Kirk-Othmer Encyclopedia of Chemical Technology.

SOLDERS AND BRAZING FILLER METALS

Metals joining by brazing and soldering is an ancient practice that has become a sophisticated modern technology owing to the contribution of modern materials science. The ultimate goal of these process is to join parts into an assembly through metallurgical bonding (1–4). A relatively low melting temperature alloy, a filler metal (FM), is placed in the clearance (gap) between the pieces of base materials (BM) to be joined and the assembly is subsequently heated until the FM has melted and spread throughout the gap. The molten metal fills the gap and reacts with parts to be brazed, forming after solidification an integral solid whole. Assembly heating can be carried out by various means. These include electromagnetic induction, Joule heating, or use of an oven, flame, etc. Joining temperatures above 723 K are arbitrarily associated with brazing rather than with soldering. However, these processes are essentially similar. In order to distinguish joining materials, those used at temperatures below 723 K are called solders; those above, brazing filler metals.

There are three principal stages in any brazing or soldering process (Fig. 1). The first occurs during the heating of an assembled workpiece. At this stage, the FM melts and flows, filling completely the gap normally existing between the parts. This gap is usually rather small, ie, on the order of 10 to a maximum of a few hundred micrometers, and sometimes even close to zero. Thus, the degree of penetration of a molten alloy into the gap is determined largely by capillary effects and by wetting. Because physical parameters such as part dimensions and surface tension forces play the primary role, this stage may be conditionally called a physical one.

The second stage, which normally sets in at a given joining temperature, is characterized by an intensive solid–liquid interaction accompanied by a substantial mass transfer through the interface at strongly uneven rates. Indeed, BM immediately adjoining the liquid filler metal dissolves in this stage. At the same time, a small amount of material from the liquid phase penetrates into the solid BM. Such mass-transfer unbalance results from dramatically different diffusion rates in the solid and liquid phases. This redistribution of components in the joint area leads to changes of phase composition and sometimes to the onset of crystallization, or, in other words, to joint solidification. All the processes of this stage may be properly called a metallurgical one. In a majority of cases in soldering, all the processes proceed but to a much lesser degree because of a substantial difference in the melting temperatures of a solder and a BM. However, even in soldering, sometimes the BM surface must be protected from erosion by molten solder.

The final stage of the brazing (soldering process) overlaps with the second and is characterized by the formation of the final joint microstructure, progressing vigorously during assembly cooling while the liquid phase is still present. Here, the crystallization process takes place. Subsequent cooling results in only minor changes such as annealing of the joint and partial relief of thermal stresses induced on cooling. The final stage has very similar features in both brazing and soldering processes.

In any brazing/soldering process, a molten alloy comes in contact with a surface of solid, which may be an alloy, a ceramic, or a composite material (see Ceramics; Composite materials). For a molten alloy to advance over the solid surface a special relationship has to exist between surface energies of the liquid–gas, solid–gas, and liquid–solid interfaces. The same relationships should, in principle, hold in joining processes where a

