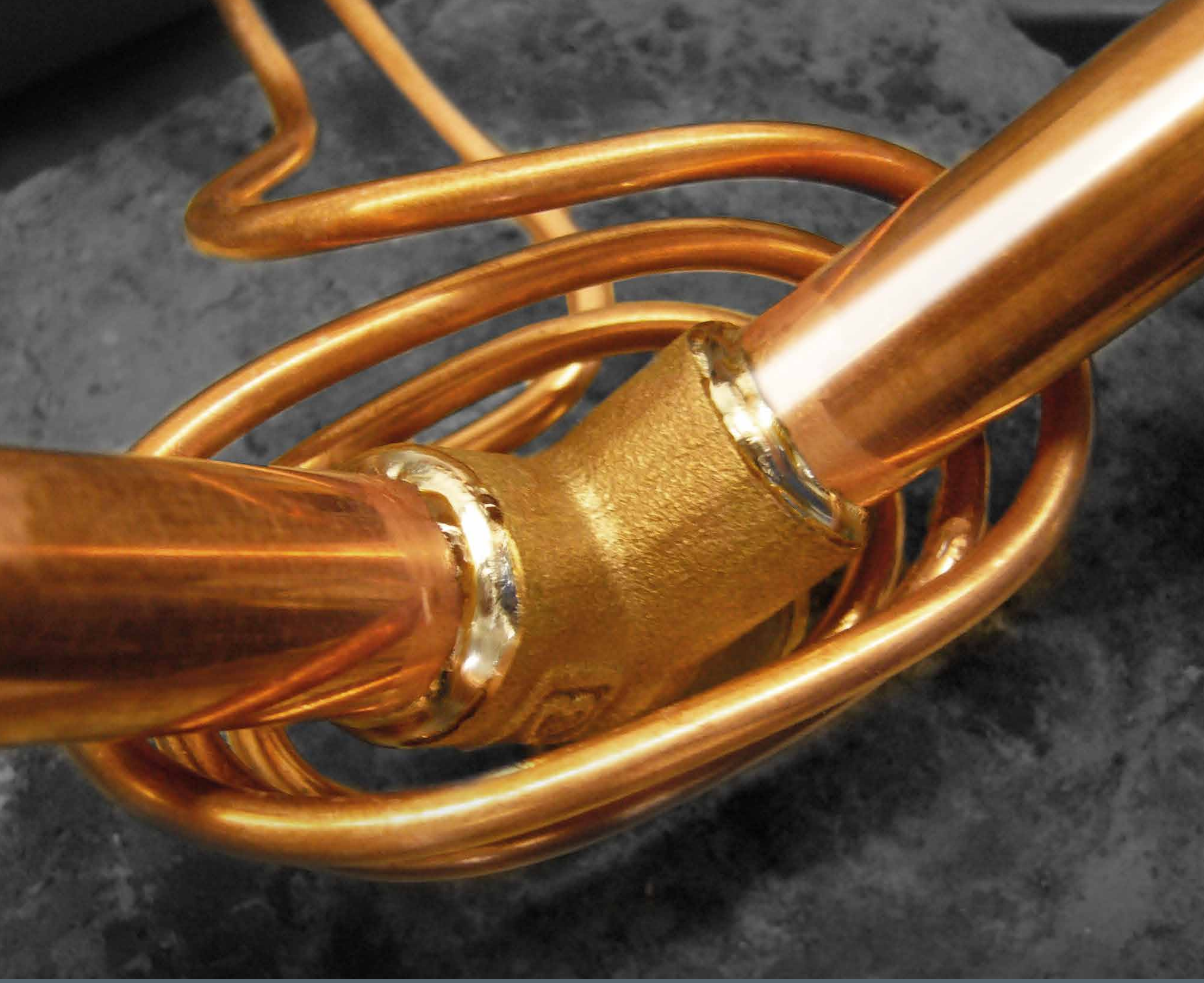


Soldering and brazing of copper and copper alloys

Deutsches Kupferinstitut
Copper Alliance

Contents

List of abbreviations

Abbreviations

Nd:YAG laser	Neodymium-doped yttrium aluminium garnet laser
SMD	Surface-mounted device
PVD	Physical vapour deposition
RoHS	Restriction of (the use of certain) Hazardous Substances
EG	Europäische Gemeinschaft
EC	European Community
MIG	Metal inert gas process
TIG	Tungsten inert gas process
DVGW	German Technical and Scientific Association for Gas and Water *[Deutsche Vereinigung des Gas- und Wasserfaches]*

Chemical elements and compounds

Ag	Silver
Al	Aluminium
Ar	Argon
Be	Beryllium
C	Carbon
CO_2	Carbon dioxide
Cr	Chromium
Cu	Copper
H_2	Hydrogen
H_2O	Water
HF	Hydrofluoric acid
Mn	Manganese
Ni	Nickel
O_2	Oxygen
P	Phosphorus
Pb	Lead
S	Sulphur
Sb	Antimony
Si	Silicon
Sn	Tin
Te	Tellurium
Zn	Zinc
Zr	Zirconium

1. Introduction

Copper is a material that has been used by man for thousands of years because of its special properties. As a native metal, i.e. one that is also found naturally in its pure metallic form, copper was used early in human history because of its good malleability and formability and because of its colour. Copper thus became man's first working metal.

With increasing industrialisation, other properties of copper became important, such as its excellent electrical and thermal conductivity and its resistance to atmospheric corrosion, and its generally high resistance to chemical attack.
Copper can form alloys with many different metals and a large numbers of alloy systems are now available that enable mechanical and technological properties, such as hardness, tensile strength, yield strength, chemical resistance, resistance to wear, to be modified in a controlled way.
If their particular physical and mechanical characteristics are taken into account, copper and the majority of copper alloys show a high degree of solderability or brazeability. Fabrication process variables, such as the particular soldering or brazing technique to be used, the choice of filler material and any preparative or after-treatment procedures, need to be carefully selected on the basis of the materials to be joined. The factors that influence the solderability or brazeability of a material are shown in figure 1 and need to be taken into account both individually and in combination.
A component is considered solderable or brazeable if the parent material is suitable for soldering or brazing, and one or more soldering or brazing techniques can be applied, and if the parts to be joined are designed so as to facilitate the soldering/brazing process and to ensure that the soldered/brazed part is safe under the conditions in which it is to be used [1].

This booklet aims to reflect the current state of soldering and brazing copper and copper alloys in industrial applications, but does not claim to be complete. As research and development work in this field is continuing, enquiries should be directed to the German Copper Institute or corresponding organisations.

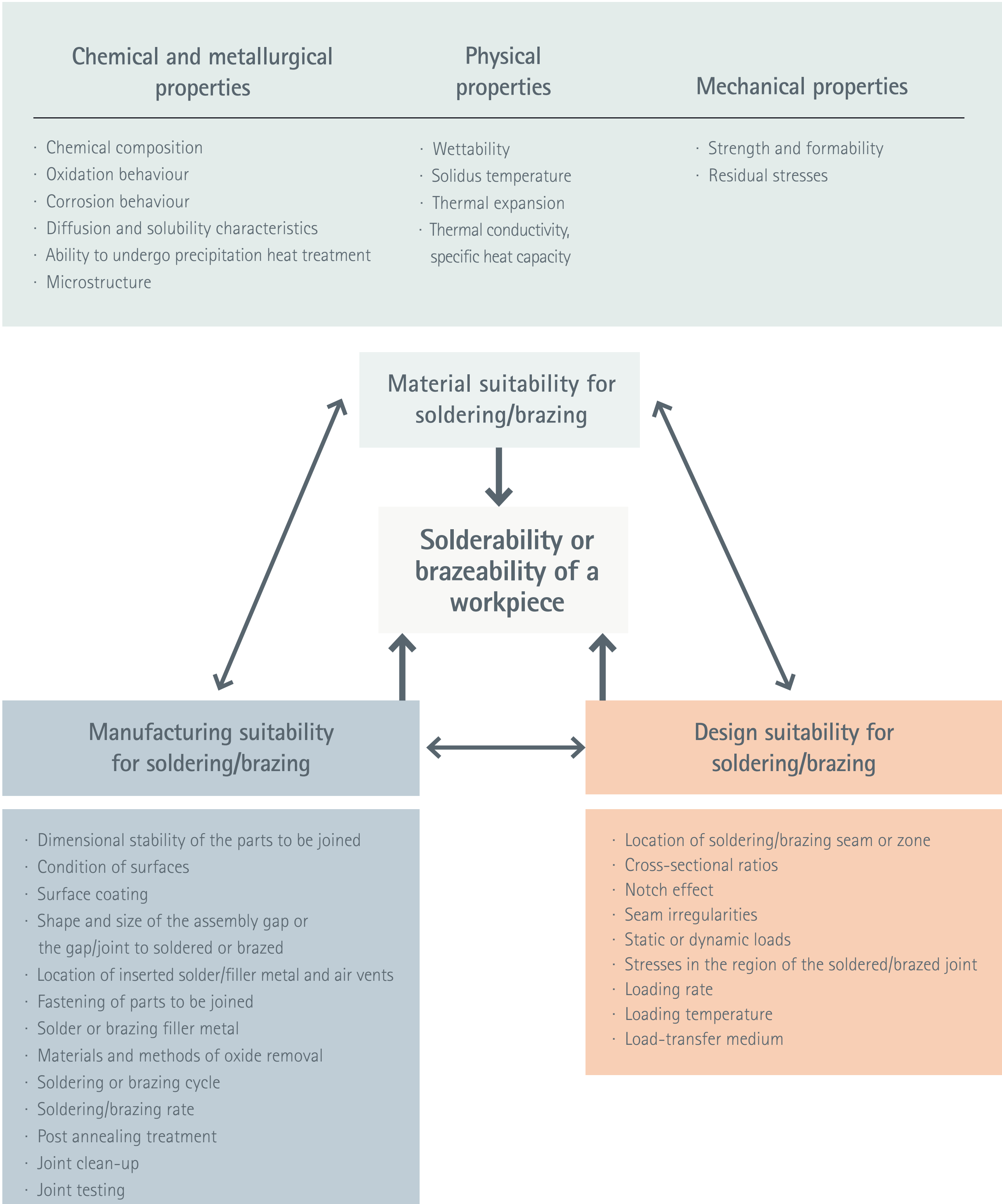


Figure 1 – Definition of solderability/brazeability (see [2])

Like welding, soldering and brazing are important methods of thermally joining materials, typically metals. As it is the resulting joint – irrespective of the method used to make it – that ultimately determines the properties of the part being fabricated, the two methods are classified (see e.g. [3]) in terms of the chemical nature of the joint, the chemical composition of the parent metal (or metals) and the type of filler material used, if any. Both welding and soldering/brazing lead to the formation of a metallic joint, however the chemical composition of these joints differ. Whereas a welded joint has the same chemical composition as that of the two identical parent metals being joined, the use of a filler alloy in a soldering or brazing procedure means that the soldered or brazed joint has a different chemical composition to that of the parent materials. A soldered or brazed joint comprises the heat-affected parent materials, the diffusion/transition phase and the solder/braze metal. The solder metal or braze metal can be formed by the action of heat either with or without a filler material.

Soldering and brazing do not involve any melting of the parent material, i.e. of the surfaces to be joined. Instead, the workpieces are joined by introducing an additional molten metal, the 'filler metal', possibly in combination with a flux and/or in a protective gas atmosphere [4].

Some of the advantages of soldering or brazing compared to other joining methods are: [5]

- soldering/brazing enables dissimilar materials to be joined;
- as less heat is applied in the joining process, soldered or brazed parts tend to exhibit greater dimensional accuracy and less distortion;
- multiple soldered/brazed joints can be created on a single workpiece in a single operation;
- intricate assemblies can be soldered/brazed without damage;
- soldered/brazed joints exhibit good thermal and electrical conductivity; and
- as soldering/brazing directs less heat into the joint than welding, there is less residual stress and distortion in the component.

The following points should, however, be noted: the strength of a soldered or brazed joint is typically not as great as that of the parent material; the parent metal and the solder/braze metal have different chemical potentials; there is a risk of chemical corrosion due to the presence of flux residues; design restrictions may be relevant because of factors such as narrow soldering/brazing gaps and tight dimensional tolerances at the joint. Extensive preparatory and after-treatment procedures are often required, such as degreasing, etching, removal of flux residues, etc. [6]. The related joining techniques of soldering and brazing are distinguished in the DIN ISO 857-2 standard by the liquidus temperature of the filler metal used. In soldering, the liquidus temperature of the filler metal is below 450 °C; in brazing it is above 450 °C. Up until February 2007, high-temperature brazing (at temperatures above 900 °C) was defined in the earlier and now withdrawn DIN 8505 standard. Today, high-temperature brazing is classified simply as brazing.

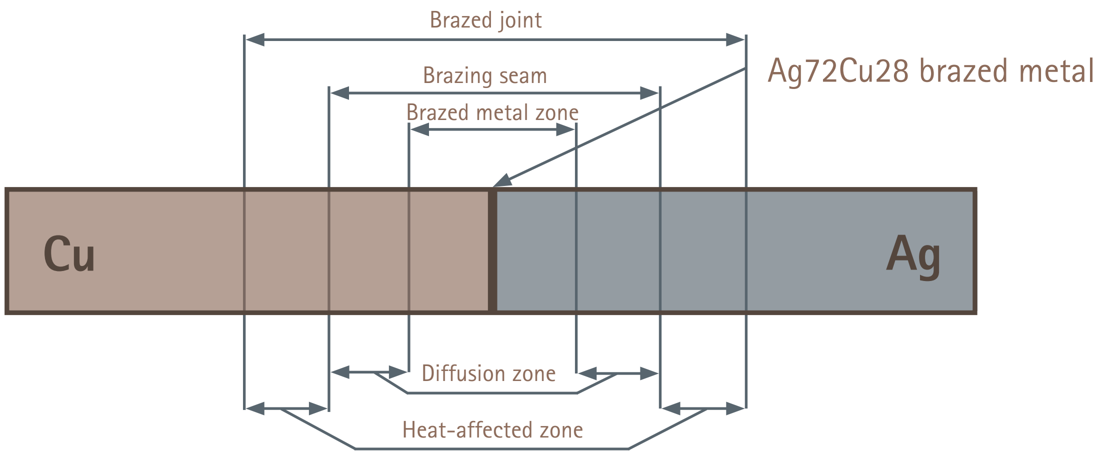
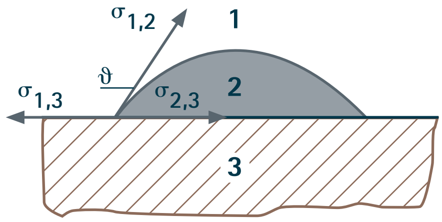


Figure 2 – Example of a brazed copper-silver joint.
(Note that no filler metal was used; the alloy Ag72Cu28 is formed by diffusion during the brazing process.)

