft solder wire with a core of rosin is obtainable commercially. Palm oil, olive oil, or rosin, or mixtures of these have been recommended as suitable fluxes for soldering pewter.

(c) Application

Soft solders are usually applied with a soldering "iron" (actually made of copper), but may be applied with a flame as the source of heat. Difficulties may arise by using a blow torch if precautions are not taken against overheating. An excessive amount of solder is to be avoided. Except in "wiped" joints the minimum amount of solder that will spread evenly throughout the area of contact between the metals to be joined produces the strongest joints.

(d) Remarks

Because of the comparatively low melting temperatures of the solders, joints soldered with lead-tin solders do not withstand temperatures higher than about 350°F (177°C); those soldered with the tin-antimony solder would melt apart at about 450°F (232°C); and those soldered with the cadmium-silver solder, at about 640°F (378°C). Hard solders melt at temperatures above about 1200°F (649°C). There are at present no satisfactory solders, with high ductility and strength, that melt between 640°F and 1200°F.

V. Hard solders

There are several types of hard solders, namely precious metal alloy solders and brazing solders. The most widely used precious metal alloy solders are the silver solders, generally alloys of silver, copper, and zinc. Silver solders are malleable and ductile and silver soldered joints in many metals may be as strong as the metals themselves.

Other precious metal alloys used as solders are the gold solders and the platinum solders. Gold solders are used primarily for joining gold and gold alloys. The solders are generally alloys of gold with copper, silver, and zinc, and having lower melting points than the alloys which are joined. Gold solders are generally designated by karat numbers indicating the fineness or karat number of the alloy with which they should be used.

Soldered joints in platinum and platinum metal alloys may be made with fine gold or the higher karat gold alloys.

Brazing solders are generally alloys of copper and zinc. They are more brittle than silver solders and do not withstand bending and impact as well as the more ductile solders.

VI. Silver solders

(a) Composition and properties

There are many variations in the proportions of silver, copper and zinc used in commercial silver solders. The following compositions, Table I, together with their melting points and flow points are given in the American Society for Testing Materials Specification B 73-29 for Silver Solders. It is believed that a solder satisfactory for most purposes for which silver solder is suitable can be selected from this list. The melting point as given in the table is the temperature at which the solder begins to melt; the flow point, the temperature at which the solder is completely molten.

Table 1 (Silver solders, American Society for Testing Materials Specification B 73-29)

Designating number	Chemical composition in percent			Melting point		Flow point		Color
	Silver	Copper	Zinc	°F	°C	°F	°C	
1	10	52	38	1510	820	1600	870	yellow
2	20	45	35	1430	775	1500	815	yellow
4	45	30	25	1250	675	1370	745	nearly white
5	50	34	16	1280	690	1425	775	nearly white
6	65	20	15	1280	695	1325	720	white
7	70	20	10	1335	725	1390	755	white
8	80	16	4	1360	740	1460	795	white

Small amounts of cadmium are sometimes added to the ordinary silver solder compositions. One such solder contains 20 percent silver, 45 percent copper, 30 percent zinc, and 5 percent cadmium. This solder has the same melting and flow points as the no. 2 alloy.

A method commonly used in metal working shops to prepare silver solder for miscellaneous uses is to melt together silver and yellow brass (copper 60 percent, zinc 40 percent) in the proportions of 1 part silver to 2 parts brass.

A recently developed general purpose silver solder, suitable also for hard soldering stainless steels, is the alloy containing 50 percent silver; 15.5 percent copper; 16.5 percent zinc; and 18 percent cadmium. This solder is stated to melt in the range 1160°F to 1175°F (627°C to 635°C).

(b) Fluxes

For ordinary purposes, borax or mixtures of borax and boric acid (75 to 25 percent borax with 25 to 75 percent boric acid) will meet most requirements as a flux for soldering with silver solders, or gold and platinum solders. Zinc chloride fluxes used for soft soldering are not satisfactory for hard soldering because they do not remain on the work at the temperatures necessary for hard soldering.

(c) Application

All silver solders melt at temperatures above a red heat and cannot be applied with soldering irons. Blow torches of various kinds are commonly used. Silver solders (and also brazing solders) are frequently applied by heating the whole object in which the joint is to be made to the soldering temperature in a suitable furnace.

VII. Brazing solders

( ) Composition and properties

The common brazing solders or brazing "spelters" are really brasses containing more zinc, and consequently with lower melting points, than the commercial brasses or bronzes. Hence, they can be used for joining brass, bronze, and other commercial copper alloys as well as ferrous metals. Joints made with pure copper would be classed as brazed joints although they are often termed "coppered" joints in trade practice.

The commonly used brazing solders contain from 40 to 55 percent copper and 60 to 45 percent zinc, the composition most frequently used being the one containing equal weights of copper and zinc. These are brittle alloys and are ordinarily supplied in granular form. Their flow points are above 1600°F (871°C).

(b) Fluxes

The same fluxes used for silver soldering, described above, are generally used with the brazing solders.

(c) Application

Brasing solders are ordinarily applied by means of a blow torch.