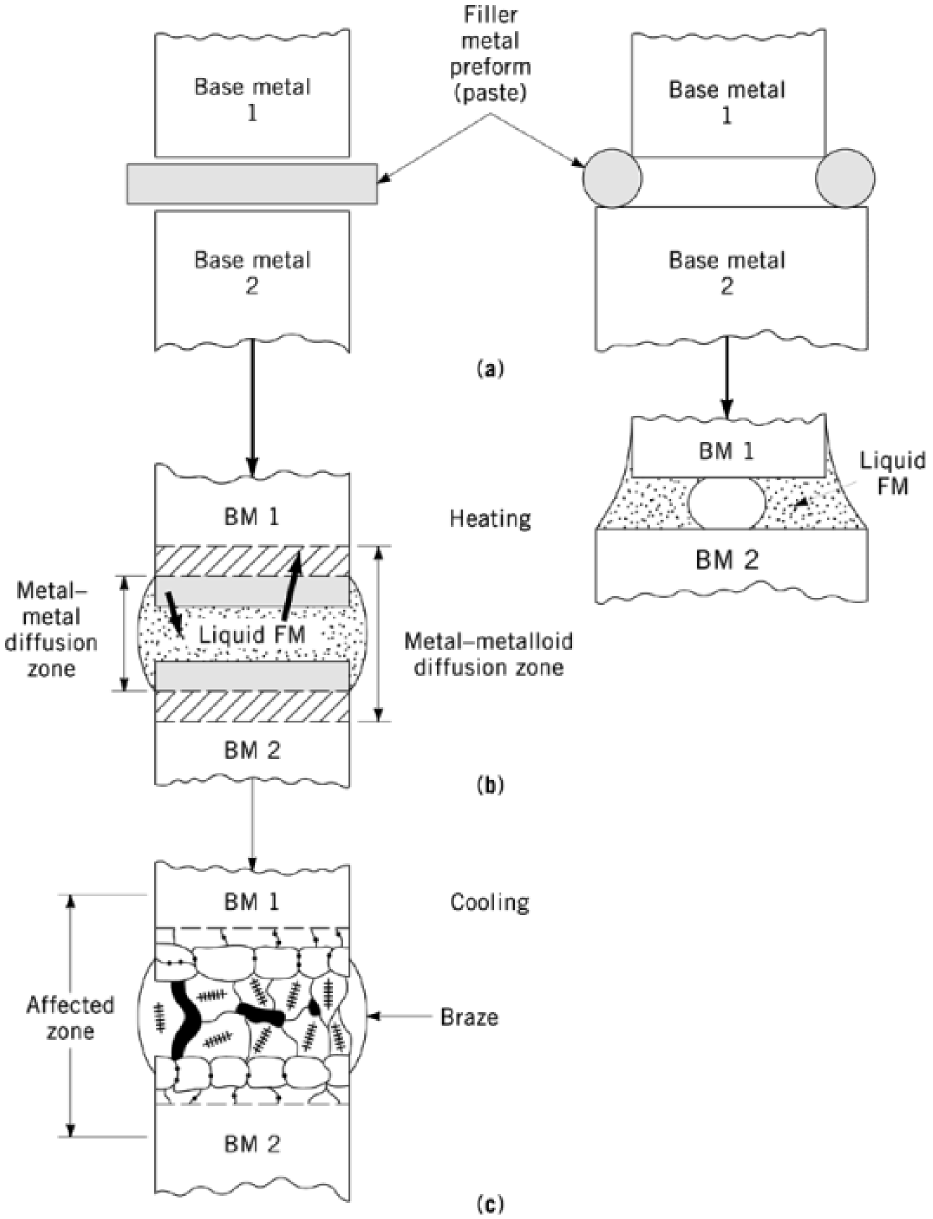

Fig. 1. The essence of the brazing/soldering processes: (**a**) before brazing/soldering; (**b**) heating to the brazing/soldering temperature, $T_{\mathrm{br/sold}}$; and (**c**) cooling to the use of service temperature after brazing/soldering, T_{serv}. The two thick arrows in (**b**) denote mass transfer.

molten alloy has to fill the gaps existing between surfaces of the parts to be joined. In general, the molten alloy should have a lower surface tension than that of the base material.

All transition metals, particularly iron (qv), which is the base element of steel (qv), and the majority of alloys, have surface tension higher than 1500 mN/m, whereas nontransition metals such as silver, tin, and lead, and particularly metalloids such as silicon, have surface tension substantially lower than those of the principal groups of steels and other BM alloys. The addition of phosphorus (qv), silicon, boron (qv), etc, to aluminum, nickel, and copper (qv) results in a precipitous drop in the surface tension of the resultant material. Therefore, for low temperature joining, tin- and lead-based alloys have been used as solders, whereas aluminum-, copper-, and nickel-based alloys having additions of P, Si, and B have been used as brazing filler metals. Both groups of alloys in the molten state have surface tension values favorable for strong wetting (see Aluminum and aluminum alloys; Copper alloys; Lead alloys; Nickel and nickel alloys).

Because the surface tension of oxides such as Fe_xO_y, Al_2O_3, Cr_2O_3, etc, is much lower than that of the majority of metals and alloys, the presence of an oxide film on a BM surface impedes wetting. It is of paramount importance to keep the BM surface clean from the so-called virgin oxides and oxides that may have formed during the brazing operation if the heat-treating atmosphere is oxidizing. This is particularly important in brazing stainless steels and high temperature alloys (qv) containing active metals, such as chromium, titanium, and aluminum, that form corresponding protective oxide films. The wettability of base metals is strongly affected by cleanliness not only with respect to oxides but also by the presence of traces of grease, oil, etc, on part surfaces. Therefore, cleaning of the BM pieces to be joined and their subsequent protection from oxidation during heating are essential steps in joining operations.

Chemically active substances (fluxes) are used to accomplish cleaning and to provide protective shielding when vacuum or protective atmospheres are not available (see Metal surface treatments). However, the use of nonmetallic agents in fluxes is not always desirable owing to the increased propensity for their entrapment and the subsequent formation of voids in the brazed joint. On the other hand, if the brazing environment is not oxidizing, then boron, silicon, and phosphorus, which are used as inherent constituents of FM alloys, can play the role of a flux, ie, reducing original oxide films and making the FM self-fluxing.

1. Basic Forms of Filler Metal

Filler metal forms include solid preforms and powders, used mostly in the compound form of paste, plastic-bonded tape, and, in the case of soldering, rosin core wire. In special soldering applications, solders may be used as a liquid medium of the soldering baths in which electronic boards are immersed for a short time to solder multiple joints. Conventional paste forms of joining alloys, eg, FM powder plus fluxing agent plus binder/solvent, are applied at externally accessible locations of the clearance between BM pieces. Such practice requires substantial FM fluid flow during joining to achieve fusion of constituent FM phases and binder/solvent extraction. In addition, organic binders decompose when compound FM forms are used in the high vacuum brazing of parts intended for critical high temperature service. Such decomposition of binders can result in the formation of soot in the joint, which can act to degrade the performance of expensive vacuum equipment.