Both physical and chemical processes are involved in soldering/brazing. Soldering/brazing joints are created through surface chemical reactions and diffusional processes of the liquid filler metal and the solid parent material. The soldering/brazing mechanism comprises the following steps: [7]

1. Heating of the parts to be joined
2. Surface activation, e.g. by a flux or a shielding gas
3. Flow of filler metal and wetting – the molten filler metal flows into the gap between the mating surfaces or spreads across the surface
4. Formation of the solder/braze metal through (physical and chemical) interaction between the molten filler and the parent material
5. Solidification of the liquid solder/braze metal.

Heat is applied to melt the filler metal and any flux being used. The method used to heat the parts to be joined will depend on the type of join to be created (see Section 4.3). Fluxes serve to activate the surfaces to be joined. The molten filler metal will only be able to wet the surfaces to be joined if they are clean and free from oil, grease and other surface deposits. The wetting process is also influenced by capillary action of the molten filler, adhesion and diffusion processes between the liquid phase and the parent material. figure 3 shows the wetting of the surface by the molten filler metal. The contact angle ϑ is determined by the interaction between the three surface tensions involved in the wetting process: $\sigma_{1,2}$ (vapour-liquid surface tension), $\sigma_{1,3}$ (vapour-solid surface tension) and $\sigma_{2,3}$ (liquid-solid surface tension).



1 Surrounding vapour phase
2 Molten filler
3 Parent material
ϑ Contact angle

$\sigma_{1,2}$ Surface tension between molten filler and the surrounding atmosphere
$\sigma_{1,3}$ Surface tension between the solid base metal and the surrounding atmosphere
$\sigma_{2,3}$ Surface tension between molten filler and solid base metal

Figure 3 - Wetting of a metallic surface with a liquid filler metal [7]

Perfect wetting	Adequate wetting	Dewetting
$\vartheta = 0°$	$\vartheta \leq 30°$	$\vartheta > 90°$

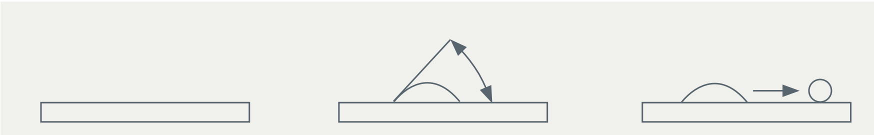
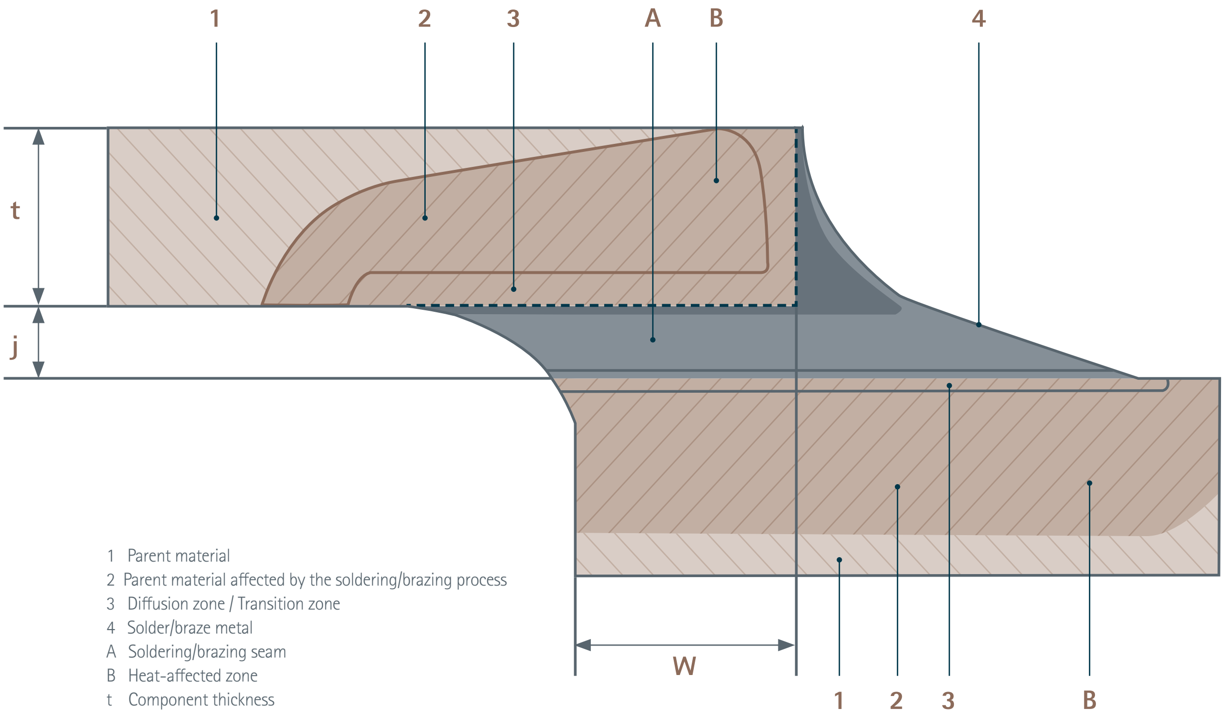


Table 1 – Relationship between contact angle and degree of wetting [7]

The smaller the contact angle, the better the wetting of the surface. Table 1 defines the three regimes 'perfect wetting', 'adequate wetting' and 'dewetting' in terms of the corresponding contact angle.

After soldering or brazing, alloying elements from the filler metal can be found in the parent material and alloying elements from the parent metal are detectable in the filler metal. This change in the chemical composition is referred to as diffusion. Although the parent material does not melt, a diffusion zone is established in the wetted area. An alloying element in the parent material and at least one of the alloying elements in the filler alloy combine to form a solid solution, a eutectic system or an intermetallic compound. Phase diagrams can be consulted prior to soldering/brazing to determine whether any diffusion will occur between the metal pairs. Diffusion is both time- and temperature-dependent. The time spent at the soldering/brazing temperature (the 'holding time') should be as short as possible to prevent extensive alloying within the parent metal or the formation of brittle phases in the transition zones. To achieve optimum strength in the soldered/brazed joint, the filler metal needs to remain in its liquid phase for several seconds so as to create a sufficiently deep diffusion zone [1] [6] [9].

Figure 4 depicts the cross-section of a locally heated soldered/brazed joint. The parent material was heated only in the region of the joint, as would be the case in torch brazing or torch soldering. This localised heating can increase the level of residual stress within the part. If the whole assembly is heated, as in furnace brazing or furnace soldering, the result is lower residual stress and less distortion. In this case, the entire assembly is heated and cooled uniformly, which means that the heat-affected zone covers the entire structure (i.e. all of the parent material). An advantage of this approach is that soldering/brazing can be carried out at the same time as heat treatment (e.g. precipitation hardening) of the workpiece.



1 Parent material
2 Parent material affected by the soldering/brazing process
3 Diffusion zone / Transition zone
4 Solder/braze metal
A Soldering/brazing seam
B Heat-affected zone
t Component thickness
j Effective joint width
W Overlap or lap length

Figure 4 - Schematic diagram of a soldered/brazed joint [10]

2. Material engineering fundamentals

2.1 Fundamentals of copper and copper alloys

Copper is a non-ferrous metal with a density of 8.94 kg/dm³. Copper has a face-centred cubic (fcc) crystal lattice structure and as such retains its excellent ductility and cold-working capacity down to low temperatures. Cold working copper causes an increase in hardness ('strain hardening', 'work hardening').

Copper also exhibits high electrical and thermal conductivity (the ratio of electrical to thermal conductivity is constant) and shows good corrosion resistance to a wide variety of chemical media.

Copper alloys may be classified in terms of the treatment they have undergone:

- **Precipitation hardening alloys** (e.g. CuBe alloys) and
- **Work-hardened alloys (=cold-worked alloys),**

or in terms of their chemical composition:

- **Single-phase materials** ((e.g. pure Cu) or alloys that exist as a solid solution of the elements (e.g. CuNi alloys, single-phase brass) and
- **Multiphase materials** (e.g. two-phase brass alloys) [11].

Copper alloys are also classified as casting alloys, wrought alloys (e.g. strip, wire, tubing, forgings) and sintered alloys. Some of the best-known copper alloys are brasses (copper-zinc alloys) and bronzes (copper-tin alloys), but alloys of copper with nickel, manganese, aluminium, iron, beryllium, chromium and silicon are also common. It should be noted that the terms 'brass', 'bronze', 'Gunmetal' and 'nickel silver' are not standardised, though these designations are still common commercially and elsewhere.

Material group	Coefficient of expansion 10^{-6}/K	Electrical conductivity [MS/m]	Thermal conductivity at 20 °C W/(m·K)	0.2 % yield strength $R_{p0.2}$ approx. N/mm²	Tensile strength Rm min. N/mm²	Elongation after fracture A min. %
Cu	17,0	59,1	393	40 ... 90	200 ... 360	max. 42
CuZn	18,0 ... 20,5	15,0 ... 33,3	117 ... 243	60 ... 500	230 ... 560	4 ... 50
CuNiZn	16,5 ... 19,5	3,0 ... 5,0	27 ... 35	220 ... 660	360 ... 800	8 ... 45
CuSn	17,1 ... 18,5	8,7 ... 11,5	62 ... 84	140 ... 1000	360 ... 1000	30 ... 65
CuNi	14,5 ... 17,6	2,04 ... 6,4	21 ... 48	90 ... 520	290 ... 650	10 ... 40
CuAl	17,0 ... 18,0	5,0 ... 10,0	40 ... 83	110 ... 680	350 ... 830	5 ... 50
Unalloyed steel	12,0	5,5 ... 7,0	48 ... 58	175 ... 355	290 ... 630	18 ... 26

Additional information on these materials is available from the DIN Handbooks 456-2 and 456-3 and from the corresponding material data sheets issued by the German Copper Institute (www.kupferinstitut.de)

Table 2 - Comparison of the physical and mechanical properties of copper, important copper alloys and unalloyed steel

2.2 Filler metals

Copper can form alloys with numerous metallic elements. Many of these alloys are sold commercially as semi-finished products or brazing and soldering filler metals. Filler metals are available in a variety of forms: wires, strips, preforms (see figure 5), powders, pastes, etc. Copper-based filler metals are characterised by their good flow properties, good gap-filling ability and good ductility.

Figure 5 – Filler metal preforms [11]

The filler metals are classified as soft solders or brazing filler metals depending on the liquidus temperature. There are a number of criteria that can be used when selecting a suitable filler metal:

- Type and physical/mechanical properties of the parent material
- Dimensions and manufacturing tolerances of the workpiece
- Stresses at the soldered/brazed joint
- Operating temperatures and pressures
- Ambient conditions at the soldered/brazed joint (e.g. aggressive media)
- Cost-efficiency
- Work safety
- Soldering/brazing method [6].

Phase diagrams can be consulted in order to determine key temperatures (melting points, eutectic temperature), the mutual solubility of the elements and the phases present (solid solution, eutectic phases). It is important to realise that the phase diagrams only apply under equilibrium conditions. The phase diagram for the binary silver-copper system is shown in figure 6. The phase diagram has a number of different phase fields that are separated from one another by phase boundary lines. Important phase boundary lines are the liquidus and the solidus curves. The liquidus curve separates the higher lying region L, which represents the homogeneous liquid phase and the liquid-solid phase lying below. The solidus line represents the boundary between the solid phase and the liquid-solid phase. The phase diagram for the copper-silver binary system also shows that there is a eutectic point at one specific chemical composition (72 % silver, 28 % copper). The eutectic alloy solidifies like a pure metal, i.e. there is no solidus temperature and no liquidus temperature, the molten mixture undergoes an instantaneous phase transition from the liquid to the solid state. Solidification at 780 °C is significantly below the melting points of the pure elements in the alloy (Cu and Ag). When the eutectic mixture solidifies, numerous crystal nuclei are formed that hinder each other's growth resulting in a uniform, finely divided microstructure with good mechanical properties. This is the reason why eutectic alloys, such as Ag72Cu28, are frequently used in technical and engineering applications [13].

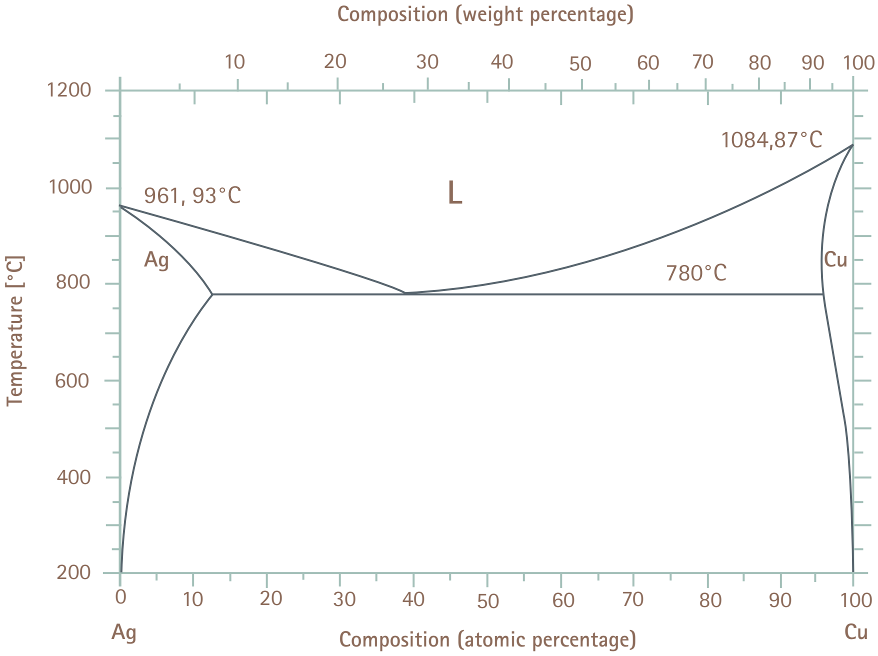


Figure 6 – Silver-copper phase diagram (from [14])

2.2.1. Soft solder alloys

The filler metals used for soldering melt at temperatures below 450 °C. The low strength of soft solder alloys and of the resulting soldered joint make these filler materials suitable for applications that are subjected to low mechanical loads. They find most frequent use in electrical and electronic applications. Soft solder alloys can be selected using the DIN EN ISO 9453 (2014) or the DIN 1707-100 (2011) standards.

In the past lead solders were often used to solder copper pipes and tubing. The presence of lead improves the flow characteristics of the solder, produces bright smooth surfaces and requires only moderate soldering temperatures. However, lead is environmentally harmful and a recognised carcinogen. Since 1 July 2006, the inclusion of lead in solders has been prohibited by the RoHS Directive 2002/95/EC of the European Parliament and of the Council on the restriction of the use of certain hazardous substances in electrical and electronic equipment (later superseded by Directive 2011/65/EU in 2011). At present, exceptions exist that permit the use of high-lead solders in certain sectors, such as medical, security and aerospace technologies. In the electronics industry, lead-free tin solders are now frequently used as a an alternative. There is, however, a risk of the formation of tin whiskers on the surface of the metal. Whiskers are filiform single crystals (diameter: approx. 1 µm; length: several millimetres) that can cause short circuiting and thus damage to electronic components. These crystals grow very slowly so that they may take years to appear. Possible reasons for whisker growth include residual stresses in plating layers due to the presence of organic inclusions/contamination, and mechanically induced stresses when tinned materials are processed. Lead-free alternatives for soft solders include tin-copper, tin-silver and tin-copper-silver alloys. It should be noted that the price of the solder increases the more silver it contains. In its technical application note GW 2, the German Technical and Scientific Association for Gas and Water (DVGW) stipulates the use of the solders Sn97Ag3 and Sn97Cu3 for drinking water applications. Antimony-free solders are used for fine soldering applications, antimony-containing solders and low-antimony solders are used for coarse soldering work in, for example, the manufacture of condensers and cooling units, in the electrical industry or for plumbing and installation work. Zinc-based and cadmium-based soft solders are used but are less common. Unlike brazing filler materials that contain cadmium, cadmium-containing solders are not prohibited. However, as cadmium is regarded as harmful to health, the accident prevention regulations (as published in Germany by the relevant employers' liability insurance associations) must be observed [15].