VIII. Aluminum solders

Hundreds of alloys have been developed for use in soldering aluminum and aluminum alloys. Most of the solders that have been found to be satisfactory contain tin and zinc in proportions varying from 30 to 75 percent tin and 30 to 25 percent zinc. The alloy containing 60 percent tin and 40 percent zinc is frequently used and will produce joints possessing satisfactory strength.

The solders may be applied without the use of a flux. Rubbing the surfaces of the aluminum under the melted solder with a wire brush or a sharp object such as an old file cleans its surface so that the solder will "wet" the aluminum. The tin-zinc solders can be applied with a soldering iron.

The chief difficulty with soldered joints on aluminum is that the aluminum adjacent to the joint corrodes when exposed to a moist atmosphere as a result of galvanic action between the dissimilar metals. This can be avoided to a certain extent by covering the joint with a moisture-proof paint or varnish.

Although it is generally considered best practice to join aluminum by welding rather than by soldering, aluminum solders serve a useful purpose in applications where the joints are normally well covered with oil or otherwise protected from the atmosphere.

IX. Additional information on solders and soldering

Many variations from the compositions of the different types of solders mentioned in this discussion have been found useful for certain purposes. No attempt has been made to discuss in detail the metallurgical principles and theories involved in the use of solders. For more detailed information on the subject reference should be made to the original papers or books listed below.

(a) General subject of soldering

"Soldering and Brazing" by Hobart. Book published by D. Van Nostrand Company, 250 Fourth Avenue, New York, New York

"Metal Worker's Handy Book of Receipts and Processes" by Brannt. Book published by Henry Carey Baird and Company, Inc., [illegible] West 45th Street, New York, New York

(b) Soft soldering

"Soft Solders and Their Application" by G. O. Hiers. Article published in "Metals and Alloys" 2, No. 5, 257, November 1931. This article contains an extended list of papers on the subject.

"Tin Solders: A Modern Study of the Properties of Tin Solders and Soldered Joints" by J. S. Nightingale. Book published by the British Non-Ferrous Metals Research Association, London.

(c) Silver solders

"Silver Solders and Their Use" by R. H. Leach. Article published in "Metals and Alloys" 2, No. 5, [illegible]78, November 1931.

"Silver Solders" by R. H. Leach. Paper published in Proceedings of the American Society for Testing Materials 30, 4[illegible]5 (1930). Reprint copies of this paper can be obtained from the headquarters of the society, 260 South Broad Street, Philadelphia, Pennsylvania.

(d) Aluminum soldering

"Solders for Aluminum". Circular of the Bureau of Standards No. 78.

"Light Metals and Alloys - Aluminum and Magnesium". Circular of the Bureau of Standards No. 346.

The first of these circulars is out of print, but may be consulted at technical libraries. The second is obtainable by purchase from the Superintendent of Documents, Government Printing Office, Washington, D. C., at $1.10 a copy. (stamps not accepted)

"The Aluminum Industry", a two volume work by Edwards, Frary and Jeffries. Published by the McGraw-Hill Book Company, Inc., 370 West 42nd Street, New York, New York; contains several pages in Volume II on the soldering of aluminum.

A recently published book, "The Technology of Aluminum and its Light Alloys", by A. v. Zeerleder, Nordemann Publishing Company, Amsterdam, contains useful information on the soldering of aluminum.

X. Specifications

The Federal Specifications Executive Committee has issued specifications for the use of the departments and independent establishments of the Government in the purchase of solders. Excerpts from these specifications giving the compositions of the various grades of each type are given below. The complete specifications can be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C. for 5 cents a copy (stamps not accepted).

1. Specification No. QQ-S-551 for brazing solder

Grade	Chemical composition in percent					
	Copper	Tin	Lead, maximum	Iron, maximum	Aluminum, maximum	Zinc
A	49.0 - 52.0	none*	0.50	0.10	0.10	remainder
B	49.0 - 52.0	3.0 - 4.0	.50	.10	--	"
C	68.0 - 72.0	none*	.30	.10	--	"
D	78.0 - 82.0	none*	.20	.10	--	"

* As determined on a one-gram sample.

2. Specification No. QQ-S-561a for silver solder

Grade	Chemical composition in percent				
	Silver	Copper	Zinc	Phosphorus	Impurities, maximum
No. 0	20	45	35	nil	0.15
1	45	30	25	nil	.15
2	65	20	15	nil	.15
3	15	80	nil	5	.15

3. Specification No. QQ-S-571 for tin-lead solders

Grade	Chemical composition in percent				
	Tin plus lead, minimum	Tin, minimum	Antimony	Copper, maximum	Sum of zinc, aluminum, and cadmium, maximum
A	99.65	49.0	0.12***	0.08	none*
B	99.65	44.0	.12***	.08	none*
C	99.65	38.0	.12***	.08	none*
D	97.50	35.0	1.25-1.50	.15	0.50**
E	97.50	30.0	0.50-0.75	.15	.50**
F	99.65	70.0	.12***	.08	none

* As determined on a five-gram sample.
** Not more than 0.30 percent of zinc, aluminum, or cadmium individually will be permitted.
*** Maximum.