2. Joint Requirements

A basic requirement for any joint is that its strength and ductility be equal or at least close to that of the BM. In general, the strength of a material increases with decreasing grain size, whereas ductility is affected by the presence of brittle phases. Therefore, in addition to limiting porosity in joints, it is important to limit grain size and the amounts of brittle phases. Ideally, the maximum size that the grains in a joint may achieve is equal to half the clearance between the BM pieces. Thus, the use of a smaller clearance during BM joining necessarily limits maximum grain size, promotes higher cooling rates of the FM alloy, and thereby results in a refined joint microstructure. A smaller clearance in brazing also promotes improved retention of BM properties because of curtailed BM erosion by the use of a smaller volume of FM. For these reasons, a preplaced self-fluxing thin FM foil used as a preform is superior to the use of powder-containing paste. The latter requires larger clearances for filling joint cross sections, thus resulting in deleterious effects on properties owing to a coarser joint grain size, more fully developed intermetallic compounds, and the presence of substantial amounts of contaminants.

The grain size and brittle intermetallic size and extent in the parent FM have a direct effect on the strength of the formed joint. This consideration is particularly important under transient heating/cooling conditions such as torch or belt oven brazing and automatic solder die bonding. The rapid dissolution of constituent FM alloy phases allows the use of higher joining throughput speeds and/or lower joining temperatures. The newer rapidly solidified microcrystalline and amorphous joining materials are thus the epitome of FM microstructural possibility. These materials possess ultimate uniformity of their elemental components, which is beneficial for formation of a fine microcrystalline joint microstructure in both soldering and brazing. In the case of brazing, amorphous foil has the ability of self-fluxing because practically all brazing amorphous foils contain a large amount of phosphorus, boron, and silicon (5).

3. Solder and Brazing Filler Metals

3.1. Solders

In spite of the wide use and development of solders for millennia, as of the mid-1990s most principal solders are lead- or tin-based alloys to which a small amount of silver, zinc, antimony, bismuth, and indium or a combination thereof are added. The principal criterion for choosing a certain solder is its melting characteristics, ie, solidus and liquidus temperatures and the temperature spread or pasty range between them. Other criteria are mechanical properties such as strength and creep resistance, physical properties such as electrical and thermal conductivity, and corrosion resistance.

According to International Organization for Standardization (ISO)/DIS 9543 specifications (Table 1), the majority of solders can be divided into three categories: tin–lead alloys, tin–lead alloys with antimony, and lead–tin–silver alloys. The tin–lead eutectic and near-eutectic alloys are the most commonly used solders that find application in electronics, particularly for soldering of circuit boards, and electrical connections and general purposes such as joining pipelines (qv) for a wide range of gases and fluids. Small (ca 0.25 wt %) additions of antimony are used to suppress the formation of the low temperature allotrope of tin, whereas 2–4 wt % additions are used to improve monotonic and creep strength of the solder. Because of relatively high melting temperature, lead–silver solders are used in applications where joint strength at moderately high temperatures is needed. The addition of tin improves wetting and flow and reduces corrosion in a humid atmosphere. These solders are used in cryogenic apparatuses and for soldering of fine copper wires because of their lower tendency to dissolve copper.

The presence of the so-called heavy metals, eg, lead, cadmium, and antimony, in traditional solders has become an important environmental issue owing to concerns for health and safety. As a result, solders containing no lead and antimony such as tin–silver are finding a growing number of applications (Table 2).

3.2. Brazing Filler Metals

The choice of both specific FM alloy composition and optimal brazing conditions is mostly determined by joint performance under specific service conditions. Ideally, the composition of an FM alloy must be such that the following four functions are achieved: (*1*) the FM melting temperature must be lower than that of the corresponding BM; (*2*) the FM surface tension for both solid and liquid states must be lower than that of the BM to provide a driving force for wetting; (*3*) the FM must be compatible with the BM in order to form good metallic bonding, ie, the FM and BM structure, composition, and properties should be similar; and (*4*) the

Table 1. ISO/DIS 9453 Specification for Tin–Lead and Other Lead–Alloy Solders[a]