Group	Alloy designation in acc. with		Melting range (solidus/ liquidus) in °C	Average chemical composition			Preferred soldering method				Areas of use
	DIN EN ISO 9453 (2014)	DIN 1707-100 Part 100 (2011)		Sn	Pb	Cu	T	I	H	D	
Soft solders with copper	Sn50Pb49Cu1 (162)	–	183/ 215	50	bal.	1,4			X		Electrical, electronics
	–	S-Sn60Pb40Cu	183/190	60	bal.	0,15				X	Electrical, electronics, PCBs
	Sn60Pb39Cu1 (161)	–	183/190	60	bal.	1,4			X	X	
	Sn97Cu3 (402)	–	227/310	bal.	0,07	3	X	X	X	X	Installation of copper piping/tubing, metal goods
Soft solders with silver				Sn	Pb	Ag					
	–	S-Sn50Pb46Ag4	178/210	50	bal.	3,5			X	X	Electrical, electronics, PCBs
	–	S-Sn63Pb35Ag2	178	63	bal.	1,4		X	X	X	
	Sn96,3Ag3,7 (701)	–	221/228	bal.	0,07	3,7	X	X	X	X	Installation of copper piping/tubing; electrical
	Sn97Ag3 (702)	–	221/224	bal.	0,07	3	X	X	X	X	
				Ag	Cd	Zn					
	–	S-Cd82Zn16Ag2	270/280	2	bal.	16	X		X		Electrical, electric motors
	–	S-Cd73Zn22Ag5	270/310	5	bal.	22	X		X		
	–	S-Cd68Zn22Ag10	270/380	10	bal.	22	X		X		
				Ag	Pb	Others					
	Pb98Ag2 (181)	–	304/305	2,5	bal.	Sn 0,25	X		X		Electrical, electric motors
	Pb95Ag5 (182)	–	304/370	5,5	bal.	Sn 0,25	X		X		for high operating temperaturesr
	–	S-Pb95Sn3Ag2	304/310	1,75	bal.	Sn 2,0	X		X		Electrical, electric motors
	–	S-Cd95Ag5	340/395	5	0,1	bal. Cd	X				for high operating temperatures
Soft solders with phosphorous				Sn	Pb	P					
	–	S-Pb50Sn50P	183/215	50	bal.					X	Electronics, PCBs, particularly drag, wave and dip soldering
	–	S-Sn60Pb40P	183/190	60	bal.					X	
	–	S-Sn63Pb37P	183	63	bal.					X	
	–	S-Sn60Pb40CuP	183/90	60	bal.					X	
Other soft solders				Sn	Pb	Others					
	Sn50Pb32Cd18 (151)	–	145	50	bal.	Cd18	X	X	X	X	Fine soldering and cable
	–	S-Sn80Cd20	180/195	bal.	0,05	Cd20		X	X	X	Electrical engineering
	Sn95Sb5 (201)	–	235/240	bal.	0,07	Sb 5	X		X	X	Industrial refrigeration

D-Dip soldering; H-Hot-iron soldering; I-Induction soldering; T-Torch soldering

Table 3 - Soft solders for copper and copper alloys as classified in the DIN EN ISO 9453 (2014) and DIN 1707-100 (2011) standards

2.2.2. Brazing filler metals

The filler metals used to braze copper and copper alloys are typically copper-based, silver-based and brass-based alloys that are suitable for fabricating joints able to withstand higher levels of mechanical stress. Brazing temperatures are usually within the approximate range 500–1000 °C. DIN EN ISO 17672 (2010) divides brazing filler metals into classes. The filler metal classes suitable for brazing copper are: 'Class Cu' (copper), 'Class CuP' (copper-phosphorus), 'Class Ag' (silver alloy) and 'Class Au' (gold alloy).
Copper-zinc brazing filler metals are recommended for brazing pure copper and high-melting copper alloys. As the amount of zinc in the brazing alloy rises to about 40 %, the melting temperature decreases while the strength of the material increases, which is why brass filler rods typically have a zinc content not exceeding 40 %. Small amounts of silicon (0.1 % to 0.2 %) are often added to avoid the formation of voids in the joint caused by zinc vaporisation and hydrogen absorption. Torch brazing (also known as 'flame brazing') is carried out using a slightly oxidising flame of moderate intensity [16].

As an alloying element, phosphorous shows low solubility in copper and is present mainly as the intermetallic compound copper(I) phosphide (Cu_3P). The mechanical properties of copper-phosphorous filler metals are determined by size, shape and arrangement of the Cu_3P particles, whose precipitation is a function of the phosphorous content. If the phosphorous content of the filler metal is above 7 %, the brazed structure cannot be cold worked. However, at temperatures of about 300 °C and above, all copper-phosphorus brazing filler metals exhibit excellent formability. Filler metals with a wide melting range (e.g. CuP 179) can be used for brazing assemblies with large joint clearances. As phosphorus has a deoxidising effect, copper-phosphorus filler metals tend to be self-fluxing and can therefore be used to braze copper and to a certain extent bronze (CuSn6) surfaces without requiring the use of a flux. This is because at high temperatures the phosphorus in the copper reacts with the oxygen in the air to form phosphorus pentoxide, which itself then reacts with the Cu(I) and Cu(II) oxides on the surface of the parent copper to yield copper metaphosphate. By chemically reducing the oxide layer in this way, the surface of the parent copper becomes wettable.
Silver alloy filler metals and copper-phosphorus filler metals with the appropriate DVGW or RAL quality mark are used for brazing gas and water pipes. Silver alloy filler metals have relatively low melting temperatures and exhibit good wettability and adequate corrosion resistance in a variety of media. Silver-copper-phosphorus filler metals are particularly well suited for brazing copper, Gunmetal, copper-tin and copper-zinc alloys. Up until 2011, cadmium was added to brazing filler metals to further lower the melting temperature. Since December 2011, the use of cadmium-containing filler metals for brazing applications has been prohibited by EU (Regulation (EU) 494/2011). They may only be used for safety reasons or for defence or aerospace applications.

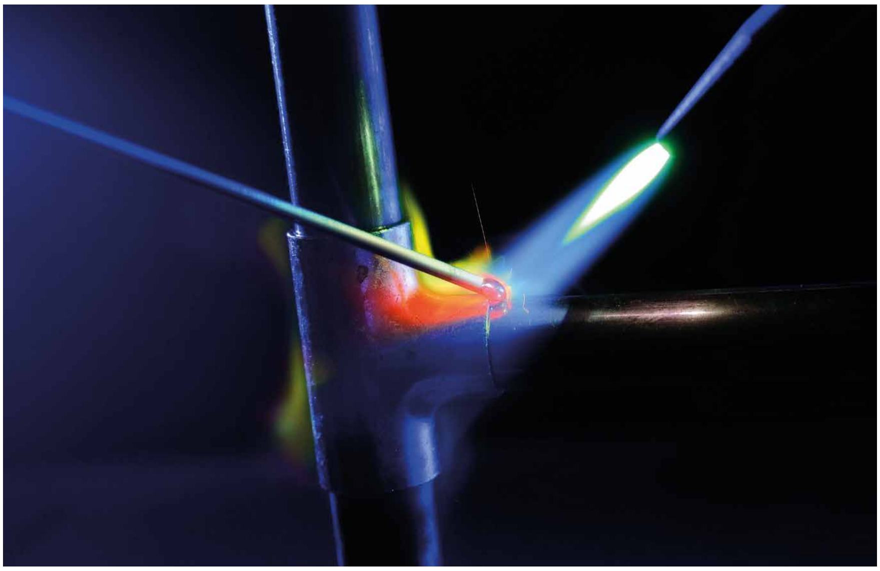


Figure 7 – Torch brazing a copper tube joint [12]

Designation in acc. with			Average chemical composition (mass fractions in %)	Melting range in °C Brazing temperature in °C		Usage notes		
DIN EN ISO 17672 (2010)	DIN EN 1044 (1999; previous standard)	DIN EN ISO 3677 (1995)		Sol.	Liq.	Parent material	Gap width	Application of filler metal
			Copper-based brazing filler metals			Cu-Zn-alloys		
Cu 470a	Cu 301	B-Cu60Zn (Si)-875/895	60Cu; 0,3Si; Rest Zn	875	895	Copper and copper alloys with a solidus temperature above 950 °C	narrow or wide	hand-fed or inserted
Cu 471*1	Cu 304*2	B-Cu60Zn(Sn)(Si)(Mn)-870/890	58*1 Cu/ 60*2 Cu; 0,175*1 Si/0,275*2 Si; 0,35Sn; 0,15Mn; bal. Zn	870	900		narrow or wide	
			Copper-phosphorus brazing filler metals			CuP-alloys		
CuP 182	CP 201	B-Cu92P-710/770	bal. Cu; 7,8 P	710	770	Preferentially copper, Gunmetal, copper-zinc alloys (brasses), copper-tin alloys (bronzes)	narrow	hand-fed or inserted
CuP 180	CP 202	B-Cu93P-710/820	bal. Cu; 7P	710	820			
CuP 179	CP 203	B-Cu94P-710/890	bal. Cu; 6,2P	710	890			
			Copper-phosphorus brazing filler metals			Ag-CuP-alloys		
CuP 284	CP 102	B-Cu80AgP-645/800	15Ag; 5P; bal. Cu	645	800	Copper, Gunmetal, copper-zinc alloys (brasses) and copper-tin alloys (bronzes)	narrow	hand-fed or inserted
CuP 281	CP 104	B-Cu89AgP-645/815	5Ag; 6P; bal. Cu	645	815		narrow or wide	
CuP 279	CP 105	B-Cu92AgP-645/825	2Ag; 6,3P; bal. Cu	645	825			
			Silver alloy brazing filler metals			Ag-Cu-Zn-alloys		
Ag 212	AG 207	B-Cu48ZnAg(Si)-800/830	12Ag; 48Cu; 40Zn; 0,15Si	800	830	Copper and copper alloys	narrow	hand-fed or inserted
Ag 205	AG 208	B-Cu55ZnAg(Si)-820/870	5Ag; 55Cu; 40Zn; 0,15Si	820	870		narrow or wide	

Table 4 - Selection of copper-based filler metals for brazing copper and copper alloys

Designation in acc. with			Average chemical composition (mass fractions in %)	Melting range in °C		Usage notes		
DIN EN ISO 17672 (2010)	DIN EN 1044 (1999; Vorgängernorm)	DIN EN ISO 3677 (1995)		Sol.	Liq.	Parent material	Gap width	Application of filler metal
				Ag-Cu-Zn-Sn-alloys				
Ag 156	AG102	B-Ag56CuZnSn-620/655	56Ag; 22Cu; 17Zn; 5Sn	620	655	Copper alloys	narrow	hand-fed or inserted
Ag 145	AG 104	B-Ag45CuZnSn-640/680	45Ag; 27Cu; 2,5Sn; 25,5Zn	640	680	Copper and copper alloys		
Ag 140	AG 105	B-Ag40CuZnSn-650/710	40Ag; 30Cu; 2Sn; 28Zn	650	710			
Ag134	AG 106	B-Cu36AgZnSn-630/730	34Ag; 36Cu; 2,5Sn; 27,5Zn	630	730			
Ag 130	AG 107	B-Cu36ZnAgSn-665/755	30Ag; 36Cu; 2Sn; 32Zn	665	755			
Ag 125	AG 108	B-Cu40ZnAgSn-680/760	25Ag; 40Cu; 2Sn; 33Zn	680	760			
Ag 244	AG 203	B-Ag44CuZn-675/735	44Ag; 30Cu; 26Zn	675	735			
Ag 230	AG 204	B-Cu38ZnAg-680/765	30Ag; 38Cu; 32Zn	680	765			
Ag 225	AG 205	B-Cu40ZnAg-700/790	25Ag; 40Cu; 35Zn	700	790			
				Ag-Cu-Zn-Ni-Mn-alloys				
Ag 450		B-Ag50CuZnNi-660/705 50Ag; 20 Cu; 28Zn		660	750	Copper alloys	narrow	hand-fed or inserted
				Zinkfreie Ag-Cu-Lalloys (without zinc)				
Ag 272	AG 401	B-Ag-72Cu-780	72Ag; 28Cu	780	780	Copper and copper alloys	narrow	inserted

Table 5 - Selection of silver alloy filler metals containing more than 20 % silver for brazing copper and copper alloys

2.3. Soldering or brazing pure copper

Copper is very well suited to both soldering and brazing. Care must be taken to ensure that the oxide layers on the surfaces to be joined have been properly removed by mechanical or chemical cleaning. The most commonly used cleaning agents are: isopropanol, ethanol, acetone, aqueous cleaner and nitric acid. The soldering/brazing (or tinning) process should take place immediately after the surfaces have been prepared. Table 6 presents a selection of copper metals that are particularly well suited to soldering or brazing.

Designation	Material number	Composition [%]			Suitability for soldering/ brazing	Area of use
		Cu min.	O max.	P		
Oxygen-containing copper						
Cu-ETP	CW004A	99,9	0,04	–	Soldering: v. good; Brazing: good (not for torch brazing)	Electrical
Deoxidised copper (with phosphorus), oxygen-free						
Cu-HCP	CW021A	99,95	–	0,002-0,007	Soldering: v. good; Brazing: v. good	Electrical, cladding
Cu-DHP	CW024A	99,90	–	0,015-0,040	Soldering: v. good; Brazing: v. good	Construction, piping/tubing
Oxygen-free copper, non-deoxidised						
Cu-OFE	CW009A	99,99	–	–	Soldering: v. good; Brazing: v. good	Vacuum technology, electronics

Additional information on these materials is available from DIN CEN/TS 13388 and from the corresponding material data sheets issued by the German Copper Institute (www.kupferinstitut.de)

Table 6 - Selected types of copper

Soldering

Electronics is one of the main areas of application of copper soldering. The solders most commonly used for soldering electronic components are the tin-based filler alloys as defined in DIN EN ISO 9453 (2014) and DIN 1707-100 (2011). The filler alloys used for electrical and electronic soldering applications are usually unleaded. Lead-containing solders may only be used in exceptional cases, as listed in the Annex to 'Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment' (RoHS).

Components of electric motors that are subjected to high temperatures during operation should be preferentially soldered using soft solders that have a higher solidus temperature. Soldered joints made with these solders usually tend to show a higher shear strength than those made with tin-lead solders. The short-term shear strengths of lap joints made with these solders have been shown to be about 20 N/mm^2. Lead-free soft solders are also preferred when joining copper piping that carries drinking water (see DVGW technical application note GW 2) or when the soldered joint will be exposed to low temperatures, e.g. in industrial refrigeration applications. In some cases, the strength of a soldered lap joint between two tubular parts is greater than that of a brazed joint, as the brazing process can reduce the strength of the copper parent metal. Soldered joints that will be subjected to higher temperatures should be made with lead-free, thermally stable solders that can withstand permanent temperatures of up to 120 °C without damage.

Like wrought copper, copper casting alloys as defined in DIN EN 1982 (2008) can be soldered without difficulty.

Designation	Specific examples	Selected areas of use	Flux
Antimony-containing solders	Pb88Sn12Sb Sn60Pb40Sb	Manufacturing of condensers and cooling units	2.1.1 2.1.2 2.1.3 2.2.2 2.2.3
Low-antimony solders	Pb60Sn40 Sn60Pb40	Tinning, plumbing, galvanised thin sheet	
Antimony-free solders	Sn60Pb40E	Electrical and Electronics	1.1.1 1.1.2 1.1.3
Lead-free solders for electronic applications	Sn99Cu1 Sn96Ag4 Sn96Ag3Cu1 Sn95Ag4Cu1	Electrical and electronics	1.1.2 1.1.3 1.2.3
High-lead, RoHS-compatible soft solders	Pb93Sn5Ag2 Pb98Sn2 Pb98Ag2	For operating temperatures up to 200 °C	1.1.2 1.1.3 1.2.3
Lead-free solders for drinking water pipes	Sn97Ag3 Sn97Cu3	Drinking water piping Other important applications in the DVGW regulations	2.1.2 3.1.1 3.1.2
Lead-free solders for low-temperature applications	Sn95Sb5 Sn97Ag3 Sn95Ag5	Industrial refrigeration	3.1.1

Table 8 – Filler metals suitable for brazing copper

Brazing
Brazing is used if the joint will be subjected to high mechanical and thermal stresses. When brazing copper, the filler metals of choice are brass brazing alloys, copper-phosphorus and silver brazing alloys. Silver brazing filler metals have lower brazing temperatures, which reduces the risk of forming coarse grains and enables faster brazing speeds
It is important to consider the oxygen content of the parent copper when selecting the brazing method. Brazing oxygen-containing copper can cause hydrogen embrittlement, i.e. the formation of cracks and voids after contact with hydrogen-containing gases. Types of copper susceptible to this problem include those used in electrical and electronic applications. At high temperatures (above 500 °C), hydrogen diffuses into the copper and reacts with the oxygen in the copper to form water. As hydrogen embrittlement is more likely to occur in torch brazing or when brazing in a reducing atmosphere, induction brazing or vacuum brazing are preferred. If torch brazing has to be performed, the parent metal should be an oxygen-free and/or deoxidised copper in order to avoid hydrogen embrittlement.

Brazing filler metal class	Specific examples as defined in DIN EN ISO 17672 (2010)	Notes	Example flux
Silver alloy brazing filler metals (Class Ag)	Ag 244 Ag 134 Ag 145	· suitable for drinking water pipes · composed primarily of Ag, Cu, Zn · Brazing temperature: approx. 650–830 °C	FH10
Copper-phosphorus brazing filler metals (Class CuP	CuP 182 CuP 180 CuP 179 CuP 284 CuP 281 CuP 279	· no flux necessary due to presence of phosphorus · recommended joint clearance for P content of 5 %: 0.125 mm · Brazing temperature: approx. 650–730 °C	–
Brass brazing filler metals (Class Cu)	Cu 470a Cu 470 Cu 680 Cu 681	· suitable for brazing solid structures · composed primarily of Cu and Zn · Brazing temperature: approx. 870–920 °C	FH10

Table 8 – Filler metals suitable for brazing copper

2.4. Soldering / brazing copper alloys

A copper alloy consists of copper and at least one other metal. Alloying produces a new material with new properties. Some of the most well-known copper alloys include brass, nickel silver, bronze and Gunmetal.

2.4.1. Low-alloyed copper alloys

Low-alloy coppers contain up to about 5 % of alloying elements. One characteristic feature of these alloys is their behaviour at low temperatures, with no embrittlement observed even down to -200 °C. Copper alloys not included in this group are CuZn5, CuSn2, CuSn4, CuSn5, CuAl5As and CuNi2, as these are classified as belonging to the copper-zinc, copper-tin, copper-aluminium and copper-nickel alloy groups. The compositions of low-alloyed coppers are specified in DIN CEN/TS 13388 (2013). A distinction is made between heat-treatable/hardenable and non-heat-treatable/ hardenable wrought copper alloys. In the case of heat-treatable alloys, such as CuBe2, CuCr1Zr and CuNi1Si, material strength can be improved not only by suitable heat treatment (precipitation hardening), but also by cold working. In contrast, the strength of the non-heat-treatable wrought copper alloys, such as CuAg0,10, CuSi1 and CuSn0,15, can only be achieved by cold working [17]. Further information on low-alloyed copper alloys is available in the DKI monograph i8 (2012).

Cold-worked (work hardened) alloys

Copper-silver

Copper-silver alloys such as CuAg0,10 (CW013A) and CuAg0,10P (CW016A) are characterised by their high electrical and thermal conductivity values. These alloys are particularly well suited to applications in which they are subject to continuous loads at high temperatures, as is the case in many electrical engineering applications. The presence of silver raises the alloy's softening temperature (to about 350 °C in an alloy with 0.1 % Ag) without having a detrimental effect on electrical conductivity. Copper-silver alloys are standardised in DIN CEN/TS 13388 (2013) and are very well suited to both soldering and brazing.

Soldering is best carried out with lead-free, tin-based solders (e.g. Sn99Cu1). Suitable fluxes for electrical applications are those in the classes 3.1.1, 2.1.1 and 1.1.1 and 1.2.3. Because of the high softening temperature of the parent metal, soldering, if performed correctly, does not have a detrimental effect on the high strength achieved through cold working.

Brazing, however, is carried out at higher temperatures and thus produces a significant reduction in the strength of work-hardened copper-silver alloys. Oxygen-free deoxidised alloys such as CuAg0,10P (CW016A) containing 0.001 % to 0.007 % of phosphorus or another deoxidising element, like lithium, are the most suitable parent metals for brazing applications. Generally speaking, brazing can be carried out with most silver alloy brazing filler metals using a flux such as FH10. If the electrical conductivity of the brazed joint is particularly crucial, fluxless brazing can also be carried out using the filler metal Ag 272 (Ag72Cu28) under vacuum or in a reducing atmosphere. No flux is required when brazing with a phosphorus-containing brazing filler metal. The heating zone created when brazing should be kept as small as possible so that any reduction in material strength is localised, though it is very important to make sure that the brazing temperature is attained across the entire area to be brazed.

Copper-iron

The copper-iron alloy CuFe2P (CW107C) contains between 2.1 % and 2.6 % of iron as well as the alloying elements phosphorus and zinc. This material exhibits high thermal and electrical conductivity as well as high tensile strength and a high softening temperature. CuFe2P is therefore mainly used for electrical applications and large quantities are used in the fabrication of lead frames in chip packages (see figure 8).

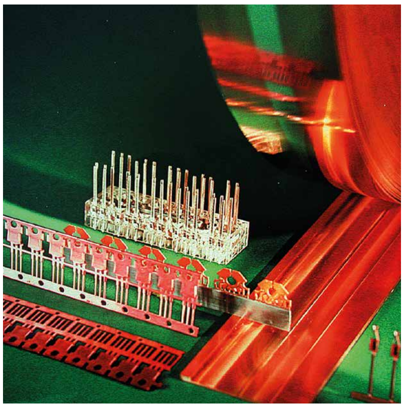


Figure 8 – Lead frames [17]

Soldering can be carried out using tin-copper solders that conform to DIN EN ISO 9453:2014, such as Sn99.3Cu0.7, and using fluxes in class 3.1.1.

For *brazing* applications, silver alloy, copper and phosphorus brazing filler metals may be used in combination with FH10 fluxes.

Copper-lead

The CuPb1P (CW113C) alloy contains between 0.7 % and 1.5 % lead to improve its machinability. A trace phosphorus content in the range 0.003 % to 0.012 % ensures a high level of deoxidation in the material and safeguards against hydrogen embrittlement. CuPb1P has a very high electrical conductivity. It is often used instead of pure copper whenever both good machinability and good electrical conductivity are required, such as when fabricating screw-machine products from a high-conductivity material. The presence of lead means that this alloy shows only limited weldability. CuPb1P is also not well suited for brazing, but it can be soldered successfully.

As is the case with pure copper, *soldering* is carried out using tin-lead soft solders containing between 40 % and 60 % tin. Class 3.1.1 fluxes are recommended. For electrical applications, lead-free tin-based solders are used in combination with non-corrosive fluxes (e.g. 1.1.2 or 1.1.3).

If *brazing* cannot be avoided, it is recommended that a silver alloy brazing filler metal with a low brazing temperature (e.g. Ag 156) is used together with a flux of type FH10.

Copper-Sulphur

The copper-sulphur alloy CuSP (CW114C) contains between 0.2 % and 0.7 % sulphur to improve the machinability of the alloy while maintaining the material's high electrical conductivity. The phosphorus content of between 0.003 % and 0.012 % makes the alloy resistant to hydrogen embrittlement.

For information on solders, see section on copper-silver.

Silver alloy filler metals in combination with FH10 fluxes are recommended for brazing applications. Brazing reduces the strength of the cold-worked copper-sulphur alloy back to that of the material in its original not cold worked condition.

Copper–tellurium
The copper-tellurium alloy CuTeP (CW118C) with 0.4–0.7 % tellurium and 0.003–0.012 % phosphorus has the same properties as the copper-sulphur alloy described above.

For information on *solders*, see section on copper-silver.

By adding tellurium to the alloy composition, the temperature at which tempering causes a loss of strength in the material (stress relaxation resistance) can be raised to about 300 °C. If soldering is performed correctly, it is possible to avoid any significant reduction in the strength of the cold-worked alloy.

Brazing is usually carried out using silver alloy filler metals and a type FH10 flux. However, brazing reduces the strength of the worked-hardened parent metal back to that of the material in its original untreated state.

Copper–zinc
The alloy CuZn0.5 (CW119C) contains between about 0.1 % and 1.0 % zinc and up to 0.02 % phosphorus. CuZn0.5 exhibits high electrical conductivity, has excellent cold working properties, is resistant to hydrogen embrittlement and is also well suited for both welding and brazing. Its main area of application is therefore semiconductor technology where the alloy is used for manufacturing lead frames. As the alloy also exhibits good deep-drawing capabilities it also finds frequent use in the production of hollow ware of all kinds and of heat exchanger elements.

For information on *solders*, see section on copper-silver.
Rapid soldering does not lead to any softening of the cold-worked parent material.

Brazing is usually carried out with silver alloy filler metals and a type FH10 flux.

Heat-treatable/hardenable alloys
If cold-worked wrought copper alloys are brazed, they tend to suffer some loss of material strength in the region that is heated. In the case of heat-treatable/hardenable alloys, in contrast, certain types of brazing can be used without having a negative impact on the material's mechanical properties. In fact in furnace brazing, the brazing step and the heat treatment can be combined into a single operation.

Copper–beryllium
The copper-beryllium alloys CuBe 1.7 (CW100C) and CuBe2 (CW101C) with 1.6–2.1 % beryllium exhibit average electrical conductivity, very high tensile strength in their hardened state and a high degree of thermal stability. Copper-beryllium is used in a wide variety of applications, such as in the manufacture of membranes, wear-resistant components and non-sparking tools. Parts that are to be soldered or brazed should be free of grease and cleaned by acid pickling. Once the parent alloy has been prepared, soldering or brazing should be carried out immediately before the surfaces to joined become tarnished. If it is not possible to solder or braze the parent material immediately, the surfaces to be joined should be plated with a thin protective coat of copper, silver or tin that acts as a compound layer and improves surface wettability.

Soldering is always carried out after the hardening stage using solders with a flow temperature below the typical softening temperature of the copper-beryllium parent metal. Soldering is typically carried out using the lead-free solder Sn60Pb39Cu1. Copper-containing solders such as Sn97Cu3 can also be used. Depending on the nature of the surfaces to be joined, fluxes of type 3.2.2 or 3.1.1 can be used. Pre-tinned parts can be soldered using rosin-based (colophony-based) fluxes of type 1.1.2 or 1.1.3.

Where possible, brazing should be carried out between the solution treatmentstage and the precipitation hardening (heat treatment) stage. In most cases, low-melting silver alloy filler metals with low brazing temperatures in the range 650–670 °C, such as Ag 156, are used in combination with low-melting fluxes that contain high-activity fluorides. In order not to compromise the later precipitation hardening stage, the brazing joint must be heated rapidly (it may even be necessary to cool the areas surrounding the joint) and the part quenched once the filler metal has solidified. Rapid brazing is essential, as even a brazing time exceeding 30 seconds will impair the ability of the parent material to respond to precipitation hardening. High-melting brazing alloys, such as Ag 272 (Ag72Cu28) which melts at 780 °C, are available for special cases. Though high, the melting temperature is always within the solution annealing range. Because of the greater propensity for oxidation at these temperatures, brazing under a shielding gas with a flux is recommended. In order to ensure that the material can undergo subsequent precipitation hardening, the brazed parts are held at about 760 °C until the filler metal has solidified and are then quenched in water.

Copper–beryllium–lead
The alloy CuBe2Pb (CW102C) has properties similar to those of CuBe2. The presence of lead does, however, improve the machinability of the alloy. CuBe2Pb can be soldered and brazed in a manner analogous to the copper-beryllium alloys.

Copper-cobalt-beryllium
The alloy CuCo2Be (CW104C) with between 2.0 and 2.8 % cobalt and 0.4 to 0.7 % beryllium is a highly conductive copper-beryllium alloy. Compared with the binary copper-beryllium alloys, CuCo2Be is of slightly lower strength but exhibits more than double the electrical conductivity while also having a significantly higher thermal stability. This alloy is used mainly to manufacture electrically conducting and thermally stressed springs, as well as components for the plastic processing industry and resistance welding electrodes.

The information on soldering and brazing copper-beryllium alloys applies for the most part also to copper-cobalt-beryllium. If it is important to retain the strength of the precipitation hardened state, low-melting silver alloy filler metals should be used and soldering/brazing times kept short.

Copper-nickel-beryllium
Shortages in the supply of cobalt led to the development of the alloy CuNi2Be (CW110C), in which the cobalt in copper-cobalt-beryllium alloy is replaced by nickel. The mechanical and physical properties of this alloy are equivalent to those of CuCo2Be. In terms of soldering and brazing, the two alloys behave very similarly. The advantage of a CuNi2Be alloy compared with a CuCo2Be alloy is that the former exhibits slightly higher electrical and thermal conductivity values.