Alloy number	Alloy desig-nation	Melting or solidus/liquidus temperature[b], °C	Chemical composition[c,d], %										Sum of all impurities except Sb, Bi, and Cu, %
			Sn	Sb	Cd	Zn	Al	Bi	As	Fe	Cu	Ag	
					Tin–lead alloys								
1	S–Sn63Pb37	183	62.5–63.5	0.12	0.002	0.001	0.001	0.10	0.03	0.02	0.05		0.08
1a	E–Sn63Pb37	183	62.5–63.5	0.05	0.002	0.001	0.001	0.05	0.03	0.02	0.05		0.08
2	S–Sn60Pb40	183–190	59.5–60.5	0.12	0.002	0.001	0.001	0.10	0.03	0.01	0.05		0.08
2a	E–Sn60Pb40	183–190	59.5–60.5	0.05	0.002	0.001	0.001	0.05	0.03	0.02	0.05		0.08
3	S–Pb50Sn50	183–215	49.5–50.5	0.12	0.002	0.001	0.001	0.10	0.03	0.02	0.05		0.08
3a	E–Pb50Sn50	183–215	49.5–50.5	0.05	0.002	0.001	0.001	0.05	0.03	0.02	0.05		0.08
4	S–Pb55Sn45	183–226	44.5–45.5	0.50	0.005	0.001	0.001	0.25	0.03	0.02	0.08		0.08
5	S–Pb60Sn40	183–235	39.5–40.5	0.50	0.005	0.001	0.001	0.25	0.03	0.02	0.08		0.08
6	S–Pb65Sn35	183–245	34.5–35.5	0.50	0.005	0.001	0.001	0.25	0.03	0.02	0.08		0.08
7	S–Pb70Sn30	183–255	29.5–30.5	0.50	0.005	0.001	0.001	0.25	0.03	0.03	0.08		0.08
8	S–Pb90Sn10	268–302	9.5–10.5	0.50	0.005	0.001	0.001	0.25	0.03	0.02	0.08		0.08
9	S–Pb92Sn8	280–305	7.5–8.5	0.50	0.005	0.001	0.001	0.25	0.03	0.02	0.08		0.08
10	S–Pb98Sn2	320–325	1.5–2.5	0.12	0.002	0.001	0.001	0.10	0.03	0.02	0.05		0.08
					Tin–lead–antimony alloys								
11	S–Sn63Pb37Sb	183	62.5–63.5	0.12–0.50	0.002	0.001	0.001	0.10	0.03	0.02	0.05		0.08
12	S–Sn60Pb40Sb	183–190	59.5–60.5	0.12–0.50	0.002	0.001	0.001	0.10	0.03	0.02	0.05		0.08
13	S–Pb50Sn50Sb	183–216	49.5–50.5	0.12–0.50	0.002	0.001	0.001	0.10	0.03	0.02	0.05		0.08
14	S–Pb58Sn40Sb2	185–231	39.5–40.5	2.0–2.4	0.005	0.001	0.001	0.25	0.03	0.02	0.08		0.08
15	S–Pb69Sn30Sb1	185–250	29.5–30.5	0.5–1.8	0.005	0.001	0.001	0.25	0.03	0.02	0.08		0.08
16	S–Pb74Sn25Sb1	185–263	24.5–25.5	0.5–2.0	0.005	0.001	0.001	0.25	0.03	0.02	0.08		0.08
17	S–Pb78Sn20Sb2	185–270	19.5–20.5	0.5–3.0	0.005	0.001	0.001	0.25	0.03	0.02	0.08		0.08
				Lead–silver and lead–tin–silver alloys									
32	S–Pb98Ag2	304–305	0.25	0.10	0.002	0.001	0.001	0.10	0.03	0.02	0.05	2.0–3.0	0.2
33	S–Pb95Ag5	304–365	0.25	0.10	0.002	0.001	0.001	0.10	0.03	0.02	0.05	4.5–6.0	0.2
34	S–Pb93Sn5Ag2	296–301	4.8–5.2	0.10	0.002	0.001	0.001	0.10	0.03	0.02	0.05	1.2–1.8	0.2

[a] Ref. 1.

[b] Temperatures given are for information purposes and are not specified requirements for the alloys.

[c] The balance of material is lead.

[d] Single values given are maximums.

Table 2. ISO/DIS 9453 Specification for Tin–Silver Solders[a]

Alloy number	Alloy designation	Melting or solidus/liquidus temperature[b], °C	Chemical composition[c,d,e], %										
			Pb	Sb	Bi	Cd	Cu	In	Ag	Al	As	Fe	Zn
28	S–Sn96Ag4	221	0.10	0.10	0.10	0.002	0.05	0.05	3.5–4.0	0.001	0.03	0.02	0.001
29	S–Sn97Ag3	221–230	0.10	0.10	0.10	0.005	0.10	0.05	3.0–3.5	0.001	0.03	0.02	0.001

[a] Ref. 1.
[b] Temperatures given are for information purposes and are not specified requirements for the alloys.
[c] The balance of material is tin.
[d] Single values given are maximum.
[e] The sum of all impurities is 0.2%.

FM-containing elements should be able to bring about chemical reduction/decomposition or physical removal of BM oxide film.

Five families of brazing FM alloy compositions have emerged with respect to metallurgical nature or type. Of these, the first four families of conventional brazing FM have been classified by the American Welding Society (AWS) into eight well-defined classes as indicated in Table 3. The preferred base metals with which each specific family is most compatible as well as the principal areas of FM applications are also given. Compositions of specific alloys are given in Tables 4, 5, 6, 7, 8.