Copper-nickel-silicon
Copper-nickel-silicon alloys, such as CuNi1Si (CW109C), CuNi2Si (CW111C), CuNi3Si (CW112C) with between 1.0 and 4.5 % nickel and 0.4 to 1.3 % silicon, are materials that have average electrical conductivity values but high tensile strengths. They are used primarily for the production of screws, bolts and overhead line hardware. They are also being used increasingly for connector plugs in the automotive industry.

Here, too, soldering temperatures are below the precipitation hardening temperature so that soldering does not have any appreciable effect on the mechanical properties of the parent material. Suitable solders are tin-lead solders used in combination with fluxes in class 3.1.1.

It is recommended that brazing is carried out using low-temperature silver brazing alloys together with fluxes of type FH10. The strength of the parts being brazed can be detrimentally affected at high brazing temperatures or if brazing times are long.

Copper-chromium-zirconium
The alloy CuCr1Zr (CW106C) contains 0.5–1.2 % chromium and 0.03–0.3 % zirconium. In contrast to the binary copper-chromium alloy, copper-chromium-zirconium shows higher notch strength at elevated temperatures and is often now preferred in applications in which CuCr1 (CW105C) was formerly used. The alloy exhibits high strength at room temperature, has a high softening temperature and improved creep rupture strength, even at elevated temperatures.

As the heat-treated (i.e. precipitation hardened) parts have a high stress relaxation resistance, soldering can normally be carried out without any loss of material hardness. Suitable solders include the tin-lead solders, but more common solders are the lead-free varieties, such as Sn95Ag5 , Sn97Ag3 or Sn95Sb5 in combination with a flux of type 3.1.1.

For brazing applications, low-melting silver brazing filler metals are used with type FH10 fluxes. The brazing heating cycle should be kept as short as possible in order to avoid the time-dependent softening of the parent metal at the elevated temperatures used in brazing.

Copper-zirconium
The copper-zirconium alloy CuZr (CW120C), which contains between 0.1 % and 0.3 % zirconium, is insensitive to annealing in a hydrogen-containing atmosphere. The alloy exhibits a very high electrical conductivity and stress relaxation resistance as well as superior strength and creep rupture strength. At high temperatures, however, there is a risk of oxidation due to the high affinity of zirconium for oxygen.

No special aspects need to be taken into account when soldering this alloy. As the alloy has a high softening temperature, high-melting solders can be used. If fluxes of type 3.2.2 are not permitted because of corrosion, a flux of type 2.1.2, 2.2.2 or 1.1.2 should be used.

If brazing is performed with a filler metal whose melting temperature is above the softening temperature of copper-zirconium, brazing times must be kept short to avoid reducing the strength of the hardened parent metal. The softening temperature rises the more zirconium is present in the alloy; with 0.2 % zirconium, the softening temperature is around 575 °C.

Copper-chromium
The copper-chromium alloy CuCr1 (CW105C) contains between 0.5 % and 1.2 % chromium. It is a wrought copper alloy that because of its reduced notch strength at elevated temperatures has now been largely replaced by the copper-chromium-zirconium alloy described above. The soldering and brazing properties of the two alloys are very similar. The copper casting alloy CuCr1-C (CC140C) continues to be used, however, as it has proved very difficult – if not impossible – to produce copper-chromium-zirconium casting alloys. The copper-chromium casting alloy is rarely soldered or brazed, but its suitability for soldering and/or brazing is no different to that of the wrought alloy.

The alloy can be *soldered* with lead-tin solders or with higher melting lead-free solders in combination with a flux without detrimentally affecting the strength of the parts being joined.
Brazing is typically performed with low-melting silver alloy filler metals. If the filler alloy Ag 156 is used and if brazing times are kept short, the loss of strength is relatively small.

2.4.2. High-alloyed copper alloys
Copper alloys that contain more than 5 % of alloying elements are referred to as high-alloyed coppers. They are standardised in DIN CEN/TS 13388 (2013). Examples include the copper-zinc alloys (brasses), copper-tin alloys (bronzes) and copper-nickel-zinc alloys (nickel silvers).

Copper-zinc alloys (Brasses)
Of all the copper alloys, the copper-zinc alloys (commonly known as 'brasses') are the most common and the most widely used. The ubiquity of these alloys is due to the appealing colour, the ease with which they can be processed and their favourable physical and strength properties.
Copper-zinc alloys are classified into

- binary copper-zinc alloys (containing no other alloying elements),
- copper-zinc-lead alloys that contain added lead and
- complex (multi-element) copper-zinc alloys that contain a number of additional alloying elements.

Copper-zinc alloys are available as both wrought and casting alloys.

Soldering
Despite the fact that the elements zinc and tin are incompatible in solders, both binary and lead-bearing copper-zinc alloys (brass and leaded brass) can be soldered without difficulty. If possible, copper-zinc alloys should be soldered using low-antimony solders (containing no more than 0.5 % antimony). If solders with a higher amount of antimony are used, tensile stresses in the soldered structure may lead to the formation of brittle antimony-zinc crystals causing solder embrittlement in both the joint and the parent material. Depending on the particular application, tin-lead, lead-tin, tin-copper and tin-silver solders can be used. The solders Sn97Ag3, Sn95Ag5 and Sn97Cu3 can be used for soldering applications in the food industry, e.g. brass fittings and taps for copper drinking water pipe systems. In contrast to pure copper, cold-worked brasses tend to exhibit soldering embrittlement if extended soldering (or brazing) times are used or if large amounts of solder (or brazing alloy) are applied. If there is a non-uniform distribution of stresses at the joint to be made, the parent material may become brittle when the parts to be joined are wetted with liquid solder. The risk of soldering embrittlement is particularly large when the parts to be soldered are worked or reshaped while they are being wetted with the molten solder. The binary copper-zinc alloys with a pure α phase (alpha brasses), e.g. CuZn30 (CW505L), are more susceptible to liquid metal embrittlement (LME) than those with an α+α structure, e.g. CuZn37 (CW508L). If in doubt, the stresses present in the parent metal should be relieved by annealing the cold-worked parts before soldering. Experience shows that this effectively eliminates the risk of LME.

Soldering is carried out using fluxes in classes 3.1.1, 3.1.2, 2.1.2 and 2.2.2.

Copper-zinc wrought alloys containing additional alloying elements (special brasses) can be soldered without difficulty. One exception to this rule is the aluminium-containing copper-zinc alloys where the higher oxygen affinity of the aluminium (propensity to form oxide films) can cause a number of problems. However, fluxes can be used to remove these aluminium oxide films.
Brass casting alloys are rarely soldered. Their ability to be soldered is very similar to that of wrought copper-zinc alloys of comparable composition.

Brazing
Brazing is used to join brass workpieces that are subjected to greater mechanical and thermal stresses. The risk of liquid metal embrittlement can, however, be avoided by stress relief annealing, by using low-melting brazing alloys and by minimising external stresses. The brass brazing filler metals Cu 470a and Cu 680 are suitable for brazing binary copper-zinc alloys with low zinc content, as their brazing temperatures are below the solidus temperatures of the parent metals. Low-melting silver brazing alloys may also be used depending on the brazing temperature and the required ductility at the joint. As a result of the heat generated during brazing, the strength of the brazed joint is lower than that of the parent metal. If the amount of overlap between the surfaces being brazed is large enough, embrittlement will not be located at the joint but in the peripheral annealed area (heat affected zone). In plumbing installations, fittings made from copper-zinc alloy are typically brazed to copper pipes using the filler metals CuP 279, CuP 179, Ag 145, Ag 134 or Ag 244 in combination with a flux of type FH10.

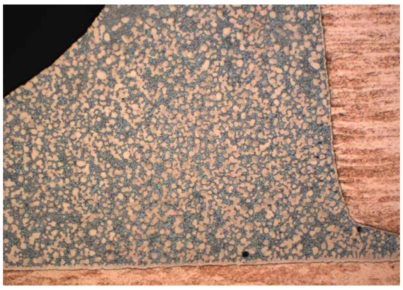


Figure 9 – Metallographic longitudinal section through a brazed joint between a pipe and a pipe fitting (filler alloy: Ag-CuP) [18]

Phosphorus-containing filler metals flow freely on pure copper. When used to braze brass, however, these filler metals need to be combined with a flux. Leaded copper-zinc alloys, particularly those with a lead content above 3 %, are harder to braze than the binary alloys and may well exhibit brittle joints. With certain limitations, leaded brasses can be brazed using low melting silver brazing alloys and a flux of type FH10. Copper-zinc alloys containing aluminium can be brazed without difficulty. If the alloy contains more than 1 % aluminium, fluxes of type FH11 must be used. Brazing can be carried out with low-melting filler metals. If the parts are likely to be subjected to a corrosive environment, silver brazing alloys with a higher silver content should be used. For parts exposed to a marine environment, brazing filler metals with a silver content of about 40–56 % are recommended. Suitable filler metals include Ag 140, Ag 155 and Ag 244. The VG 81245-3 (1991) standard lists all non-ferrous heavy-metal filler metals for welding and brazing that are suitable for use in shipbuilding or in the construction of other floating equipment [19]. The US-AWS 5.8 specification recommends the use of the nickel-bearing silver brazing alloy BAg-3 (50 % silver) for marine applications. However, BAg-3 contains cadmium, which is prohibited in the European Union by EU Regulation 494/2011. A cadmium-free alternative is, for instance, Ag 450. The brazing of copper-zinc casting alloys is carried out in the same way as brazing the corresponding wrought alloys.

Selected areas of use
Soldered/brazed components made from copper-zinc alloys are fabricated in very large volumes for a very wide range of applications in the electrical and automotive industries, communications and domestic appliance technologies, and for electrical and mechanical systems.

Copper-tin alloys (Bronzes)
Copper-tin alloys (commonly known as 'bronzes') are important materials in the electrical engineering (e.g. electrical springs) and mechanical engineering (e.g. slide bearings, bearing linings, membranes). They are classified into wrought alloys and casting alloys.

Soldering
Like pure copper, copper-tin wrought alloys can be soldered with little difficulty, although surface wetting is not as rapid. In some situations (e.g. wave soldering), it is proves expedient to tin the surfaces to be joined beforehand with the lead-free solder Sn99Cu1. Soldering is normally carried out using lead-free solders, such as Sn96Ag3Cu1 or Sn99Cu1.

For fine soldering applications, fluxes in the classes 1.1.2, 1.1.1 or 1.1.3 may be used. For general soldering applications, fluxes in classes 3.1.1 and 3.1.2 should be used. Bronze casting alloys are hardly ever soldered, however, their solderability is very similar to that of wrought copper-tin alloys of comparable composition.

Brazing
Brazing copper-tin wrought alloys also tends to cause softening in the joint. The filler metals of choice are low-melting silver brazing alloys, such as Ag 156. For capillary brazing applications copper-phosphorus filler metals such as CuP 179 or CuP 182 are used. If other filler metals are used, there is a risk of localised melting of the parent material and associated embrittlement through the formation of coarse grains. For brazing temperatures below 800 °C fluxes of type FH10 are appropriate; above 800 °C, fluxes of type FH20 are preferred. Castings from copper-tin alloys that do not contain more than 1.5 % of lead are well suited to brazing with silver brazing filler metals. For parts exposed to marine environments, the same recommendations apply as for copper-zinc alloys (see section on the brazing of copper-zinc alloys above).

Copper-nickel-zinc alloys (Nickel silvers)
Copper-nickel-zinc wrought alloys (also known as 'nickel silvers') are used in electrical engineering applications (for springs), in the construction industry, in precision engineering e.g. as spectacle temples and hinges, in the arts and crafts sector, and for jewellery. The casting alloys are used, for instance, for marine hardware, fixtures and fittings, and cast ornamental ware. The solderability of the copper-nickel-zinc casting alloys is very similar to that of the corresponding wrought alloys.

Soldering
Soldering is best carried out either with lead-tin solders or with lead-free Sn97Ag3 or Sn95Ag5 solders, as they have better bonding and wetting characteristics. The temperatures reached during soldering are not high enough to cause any softening of the work-hardened parent material. For wetting to be successful, the joint to be soldered must be free of grease and oxides. To facilitate optimum wetting, the surfaces to be soldered should be prepared by very careful acid pickling (e.g. with a 10 % sulphuric acid solution) and degreased. Strongly activating fluxes of type 3.2.2 or 3.1.1 should be used..

Brazing
Copper-nickel-zinc alloys can be brazed with silver-bearing brazing filler metals. The most commonly used brass filler metal Cu 681 has the same silver-grey colour as the copper-nickel-zinc parent metal. Suitable fluxes are those of type FH10. If the parts are brazed in a furnace, there may be some deterioration in the hardness characteristics achieved through prior cold working of the material. Leaded nickel silvers have a tendency to crack when annealed, particularly if they have been significantly cold worked prior to brazing. These alloys should therefore be brazed using low-melting silver alloy filler metals and heating should be carried out gradually.

Copper-nickel alloys (Cupronickels)
Copper-nickel alloys (also known as 'cupronickels') are some of the most corrosion-resistant copper materials known. The wrought alloys are important materials in marine construction (particularly for condensers and undersea piping), in the plant construction sector and in the electrical engineering sector (e.g. as resistance wire). In addition to marine applications, cupronickel casting alloys are used in the mechanical engineering and chemical industries.

Soldering
The solderability of these alloys is similar to that of pure copper. The somewhat sluggish wetting of these alloys with soft solders can be improved by the addition of a flux. In particularly difficult cases, the surfaces to be joined should be pre-tinned. Suitable solders are the lead-free tin-silver and tin-copper solders, such as Sn95Ag5, Sn97Ag3 or Sn97Cu3. Compared to the leaded tin solders used previously, the lead-free solders exhibit improved hardness, higher corrosion resistance and greater temperature stability. Fluxes of type 3.2.2 or 3.1.1 are appropriate. In electrical applications, copper-nickel alloys are frequently pre-tinned or pre-silvered, then soldered with rosin-based (colophony-based) fluxes of type 1.1.2 or 1.1.3. The alloy CuNi9Sn2 (CW351H), which is used particularly for the fabrication of spring components, exhibits excellent tarnish resistance and therefore very good solderability even after storage for a long period. Higher-melting solders are used for soldering electrical resistors that are exposed to elevated temperatures. The cupronickel casting alloys are rarely soldered.

Brazing
The solidus temperature of the copper-nickel alloys is higher than that of copper. This is the reason why copper-nickel alloys, particularly those with a high nickel content, can be brazed with copper as the filler metal. Generally, however, copper-based filler metals, such as Cu 470a to Cu 680 or Cu 681, are used in combination with fluxes of type FH21, or silver brazing alloys are used with fluxes of type FH10 that prevent oxidation at the brazing surfaces. The filler metals should be phosphorus-free in order to avoid embrittlement. For iron-bearing cupronickels, brazing is usually carried out with the filler metals Cu 773 and Ag 244.
CuNi13Sn8 is a CuNiSn alloy with higher nickel and tin content that is used for manufacturing high-quality, thin lightweight spectacle frames with excellent flexibility and is brazed using silver alloy filler metals. For marine applications, the brazing filler metal should have a silver content of about 40 % to 56 %. The VG 81245 Part 3 (1991) standard 'Filler metals for welding and brazing applications in shipbuilding and the construction of other floating equipment' [19], specifies the use of the silver brazing alloys Ag 140, Ag 155 and Ag 244 as defined in the ISO 17672 (2010) standard. For marine applications, the US-AWS 5.8 specification recommends the use of the nickel-bearing silver brazing alloy BAg-3 (50 % silver). BAg-3 is a cadmium-containing brazing filler metal; the cadmium-free alternative is the filler metal Ag 450 as defined in DIN ISO 17672 (2011). A brazing flux of type FH11 is recommended. The brazeability of the cupronickel casting alloys is similar to that of the copper-nickel wrought alloys of comparable composition.

Copper-aluminium alloys (Aluminium bronzes)
Copper-aluminium alloys (also referred to as 'aluminium bronzes') exhibit an exceptionally high resistance to cavitation erosion and are some of the most corrosion-resistant copper alloys known. Both the wrought and casting alloys are therefore indispensable materials in the chemical and mechanical engineering industries. Brazing and soldering of copper-aluminium alloys always requires the use of fluxes to remove the highly chemically resistant oxide films. Copper-aluminium casting alloys are rarely soldered or brazed, however, their solderability or brazeability is very similar to that of wrought copper-aluminium alloys of comparable composition.

Soldering
Copper-aluminium alloys are rarely soldered, as the wettability of the parent metal deteriorates as the amount of aluminium in the alloy increases, making bonding difficult and necessitating the use of special fluxes. If soldering is performed, it can be carried out using the solders Sn97Cu3 or Sn97Ag3; for applications in which the parts will be subjected to higher temperatures, CdAg5 can be used. Cadmium-containing solders are, however, no longer readily available as they are regarded as a health risk. Special fluxes for aluminium alloys belonging to flux classes 2.1.2 or 2.1.3 can be used.

Brazing
Brazing can be carried out without difficulty provided that appropriate fluxes are used. Suitable brazing filler metals are the silver brazing alloys with low to medium brazing temperatures, such as Ag 156. For parts exposed to marine environments, the same recommendations given for copper-zinc alloys apply (see section on brazing copper-zinc alloys above).

Copper-tin-zinc casting alloys (Gunmetal)
The copper-tin-zinc casting alloys ('Gunmetal') exhibit low friction and good anti-seizure properties, as well as high resistance to cavitation, wear and salt-water corrosion. Typical uses include water taps, valve and pump housings, fittings and sliding bearings. Depending on the particular application, Gunmetal can be soldered with selected tin-lead solders containing at least 60 % tin. Fluxes from the flux classes 3.1.1 and 3.1.2 are appropriate. In the plumbing sector, fittings and tap components used in drinking water piping systems are soldered using lead-free and antimony-free solders. Castings that contain less than 1.5 % lead can be brazed effectively using silver alloy brazing filler metals containing at least 30 % silver and fluxes of type FH10. Brazing of copper tubing with flanges made of Gunmetal is common in the equipment manufacturing sector. Undersea piping is subject to the regulations of the classification societies, which stipulate, for instance, that the brazing filler metals used must have a silver content of around 50 %. If Gunmetal fittings are used in the copper piping for drinking water supply systems, the filler metals CuP 279 or CuP 179 in combination with a flux of type FH10 are recommended.

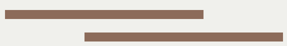
Copper-lead-tin casting alloys (High-leaded tin bronzes)
The leaded tin bronzes are important engineering and bearing materials that are rarely joined by brazing or soldering. Soldering can be performed using tin-lead solders with 50–60 % tin and a flux of class 3.1.1 or 3.1.2. Brazing is possible using low-melting silver brazing alloys (e.g. Ag 156) and a flux of type FH10, though the brazeability of leaded tin bronzes is limited. If alloys with a higher lead content are brazed, very significant diffusion should be expected.

Brazing and soldering of copper and copper alloys to themselves and to other materials
There are many practical applications in which copper and copper alloys are joined to other metals. One of the most common procedures involves brazing copper-based materials to steel. As steels and nickel alloys can both form brittle phases, they cannot be joined together by brazing with a CuP filler metal. The choice of brazing filler metal is determined by the parent material of lower brazeability. When designing the joint and the soldering/brazing method to be used, the different properties of the materials to be joined (e.g. thermal conductivity, thermal expansion, specific heat capacity) must be taken into account.
The increasing significance of metal/ceramic composites in industrial applications has led to the study of these material combinations and has driven the development of appropriate soldering and brazing solutions. Copper and alumina (Al_2O_3) can now be brazed using active filler metals or soldered with tin-lead solders. Active filler metals generally contain the metal titanium, which reacts at the interface between the filler metal and the ceramic, making the surface more amenable to wetting [9].

3. Design suitability for brazing

Design suitability for brazing is concerned with design characteristics that influence the brazing process, such as the shape and structure of the joint and the forces acting on it. This requires giving consideration to the operational stresses involved, the type of parent material to be joined and the brazing technique to be used. A distinction is made between the brazing techniques used to join materials and those used for surface cladding work (also known as hardfacing). Brazing joining techniques are further classified into normal (i.e. 'narrow-gap') brazing and braze welding.

(Narrow-gap) brazing
A narrow gap between the parts to be joined is filled with filler metal by capillary pressure.
To ensure that the joint gap is filled uniformly, the liquidus temperature of the filler metal can be exceeded by 20–50 °C [9].



Braze welding
A wider gap between the parts to be joined, which is filled with filler metal primarily by gravitational spreading [9].
The liquid braze metal is held inside the joint by surface tension.

Table 9 - Difference between standard (narrow-gap) brazing and braze welding

In normal ('narrow-gap') brazing, the gap between the surfaces to be joined (the 'faying' or 'mating' surfaces) should not be more than 0.5 mm. If the distance between the surfaces is larger, the joining technique is referred to as braze welding. Braze welding uses a larger quantity of filler metal than normal brazing. Braze welding frequently involves single-V, square and double-V butt joints The gap/joint widths for different joining techniques are shown in the following figure:

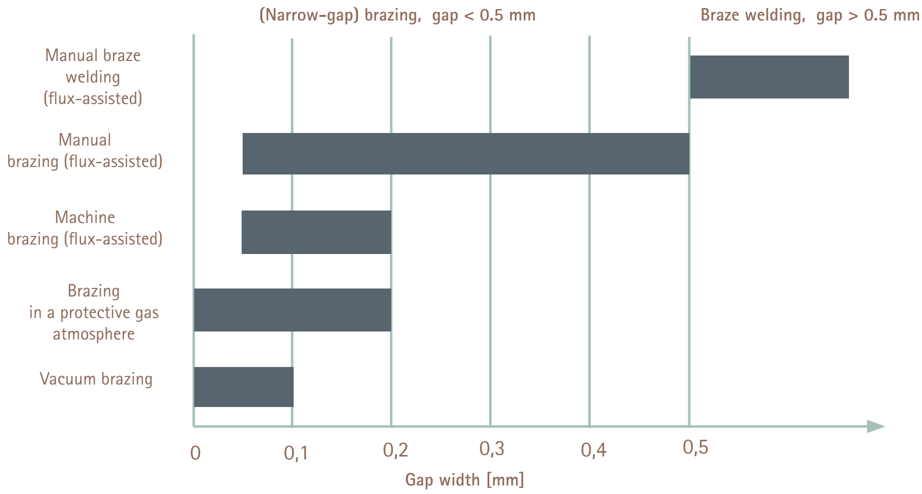
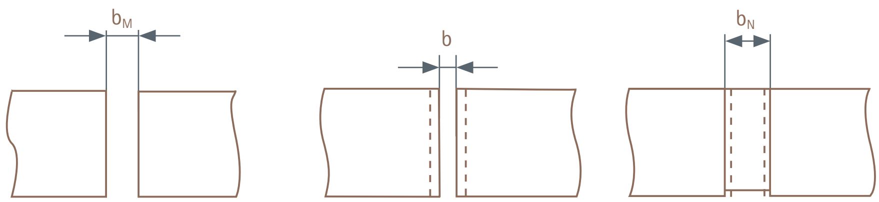


Figure 10 - Difference between 'narrow-gap' brazing and weld brazing

At room temperature, the gap between the components to be brazed is known as the 'assembly gap'. The term 'brazing gap' is the gap between the components to be brazed at the brazing temperature. It may differ from the assembly gap due to the different degrees of thermal expansion exhibited by the materials to be joined.



Assembly gap	Brazing gap	Brazing seam
Narrow, mainly parallel gap between the components to be brazed, measured at room temperature [10].	Narrow, mainly parallel gap between the components to be brazed, measured at the brazing temperature [10].	May be wider than the assembly gap due to surface melting.

Table 10 - Distinction between the terms 'assembly gap', 'brazing gap' and 'brazing seam'

The gap widths should be designed to be as narrow as possible in order to fully exploit the capillary effect when brazing (see figure 11). The capillary effect is a surface tension phenomenon. It produces a force that draws the flux and the molten filler metal into the gap between the components to be joined.

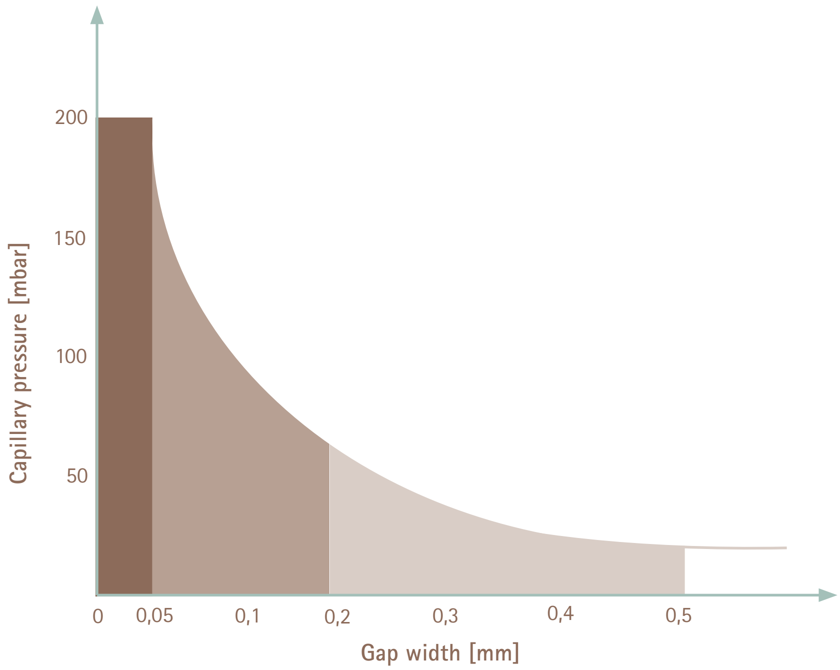


Figure 11 - Capillary pressure as a function of gap width [12]

The gap width for normal brazing should be between 0.05 mm and 0.5 mm. In addition to the width of the brazing gap, the cross-sectional area of the gap (see figure 12) also affects the capillary pressure and thus the quality of the resulting brazed joint. An open fillet has a capillary pressure 4.5 times greater than in a parallel flat gap [9].

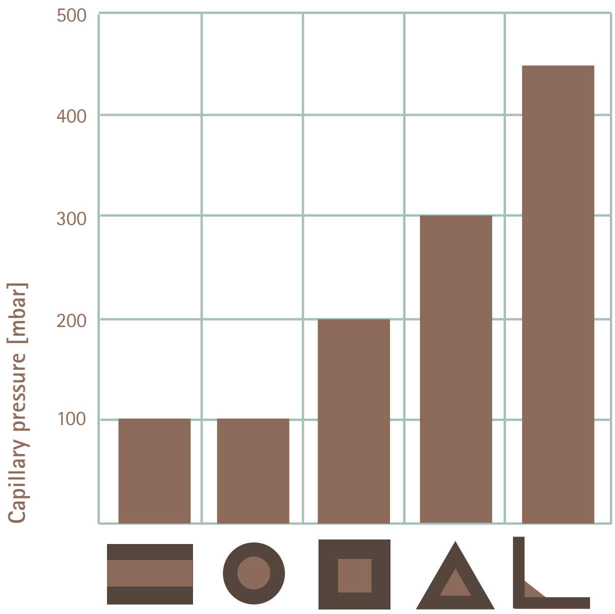


Figure 12 - Capillary pressure as a function of gap geometry [12]

When designing the assembly to be joined, the direction of flow of the filler metal should be considered. There should be no discontinuities in the gap that would prevent the filler metal from flowing and filling the joint area. The region around the joint should be designed so as to minimise stress concentration factors, bending loads and geometric notch sensitivity factors. Shear stressing of soldered/brazed joints is beneficial. If a flux is used, the gap must be configured so that the flux can flow out again and any air can escape. In general, the solders and filler metals used and the solder/braze metal in the finished joint are not as strong as the parent material. The joining surface should therefore be as large as possible in order to achieve a strong, secure join. This is frequently achieved by designing a lap or insertion joint. Other geometrical variants of soldered/brazed joints are listed in table 11.

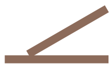
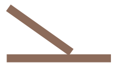
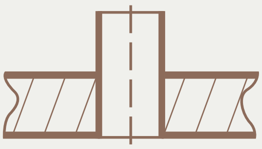
	α = 0° / 180°	**0° < α < 90°**	**α = 90°**	**90° < α < 180°**
Possible soldered/brazed joints	**Square butt joint** · Suitable for soldering/ brazing and braze welding · Relatively small joining surfaces	**Inclined joint**  **Angular or corner joint**  · Suitable for soldering/ brazing and braze welding · Relatively small joining surfaces	**T-joint**  **Angular or corner joint**  · Suitable for soldering/ brazing and braze welding · Relatively small joining surfaces	**Inclined joint**  **Angular or corner joint**  · Suitable for soldering/ brazing and braze welding · Relatively small joining surfaces
Preferred soldered/brazed joints	**Lap joint**  **Parallel or fully overlapping joint**  · Suitable for soldering/ brazing and braze welding · Large joining surfaces can be achieved · Preferred joint type for sheet metals and tubing	**Insertion joint**  · Large soldering/brazing surfaces ensure a strong joint		

Table 11 – Geometric configurations of common soldered/brazed joints [6]

Other factors that need to be taken into account when designing a soldered or brazed joint are the detailed shape of the gap and the condition of the mating surfaces. Score marks and grooves on the surfaces to be joined are generally undesirable. If there is scoring on the surface, it is important that the score marks are aligned with the direction of flow of the molten filler metal. Any component after-treatment procedures should also be taken into account when designing the brazing joint and/or assembly. Any residual flux, binder or solder mask should be readily removable. As with welded joints, the fatigue strength of a brazed or soldered joint is enhanced when there are no sharp changes in the cross-section and the joint is smoothly contoured (e.g. by forming a concave fillet). The rules governing the symbolic representation of brazed and soldered joints can be found in DIN EN 22553 (1997) [6].