The first and largest family of FM alloys, Family I, contains eutectic-type alloys having aluminum, nickel, cobalt, and copper as a base to which silicon–boron (aluminum- and nickel-base alloys) and phosphorus (copper- and nickel-base alloys) are added. Family I encompasses AWS Classes 1, 4, 6, and 7 as well as the nonclassified nickel- and palladium-based alloys. The presence of one or more of the metalloid elements in alloys tends to impart the required characteristics to the FM. Silicon combined with a small amount of magnesium is successfully used in aluminum-based FM alloys, the surface tension and melting temperature of which are depressed and good bonding is promoted. The magnesium addition serves as a fluxing agent. Boron and silicon are used in high temperature brazing alloys in which the presence of another potential melting temperature depressant and surfactant element, ie, phosphorus, can cause unacceptable joint brittleness. Of the alloy additions that promote self-fluxing of the FM during brazing, boron has the greatest penetrating power. On the other hand, phosphorus is a beneficial fluxing element for use in copper (low temperature) brazing, whereas another element, eg, silicon, would cause unacceptable copper joint brittleness. Most of these alloys are brittle because various intermetallic phases precipitate when processed by conventional technology. This brittle character has limited the available forms of conventionally produced brazing alloys to powder. The presence, however, of silicon, phosphorus, and boron in many conventional FM alloys having near-eutectic compositions facilitates the conversion of such alloys into ductile, thin amorphous alloy foil form when rapid solidification (RS) technology is used (5).

The second family of brazing FM, Family II, consists of solid solution alloys based on copper (Class 2) and gold–nickel (Class 8). These alloys are used mainly in vacuum-brazing applications and therefore require no alloying elements playing the role of fluxing agents (see Vacuum technology). Family III consists of alloys having a phase diagram where a peritectic reaction exists, such as copper–zinc alloys (Class 3) and nonclassified Cu–Sn alloys. Alloys of Family IV (Class 5) are probably the most widely used. Family IV is based on the copper–silver binary eutectic system modified by substantial additions of zinc and cadmium, both of which provide fluxing activity, and minor additions of tin and nickel. The fifth family of brazing FM alloys, Family V, although so far unclassified, consists of purely metallic eutectic/peritectic titanium–zirconium-base alloys to which copper and/or nickel are added.

Table 3. AWS Classes of Brazing Filler Metals

Class	Alloy type (and family)	AWS designation	Forms[a]	Base materialsjoined	Applications
1	Al–Si, eutectic (I)	BAlSi	preforms, wire, rods, foil, powder, RS foil[b]	aluminum and aluminum alloys, steel to aluminum and aluminum to beryllium	car radiators, heat exchangers, honeycomb aircraft structures, structural parts
2	Cu–X, solid solution (II)	BCu	preforms, wire, rods, foil, powder	copper and copper alloys, copper to mild steel, copper to stainless steel	heat exchangers, structural parts, automotive parts
3	Cu–Zn, peritectic (III)	RBCuZn	same as Class 2	same as Class 2	same as Class 2
	Cu–Sn, peritectic (III)		same as Class 2 and RS foil	same as Class 2	same as Class 2
4	Cu–P, eutectic (I)	BCuP	preforms, wire, rods, foil, powder, RS foil	copper to copper, copper to silver/oxide-powdered metal composites	electrical contacts, bus bars, heat exchangers
5	Cu–Ag, eutectic (IV)	BAg	preforms, foil, powder	most ferrous and nonferrous metals, except aluminum and magnesium	most widely used utility filler metals
6	TM–Si–B[c], eutectic (I) (Ni/Fe + Cr)–Si–B (I)	BNi	powder, tape[d], RS foil	AISI 300 and 400 series steels and nickel- and cobalt-base superalloys, carbon steels, low alloy steels, and copper	aircraft turbine components, automotive parts, heat exchangers, honeycomb structure
7	(Co, Cr)–Si–B	BCo	powder, tape, RS foil	cobalt-base heat-resistant alloys, steels	aircraft engines, honeycomb marine structures
	(Ni, Pd)–Si–B		powder, tape, RS foil	AISI 300 series stainless steels, cemented carbide, superalloys	honeycomb structures, cemented carbide/polycrystalline diamond tools, orthodontics, catalytic converters
8	Au–Ni, solid solution (II)	BAu	preforms, wire, rods, foil, tape	nickel-base heat-resistant alloys, steels	honeycomb structures, structural turbine parts
	Cu–(Ti, Zr)–Ni eutectic and peritectic (V)		clad strip, RS foil	titanium/zirconium-base alloys	titanium tubing, aircraft engines, honeycomb aircraft structures, aircraft structural parts, uchemical reactors

[a] RS = rapid solidification.

[b] May be produced as rapidly solidified, ductile, amorphous/microcrystalline foil.

[c] This family includes alloys based on transition metals, such as nickel, iron, cobalt, and palladium.

[d] Brazing filler metal is carried on a plastic-bonded tape.

Table 4. Chemical Composition Requirements for Aluminum and Magnesium Filler Metals[a]

Alloy		Composition[b], wt %						
AWS classification	UNS number	Si	Cu	Mg	Fe	Zn	Mn	Other[c]
				Aluminum-based alloys[d]				
BAlSi-2	A94343	6.8–8.2	0.25		0.8	0.2	0.1	
BAlSi-3	A94145	9.3–10.7	3.3–4.7	0.15	0.8	0.2	0.15	0.15 Cr
BAlSi-4	A94047	11.0–13.0	0.3	0.1	0.8	0.2	0.15	
BAlSi-5	A94045	9.0–11.0	0.3	0.05	0.8	0.2	0.05	0.2 Ti
BAlSi-7	A94004	9.0–10.5	0.25	1.0–2.0	0.8	0.2	0.1	
BAlSi-9	A94147	11.0–13.0	0.25	0.1–0.5	0.8	0.2	0.1	
BAlSi-11	A94104	9.0–10.5	0.25	1.0–2.0	0.8	0.2	0.1	0.02–0.2 Bi
				Magnesium-based alloys[e]				
BMg-1	M19001	0.05	0.05	[f]	0.005	1.7–2.3	0.15–1.5	0.005 Ni; 0.0002–0.0008 Be;[g]

[a] Ref. 2.

[b] Single values are maximum.

[c] The filler metal is analyzed for those specific elements for which values are shown. If the presence of other elements is indicated in the analysis, the amount of those elements is determined to ensure that the maximum for each is ≤ 0.05 wt% and the maximum total of other elements is ≤ 0.15 wt%.

[d] Remainder of material is Al.

[e] Remainder of material is Mg.

[f] Contains 8.3–9.7 Al.

[g] The maximum allowed for other elements is 0.3 wt %.

The majority of all these classes, even noneutectic alloys, have been processed successfully by rapid solidification technology. This technology provides a beneficial alternative in the form of a flexible ductile foil when materials that are inherently brittle are used. Examples are the nickel–boron–silicon alloys and many others, when produced using conventional technology (5).

4. Joining Process Technology

Joint design must ensure a variety of service criteria such as joint mechanical strength; resistance to service environment; electrical conductivity, which is of prime importance in soldering of electrical circuitries; ease of manufacturing; and economics. Compatibility of the parts to be joined (BM) with the forming braze (FM) is always considered from minimization of mechanical stresses, which may appear after brazing/soldering owing to the difference in coefficient of thermal expansion that always exists between the BM and the FM. These stresses may be very high. Specifics of joint design are available for brazing (2) and for soldering of electronic components (1).

4.1. Preparation and Protection of the Parts

One, if not the most, important technological step to guarantee success of a joining operation is the preparation of the parts to be joined. Cleaning part surfaces of oxide films, oil, grease, and dirt includes mechanical and/or chemical means, solvent usage, and, finally, rinsing and drying. If not properly cleaned, the joined assemblies may leak or lack the necessary strength owing to incomplete joining (see Metal surface treatments).

Parts must be protected from oxidation during heat treating in joining. Only then can complete wetting of parts by the molten filler metal be ensured and a quality joint result. Protection from oxidation may be

Table 5. Chemical Composition Requirements for Copper-Based Filler Metals[a]

Alloys		Composition[b], wt %		
AWS classification	UNS number	Cu	P	Other[c]
		Copper-based alloys		
BCu-1	C14180	99.90 min	0.075	0.02 Pb; 0.01 Al*
BCu-1a[d]		99.90 min		
BCu-2[e]		86.50 min		
		Copper–zinc-based alloys[f]		
RBCuZn-A	C47000	57.0–61.0		0.25–1.00 Sn; 0.05 Pb*; 0.01 Al*
RBCuZn-C	C68100	56.0–60.0		0.80–1.10 Sn; 0.25–1.20 Fe; 0.01–0.50 Mn; 0.05 Pb*; 0.01 Al*; 0.04–0.15 Si
RBCuZn-D	C77300	46.0–50.0	0.25	9.0–11.0 Ni; 0.05 Pb*; 0.01 Al*; 0.04–0.25 Si
		Copper–phosphorus-based alloys[g]		
BCuP-1	C55180		4.8–5.2	
BCuP-2	C55181		7.0–7.5	
BCuP-3	C55281		5.8–6.2	4.8–5.2 Ag
BCuP-4	C55283		7.0–7.5	5.8–6.2 Ag
BCuP-5	C55284		4.8–5.2	14.5–15.5 Ag
BCuP-6	C55280		6.8–7.2	1.8–2.2 Ag
BCuP-7	C55282		6.5–7.0	4.8–5.2 Ag

[a] Ref. 2.

[b] Single values are maximum.

[c] The filler metal is analyzed for those specific elements for values where asterisks (*) are shown. If the presence of other elements is indicated in the analysis, the amount of those elements is determined to ensure that the maximum total is ≤ 0.10 for BCu-1; ≤ 0.30 for BCu-1a; ≤ 0.50 for BCu-2, RBCuZn-A, RBCuZn-C, and RBCuZn-D; and ≤ 0.15 for all others.