4. Soldering and brazing methods

4.1. The soldering/brazing principle
Melting the solder or brazing filler metal requires the uniform application of thermal energy to the entire soldering/brazing zone. A specific temperature-time profile is followed that consists fo the following sequence of steps: [6]

1. Melting the flux
2. Activating the surface
3. Melting the solder or filler metal
4. Wetting of mating surfaces by the molten solder or filler metal
5. Flowing of solder or filler metal into the soldering/brazing gap
6. Filling of soldering/brazing gap by the solder or filler metal.

figure 13 illustrates the characteristic temperatures and times during soldering/brazing and the terminology as defined in DIN ISO 857-2 is explained in Section 6. The thermal profile shown below is typical of that observed during furnace soldering or furnace brazing.

For reasons of cost, the holding time at the soldering/brazing temperature is usually restricted to the time needed to achieve a uniform temperature in the assembly. After a relatively short holding time, the assembly is allowed to cool in still air at room temperature or under defined cooling conditions. During this period the soldered/brazed metal solidifies.

The reflow temperature of the solder/braze metal corresponds roughly to the melting temperature of the solder/filler metal applied. If the soldered/brazed assembly will be subjected to high service stresses, a higher reflow temperature is desirable in order to optimise the quality of the soldered/brazed joint. This can be achieved by significantly extending the holding temperature, which leads to a diffusion-driven change in the chemical composition of the solder/braze metal and thus to a shift in the solidus and liquidus temperatures of the solder/braze metal. The soldered/brazed joint can then be subjected to diffusion annealing at the soldering/brazing temperature [1].

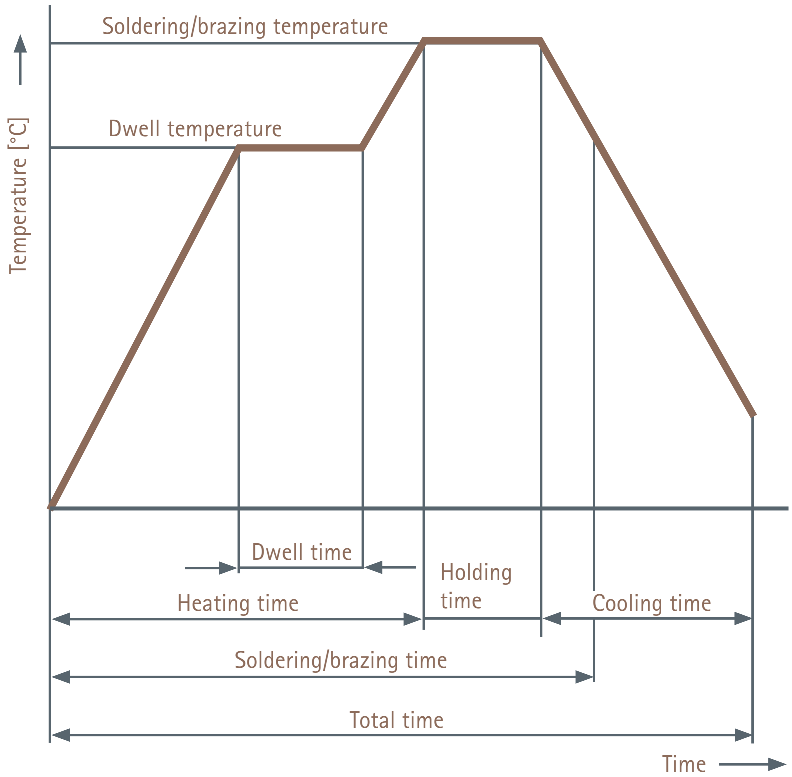


Figure 13 - Characteristic temperatures and times during soldering/brazing [20]

4.2. Surface preparation

In order to achieve a high quality soldered/brazed joint between metallic materials, the mating surfaces need to carefully prepared. Surface preparation can involve chemical, mechanical or thermal cleaning procedures or a combination thereof (see table 12 for a list of available procedures). The parts to be soldered or brazed must be clean and free from any residues that might inhibit wetting, such as oxides, oil, grease, dirt, rust, paint, cutting fluids, etc. (see figure 14). Furthermore, the wetting behaviour of the solder or brazing filler metal also depends on the following factors: the properties of the parent material, the solder or brazing filler metal and other auxiliary materials; the structure and condition of the mating surfaces; and heat transfer during the soldering/brazing process. Soldering/brazing should be carried out as soon as possible after the surfaces have been prepared. Once cleaned, the parts should be protected from recontamination and from contact with sweaty hands. Parts should be stored preferentially in an inert and dry atmosphere. The following procedures can be used to prepare the surfaces of copper and copper alloys. Which procedure(s) to adopt will depend on the type and extent of the contamination, the cleanliness requirements and the geometry of the surfaces to be cleaned [21].

Table 13 contains recommendations for pickling the surfaces of copper and copper alloys. The surfaces must always be degreased prior to pickling and rinsed thoroughly afterwards. Further recommendations regarding surface preparation techniques are described in the DVS technical leaflet 2606 (2000) [21].

Cleaning procedure	Example
Chemical cleaning	Degreasing with commercially available solvents (e.g. isopropanol, acetone); Steam degreasing with hydrocarbons and chlorinated hydrocarbons; Cleaning with aqueous alkaline solutions; emulsion cleaning using mixtures of hydrocarbons, fatty acids, wetting agents and surface activators; Pickling treatments using acids, acid mixtures or salts (see table 13)
Mechanical cleaning	Grinding, filing, abrasive blasting, polishing *Caution: Steel wire brushes must not be used to clean the surfaces of copper or copper alloys!*
Thermal cleaning	Cleaning in a reducing atmosphere, e.g. of hydrogen and hydrogen fluoride at temperatures above 800 °C

Table 12 - Cleaning procedures for copper and copper alloys [21]

Parent material	Notes	Formulation
Copper-chromium alloys		With hot sulphuric acid (H_2SO_4); sequential dipping in two solutions: I. 65 ml 96 % sulphuric acid (H_2SO_4) diluted with water to give 100 ml of solution; solution used while hot II. 3 ml 96 % sulphuric acid (H_2SO_4) diluted with water to give 100 ml of solution
Copper and copper alloys	Prior mechanical removal of oxides may be required (copper or brass wire brush, emery cloth)	a) 5 ml 96 % sulphuric acid (H_2SO_4) diluted with water to give 100 ml of solution b) 50 ml 65 % nitric acid (HNO_3) diluted with water to give 100 ml of solution
Copper-aluminium alloys	Pre-coating of surfaces may be necessary	Sequential dipping in two solutions: I. 2 ml 40 % hydrofluoric acid (HF) with 3 ml 96 % sulphuric acid (H2SO4) diluted with water to give 100 ml of solution II.2 g sodium dichromate (Na2Cr2O7) and 5 ml 96 % sulphuric acid (H2SO4) diluted with water to give 100 ml of solution
Copper-nickel alloys	Prior mechanical removal of oxides may be required (copper or brass wire brush, emery cloth)	With hot sulphuric acid (H_2SO_4); sequential dipping in two solutions: Eintauchen in zwei Lösungen I. 65 ml 96 % sulphuric acid (H2SO4) diluted with water to give 100 ml of solution; solution used while hot II. 3 ml 96 % sulphuric acid (H2SO4) diluted with water to give 100 ml of solution
Copper-silicon alloys	Prior mechanical removal of oxides may be required	Sequential treatment using the following two solutions: I. 5 ml 65 % nitric acid (HNO3) diluted with water to give 100 ml of solution II. 2 ml hydrofluoric acid (HF) and 3 ml 65 % nitric acid (HNO_3) diluted with water to give 100 ml of solution III. 2 g sodium dichromate ($Na_2Cr_2O_7$) and 3 ml 65 % nitric acid (HNO_3) diluted with water to give 100 ml of solution
Copper-zinc alloys	Prior mechanical removal of oxides may be required (copper or brass wire brush, emery cloth)	Sequential dipping in two solutions: I. 5 ml 96 % sulphuric acid (H_2SO_4) diluted with water to give 100 ml of solution II. 2 g sodium dichromate ($Na_2Cr_2O_7$) and 3 ml 96 % sulphuric acid (H_2SO_4) diluted with water to give 100 ml of solutio

Table 13 - Recommended pickling solutions for copper and copper alloys that will undergo fluxless brazing [21]

4.3. Surface activation

Proper contact between the solder or brazing alloy and the surface of the parent metal is an essential requirement in any high-quality soldered or brazed joint. However, sufficient contact between the molten solder or filler metal and the surface is not always established in all cases. Figure 14 represents a realistic cross-sectional view through the surface of an engineering metal. The dirt, contamination and adsorbed layers present on the surface have to be removed before soldering or brazing can take place. This process is known as surface activation. Some of the most common methods of surface activation are the use of fluxes, soldering/brazing in a reducing atmosphere or soldering/brazing in a vacuum. Other techniques include soldering/brazing under an inert shielding gas, arc brazing, and soldering methods involving mechanical activation of the faying surface, as in ultrasonic soldering or abrasion soldering. Surface activation always involves the absorption of solid, liquid and gaseous layers.

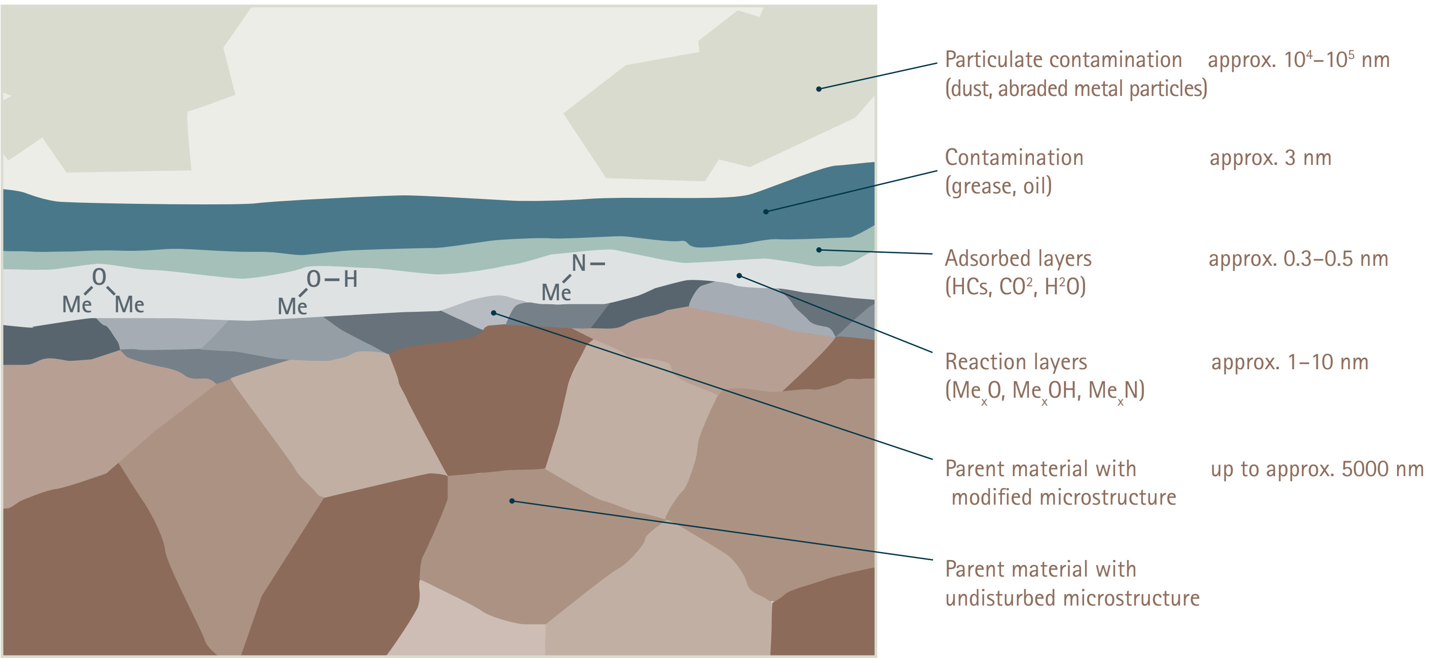


Figure 14 - Schematic cross-section of the surface of an engineering metal [22]

4.3.1. Fluxes

According to DIN ISO 857-2 (2007), a flux is defined as a 'non-metallic material which, when molten, promotes wetting by removing existing oxide or other detrimental films from the surfaces to be joined and prevents their re-formation during the joining operation' [10]. Fluxes are available as powders, pastes, liquids or as solder-flux mixtures.
The melting range of the flux should be about 50 °C below that of the solder or brazing filler metal as this ensures that the surface has been activated before it is wetted and before the solder or filler metal starts to flow. As there is no universal flux, the composition of the flux must be carefully selected for the proposed joining operation [1]. A distinction is made between fluxes for soldering DIN EN 29454-1 (2004) and fluxes for brazing DIN EN 1045 (1997).

Solder fluxes (classified according to DIN EN 29454–1 (1994)

A flux is normally required for soldering operations. Solder fluxes are classified in terms of their chemical composition [4].

In practice, solder fluxes area also categorised according to their chemical function.

Flux type	Base	Activator	Form	Areas of use
[1] Resin	[1] With rosin [2] Without rosin	[1] Without activator [2] Halide activator (other activating agents are available) [3] Non-halide activator	[A] Liquid [B] Solid [C] Paste	Electrical, Electronics
[2] Organic	[1] Water-soluble [2] Not water-soluble			Electrical, Electronics, Metal goods
[3] Inorganic	[1] Salts	[1] With ammonium chloride [2] Without ammonium chloride		Plumbing applications Cu and Cu alloys Ni and Ni-alloys Precious metals
	[2] Acids	[1] Phosphoric acid [2] Other acids		Cr, Cr-Ni-alloys Stainless steels
	[3] Alkaline	[1] Amines and/or ammonia		

Table 14 - Solder fluxes (classified according to DIN EN 29454-1 (1994) (1994) [23]

Functional class	Key chemical constituent	Mode of action
Corrosive fluxes	Zinc chloride	Flux residues cause corrosion in copper and copper alloys (pitting); workpieces must be washed after soldering with hydrochloric acid and then rinsed repeatedly with water
Non-corrosive fluxes	Zinc bromide	Residues can remain on the workpiece or can be rinsed off with water
Non-corrosive, residue-free fluxes	Organic amines and hydrobromic acid	If the temperature is controlled correctly, the flux will evaporate completely leaving a clean surface. Subsequent cleaning of the workpiece is not required.

Table 15 - Chemical function of solder fluxes [24]

Brazing fluxes (classified according to DIN EN 1045 (1997)
The DIN EN 1045 (1997) standard classifies brazing fluxes into two classes: FH and FL. Class FH fluxes are used in the brazing of heavy metals, such as steels, stainless steels, copper and copper alloys, nickel and nickel alloys, precious metals, molybdenum and tungsten. Fluxes in class FL are used when brazing light metals, such as aluminium and aluminium alloys. Only class FH fluxes should be used for brazing copper and copper alloys.