[d] The balance is oxygen, present as cuprous oxide.

[e] These chemical composition requirements pertain only to the cuprous oxide powder and do not include requirements for the organic vehicle in which the cuprous oxide is suspended, when applied in paste form.

[f] Remainder of material is Zn.

[g] Remainder of material is Cu.

accomplished by using self-fluxing brazing filler metals such as the Cu–P-based alloys, protective fluxes, protective atmospheres, and simply by using vacuum furnaces that have no trace of oxygen.

4.2. Fluxes

Fluxes often play multiple roles. Not only do fluxes protect parts from oxidation during heating but they also clean up virgin surfaces from existing tarnishing oxide films by reducing or scaling the oxides. In addition, fluxes also decrease the surface tension of molten metals and improve capillary flow. Rosin-based fluxes, for example, address these phenomena in soldering where these fluxes are often used for joining electrical circuitries. Organic-acid or water-soluble fluxes are also frequently preferred in soldering operations in which a final cleaning of soldered boards can be achieved using noncorrosive water solutions.

4.3. Heat Treatments

Heating methods in joining can be divided into two principal categories: the local one, where heat is supplied predominantly to the joint area, and the overall one, where the brazed assembly is heated to a certain temperature. Gas torches, radiation heaters, contact heaters such as soldering irons, and induction sources are used for local heating; electrical and gas furnaces are used for complete heating. Sophisticated and highly

Table 6. Chemical Composition Requirements for Silver Filler Metals [a]

Alloy		Composition, wt %			
AWS classification	UNS number	Ag	Cu	Zn	Other[b]
BAg-1	P07450	44.0–46.0	14.0–16.0	14.0–18.0	23.0–25.0 Cd
BAg-1a	P07500	49.0–51.0	14.5–16.5	14.5–18.5	17.0–19.0 Cd
BAg-2	P07350	34.0–36.0	25.0–27.0	19.0–23.0	17.0–19.0 Cd
BAg-2a	P07300	29.0–31.0	26.0–28.0	21.0–25.0	19.0–21.0 Cd
BAg-3	P07501	49.0–51.0	14.5–16.5	13.5–17.5	15.0–17.0 Cd; 2.5–3.5 Ni
BAg-4	P07400	39.0–41.0	29.0–31.0	26.0–30.0	1.5–2.5 Ni
BAg-5	P07453	44.0–46.0	29.0–31.0	23.0–27.0	
BAg-6	P07503	49.0–51.0	33.0–35.0	14.0–18.0	
BAg-7	P07563	55.0–57.0	21.0–23.0	15.0–19.0	4.5–5.5 Sn
BAg-8[c]	P07720	71.0–73.0			
BAg-8a[c]	P07723	71.0–73.0			0.25–0.50 Li
BAg-9	P07650	64.0–66.0	19.0–21.0	13.0–17.0	
BAg-10	P07700	69.0–71.0	19.0–21.0	8.0–12.0	0.15[d] Mn
BAg-13[c]	P07540	53.0–55.0		4.0–6.0	0.5–1.5 Ni
BAg-13a[c]	P07560	55.0–57.0			1.5–2.5 Ni
BAg-18[c]	P07600	59.0–61.0			9.5–10.5 Sn
BAg-19[c]	P07925	92.0–93.0			0.15–0.30 Li
BAg-20	P07301	29.0–31.0	37.0–39.0	30.0–34.0	
BAg-21	P07630	62.0–64.0	27.5–29.5		2.0–3.0 Ni; 5.0–7.0 Sn
BAg-22	P07490	48.0–50.0	15.0–17.0	21.0–25.0	4.0–5.0 Ni; 7.0–8.0 Mn
BAg-23[e]	P07850	84.0–86.0			
BAg-24	P07505	49.0–51.0	19.0–21.0	26.0–30.0	1.5–2.5 Ni
BAg-26	P07250	24.0–26.0	37.0–39.0	31.0–35.0	1.5–2.5 Ni; 1.5–2.5 Mn
BAg-27	P07251	24.0–26.0	34.0–36.0	24.5–28.5	12.5–14.5 Cd
BAg-28	P07401	39.0–41.0	29.0–31.0	26.0–30.0	1.5–2.5 Sn
BAg-33	P07252	24.0–26.0	29.0–31.0	26.5–28.5	16.5–18.5 Cd
BAg-34	P07380	37.0–39.0	31.0–33.0	26.0–30.0	1.5–2.5 Sn

[a] Ref. 2.

[b] The brazing filler metal is analyzed for those specific elements for which values are shown. If the presence of other elements is indicated in the analysis, the amount of those elements is determined to ensure that the maximum total of each is ≤ 0.15 wt%.

[c] Remainder of material is Cu.

[d] Value represents maximum.

[e] Remainder of material is Mn.

productive methods such as wave soldering and electrical resistance soldering have been applied successfully in mass production soldering (6, 7).

5. Health and Safety Factors

Brazing safety is subject to the requirements of the American National Standard (8). The specifics of brazing, which should be considered in addition to the conventional safety requirements applied to manufacturing environments, mostly relate to the metal fumes and metal and oxide particulars evolved during processing. Many brazing filler metals contain a wide variety of harmful metallic components. Among these, cadmium,

Table 7. Chemical Composition Requirements for Nickel and Cobalt Filler Metals[a]

Alloy		Composition[b], wt %												
AWS classification	UNS number	Cr	B	Si	Fe	C	P	S	Al	Ti	Zr	Co	Se	Other[c]
			Nickel-based alloys[d]											
BNi-1	N99600	13.0–15.0	2.75–3.50	4.0–5.0	4.0–5.0	0.60–0.90	0.02	0.02	0.05	0.05	0.05	0.10	0.005	
BNi-1a	N99610	13.0–15.0	2.75–3.50	4.0–5.0	4.0–5.0	0.06	0.02	0.02	0.05	0.05	0.05	0.10	0.005	
BNi-2	N99620	6.0–8.0	2.75–3.50	4.0–5.0	2.5–3.5	0.06	0.02	0.02	0.05	0.05	0.05	0.10	0.005	
BNi-3	N99630		2.75–3.50	4.0–5.0	0.5	0.06	0.02	0.02	0.05	0.05	0.05	0.10	0.005	
BNi-4	N99640		1.50–2.20	3.0–4.0	1.5	0.06	0.02	0.02	0.05	0.05	0.05	0.10	0.005	
BNi-5	N99650	18.5–19.5	0.03	9.75–10.50		0.06	0.02	0.02	0.05	0.05	0.05	0.10	0.005	
BNi-6	N99700					0.06	10.0–12.0	0.02	0.05	0.05	0.05	0.10	0.005	
BNi-7	N99710	13.0–15.0	0.01	0.10	0.2	0.06	9.7–10.5	0.02	0.05	0.05	0.05	0.10	0.005	0.04 Mn
BNi-8	N99800			6.0–8.0		0.06	0.02	0.02	0.05	0.05	0.05	0.10	0.005	21.5–24.5 Mn; 4.0–5.0 Cu
BNi-9	N99612	13.5–16.5	3.25–4.0		1.5	0.06	0.02	0.02	0.05	0.05	0.05	0.10	0.005	
BNi-10	N99622	10.0–13.0	2.0–3.0	3.0–4.0	2.5–4.5	0.40–0.55	0.02	0.02	0.05	0.05	0.05	0.10	0.005	15.0–17.0 W
BNi-11	N99624	9.0–11.75	2.2–3.1	3.35–4.25	2.5–4.0	0.30–0.50	0.02	0.02	0.05	0.05	0.05	0.10	0.005	11.5–12.75 W
			Cobalt-based alloys[e]											
BCo-1	R39001	18.0–20.0	0.70–0.90	7.5–8.5	1.0	0.35–0.45	0.02	0.02	0.05	0.05	0.05	[f]	0.005	3.5–4.5 W

[a] Ref. 2.

[b] Single values are maximum.

[c] The filler metals are analyzed for those specific elements for which values are shown. If the presence of other elements is indicated in the analysis, the amount of those elements is determined to ensure that the maximum total for each is ≤ 0.50 wt%, except for BNi-1, which is ≤ 0.05 wt%.

[d] Remainder of material is Ni.

[e] Remainder of material is Co.

[f] Contains 16.0–18.0 Ni.

lead, and zinc are the most insidious, which also evaporate easily upon melting the alloys that contain these materials. The exposure limits to these substances and to the various active fluxes and the solvents used are primary safety parameters regulating the workplace. Limits for these materials are available (1, 9).

The principal goal of safety provision in any brazing and soldering shop is the cleanliness of the atmosphere. Sufficient ventilation must be provided and proper working practices are regulated by OSHA as well as various state and federal agencies (9). Additional concerns include the high temperatures and gases under high pressure.

Stringent OSHA composition limits exist for applications of brazing filler metals and solders. For example, only no-lead solders are permitted for joining parts that may come in contact with potable water.

Table 8. Chemical Composition Requirements for Gold Filler Metals[a]

Alloy		Composition[b], wt %		
AWS classification	UNS number	Au	Pd	Ni
BAu-1[c]	P00375	37.0–38.0		
BAu-2[c]	P00800	79.5–80.5		
BAu-3[c]	P00350	34.5–35.5		2.5–3.5
BAu-4[d]	P00820	81.5–82.5		
BAu-5	P00300	29.5–30.5	33.5–34.5	35.5–36.5
BAu-6	P00700	69.5–70.5	7.5–8.5	21.5–22.5

[a] Ref. 2.

[b] The brazing filler metal is analyzed for those specific elements for which values are shown. If the presence of other elements is indicated in the analysis, the amount of those elements is determined to ensure that the maximum total is ≤ 0.15 wt%.

[c] Remainder of material is copper.

[d] Remainder of material is nickel.

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