Type	Effective temperature range	Brazing temperature	Description / Areas of use	After-treatment
FH10	approx. 550 – 800 °C	> 600 °C	contains boron compoundsand simple and complex fluorides; multi-purpose flux	Residues are corrosive; remove by washing or pickling
FH11	approx. 550 – 800 °C	> 600 °C	contains boron compounds and simple and complex fluorides and chlorides; mostly used for copper-aluminium	Residues are corrosive; remove by washing or pickling
FH12	approx. 550 – 850 °C	> 600 °C	contains boron compounds, elemental boron and simple and complex fluorides; mostly used for stainless steels, high-alloy steels and carbides	Residues are corrosive; remove by washing or pickling
FH20	approx. 700 – 1000 °C	> 750 °C	contains boron compounds and simple and complex fluorides; multi-purpose flux	Residues are corrosive; remove by washing or pickling
FH21	approx. 750 – 1100 °C	> 800 °C	contains boron compounds; multi-purpose flux	Residues are not corrosive; remove mechanically or by pickling
FH30	> 1000 °C		contains boron compounds, phos-phates and silicates; mostly used together with copper and nickel filler metals	Residues are not corrosive; remove mechanically or by pickling
FH40	approx. 600 – 1000 °C		contains chlorides and fluorides; boron-free; used when presence of boron is not permitted	Residues are corrosive; remove by washing or pickling

Table 16 - Brazing fluxes (classified according to DIN EN 1045 (1997) [25]

Table 17 lists substances that are contained in a number of fluxes and which, since 1 December 2010, are classified as Category 1B reproductive toxins if present in the amounts given in the table. Products affected must be marked with the symbol 'T' and the R phrases R60 and R61. Although products containing trimethyl borate (EC No.: 204-468-9) are not directly covered by the legislation, boric acid will be generated in the brazing torch flame and will deposit on the workpiece and in the workplace. Boric acid deposits are toxic. For this reason, brazing operations involving a product containing trimethyl borate are subject to the same regulations that apply to brazing fluxes that contain boric acid [26]. Further information on the reclassification and labelling rules for brazing fluxes containing boric acid, borax pentahydrate or boron trioxide is available (in German) in the DVS technical leaflet 2617 [26]. Table 17 also specifies the concentrations above which the product is classified as hazardous.

Substance	EC Number	Hazard classification cut-off
Boric acid	233-139-2 234-343-4	≥ 5,5 %
Boron trioxide	215-125-8	≥ 3,1 %
Borax anhydrate	215-540-4 235-541-3 237-560-2	≥ 4,5 %
Borax decahydrate	215-540-4	≥ 8,5 %
Borax pentahydrate	215-540-4	≥ 6,5 %

Table 17 - Concentration levels for hazard classification purposes [26]

4.3.2 Protective atmosphere / Shielding gases

According to DIN ISO 857-2 (2007), a protective atmosphere for soldering or brazing is the 'gas atmosphere or vacuum round a component, either to remove oxide or other detrimental films on the surfaces to be joined or to prevent the re-formation of such films on surfaces which have previously been cleaned ' [10]. A protective atmosphere of shielding gas(es) improves the quality of the soldered/brazed joint, enables precise control of soldering/brazing temperatures and soldering/brazing times, and increases process productivity as fluxes no longer need to be applied and flux residues removed. Using a protective atmosphere is, however, associated with higher process and equipment costs. Table 18 contains examples and definitions of the various protective atmospheres used in soldering and brazing operations.

Atmosphere	Shielding gas		Vacuum
	reducing	inert	
Definition from DIN ISO 857-2 (2007)	'Gas which reduces oxides' [10]	'Gas which prevents the formation of oxides during the soldering or brazing process' [10]	'Pressure sufficiently below atmospheric so that the formation of oxides will be prevented to a degree sufficient for satisfactory soldering or brazing, because of the low partial pressure of the residual gas' [10]
Example	Exothermic gas atmosphere ('exogases') formed by incomplete combustion of gases in air with a high air-to-gas ratio; endothermic gas atmosphere ('endogases') formed by partial combustion of gases in air with a low air-to-gas ratio; dissociated ammonia atmosphere	Argon, helium	Low (rough), medium, high, ultrahigh vacuum

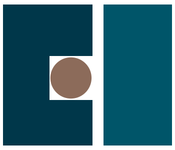
Table 18 - Protective atmospheres used in soldering/brazing operations

4.4. Applying the solder or brazing filler metal

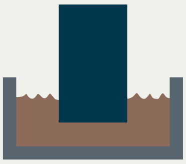
In addition to selecting the correct method of surface cleaning and surface activation, choosing the most suitable way to introduce the filler metal into the joint is also an important aspect of the soldering or brazing process. In most cases, the application of the filler metal is dictated by the design of the assembly. The solder or brazing alloy can be introduced manually, by dipping the parts into the molten filler material, or by positioning filler metal preforms where the joint is to be made. Filler metals are available in a variety of forms (e.g. wire, rod, strip, film, paste) and sizes to suit the design and dimensions of the soldering or brazing gap.

Table 19 shows a number of different ways of introducing the filler metal to the joint.

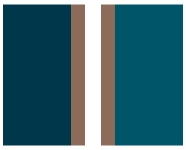
Soldering or brazing with filler metal applied to the joint
Process during which the components are heated up to the soldering or brazing temperature in the area of the joint, and the filler metal is brought to its melting point mainly by contact with the components to be soldered or brazed. gebracht.



Soldering or brazing with filler metal deposited or inserted in the joint
Process during which the filler metal is placed in the area of the joint before heating, and is then heated to the soldering or brazing temperature together with the components to be soldered or brazed.



Dip soldering or brazing
Process during which the components to be soldered or brazed are dipped in a bath of molten filler metal.



Soldering or brazing with components coated with filler metal
Process during which the filler metal is applied before soldering/brazing by coating (e.g. roll cladding, electroplating, vapour deposition or tinning).

Table 19 - Different ways of introducing the filler metal to the soldering or brazing joint (based on [10]

4.5. Soldering and brazing techniques

Soldering and brazing techniques can be classified in different ways, such as by the heating method (energy source) used (see table 20). Other classification schemes are based on the:

- nature of the soldering/brazing joint (cladding, (narrow-gap) soldering/brazing, braze welding)
- method of oxide removal (e.g. soldering/brazing in a protective gas atmosphere, vacuum soldering/brazing, flux-assisted soldering/brazing)
- method of application of the filler metal (e.g. dip soldering/brazing, soldering/brazing with filler metal applied to the joint)
- method of fabricating the joint (e.g. manual, partially automated or fully automated soldering/brazing)

Process	Energy source	Name of technique
Soldering	Soldering using a solid heat source	· Soldering with soldring iron
	Soldering using a liquid heat source	· Dip soldering · Wave soldering · Drag solderingn
	Soldering with a gaseous heat source	· Flame soldering
	Soldering using an electric current	· Induction soldering in air
	Furnace soldering	· Furnace soldering
Brazing	Brazing using a liquid heat source	· Dip brazing
	Brazing using a gaseous heat source	· Flame brazing
	Electric arc brazing	· Manual brazing with an electric arc · MIG, TIG, Plasma
	Brazing using radiation	· Laser beam brazing · Electron beam brazing
	Soldering using electrical heating	· Induction brazing · Induction brazing in a protective gas atmosphere · Indirect resistance brazing · Direct resistance brazing · Furnace brazing in a reducing atmosphere · Furnace brazing in an inert gas atmosphere · Furnace brazing in a vacuum

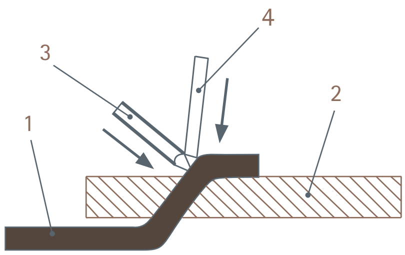
Table 20 - Classification of soldering/brazing processes (based on [10])

4.5.1. Soldering with soldring iron

Hot-iron soldering is a soldering technique in which the thermal energy is supplied by a solid medium.
The joint is heated and the solder is melted by applying heat from a hot iron that is controlled either manually or by a machine. Hot-iron soldering is not suitable for fabricating narrow-gap joints with large overlap zones.

Most soldering irons are equipped with a built-in electrical heating element or with a small tank containing a combustible gas such as natural gas, acetylene or propane. The heat capacity and the shape of the soldering iron and its tip (also known as the 'bit') must be suitable for the assembly to be soldered. The more pointed the tip is, the easier it is to access the joint, though heat losses are also higher. Soldering iron tips have masses ranging from about 20 g to 1 kg and used to be almost exclusively made of copper due to its excellent thermal conductivity and good wettability. In high-volume soldering work, these copper tips would eventually dissolve in the tin solder and the tips would need to be reconditioned or replaced. For this reason, copper-containing solders and tips plated with other materials were developed. When soldering with lead-free solders, the hot iron needs to be removed from the joint more quickly than with leaded solders to prevent spiking or solder pull-out, as the lead-free solders in use today have different flow characteristics than the SnPb solders used previously. The melting range of lead-free solders is narrower than in lead solders so that solidification occurs more rapidly [6].

The soldering time is usually less than 60 seconds. Depending on the specific soldering application to be performed, between 15 W and 2000 W of thermal energy needs to be applied. The tip of the iron can reach temperatures in the range 200–600 °C [6].



1. Conductor 2. Printed-circuit board
3. Tip of soldering iron 4. Flux-cored solder

Figure 15 - Example of hot-iron soldering on a printed-circuit board (based on [10])

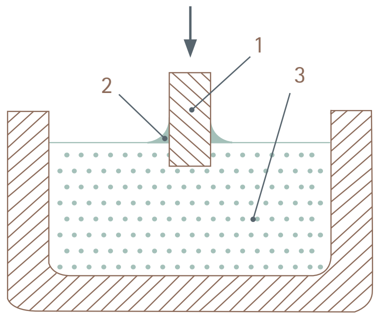
Advantages
- Low cost
- Reproducible
- Suitable for hard-to-access joints
- Suitable for temperature-sensitive components
- Good for single soldered joints

Disadvantages
- Scaling on the iron tip due to high-temperature oxidation
- Operators must have a high degree of skill and manual dexterity

Table 21 - Advantages and disadvantages of hot-iron soldering

4.5.2. Dip soldering or brazing

he parts to be soldered or brazed are mechanically cleaned and placed into position. Flux is then applied before the assembly ('workpiece') is dipped into a bath of molten solder or filler metal. The temperature of the dipping bath should be between 60 K and 100 K above the liquidus temperature of the solder or filler metal. Higher temperatures will lead to increased oxide formation on the surface of the bath. Higher temperatures are also associated with a greater risk of distortion of the parts and greater erosion of the parent material. The workpiece is typically immersed for between 20 and 60 seconds. Dipping speed needs to be carefully controlled. It should be selected so that the workpiece reaches the soldering or brazing temperature during all stages of the dipping process. A visible sign that the correct dipping speed has been chosen is the presence of a concave meniscus at the interface of the molten solder of filler metal and the workpiece. Large parts should be preheated prior to dipping to avoid too great a drop in the bath temperature when the workpiece is immersed. Dip brazing is typically used in the manufacture of condensers, cooling units and metal vessels [16].



1. Workpiece 2. Concave meniscus
3. Bath of molten solder or brazing filler metal

Figure 16 – Dip soldering/brazing (based on [10])

Advantages
- Fully automated
- Application and melting of solder or filler metal in a single step
- Cost-efficient

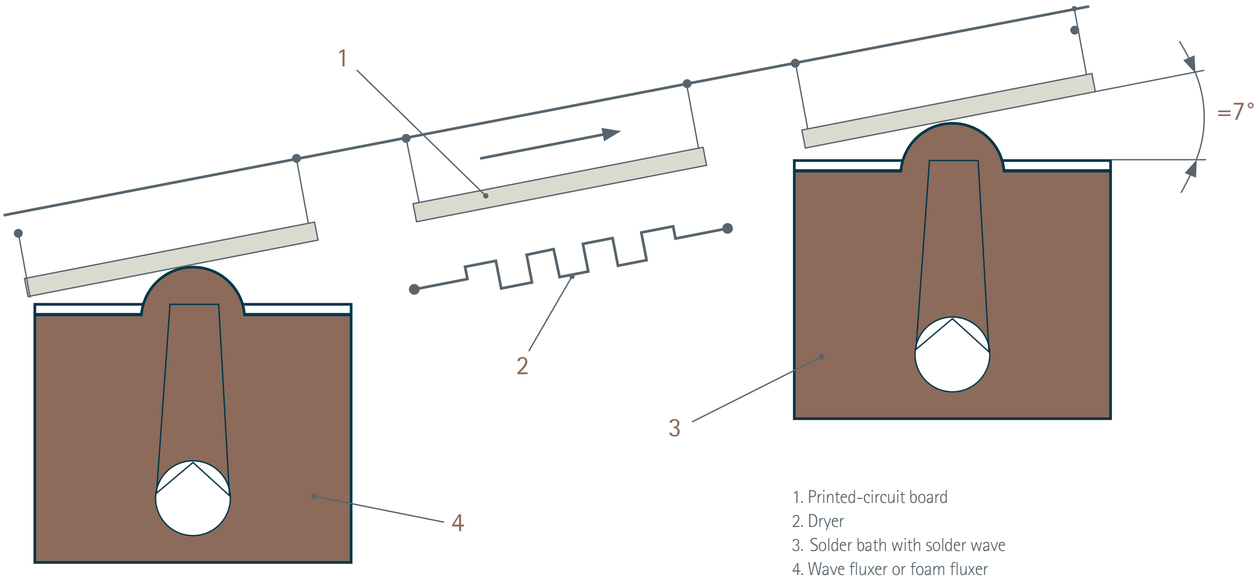
Disadvantages
- Can cause high thermal stressing of workpiece
- High maintenance

Table 22 - Advantages and disadvantages of dip soldering or dip brazing

Wave soldering
Wave soldering is chiefly used to solder electronic components onto printed circuit boards.

The process comprises four stages with a conveyor transporting the printed circuit board (PCB) to the different zones. The process begins with flux being applied to the PCB assembly. In the second stage, the PCB assembly is pre-heated using a convection heater or an infrared lamp to compensate for the different heat capacities and thermal expansion coefficients of the materials on and in the PCB. PCBs contain epoxides, which as poor conductors of heat make it difficult to raise the temperature of the assembly. The PCB laminate therefore acts to cool the surrounding metal components making it impossible to heat the assembly uniformly up to the soldering temperature. In addition, hot flux vapour causes a rise in temperature of the temperature-sensitive electronic components. If infrared radiation is used as the heat source, the high reflectivity (up to 96 %) of the shiny metallic components is not conducive to heating and needs to be taken into account when designing the process. The actual soldering stage occurs when the PCB assembly is transported through the solder wave zone. The final stage involves cooling the PCB assembly in the cooling zone, either naturally under ambient conditions or by forced cooling. [27]. Experience has shown that the PCB assembly is best drawn across the surface of the solder inclined at an angle of 7° [10].

Drag soldering is a variant of wave soldering. In drag soldering, the solder is applied not by contact with the solder wave, but by immersion in a static solder bath. The angle at which the assembly enters and exits the bath is typically between 8° and 10°, and the immersion depth is usually about half the thickness of the PCB. A rigid strip is used to remove the oxides ('dross') from the surface of the solder bath [10].



1. Printed-circuit board
2. Dryer
3. Solder bath with solder wave
4. Wave fluxer or foam fluxer
7° Conveyor angle

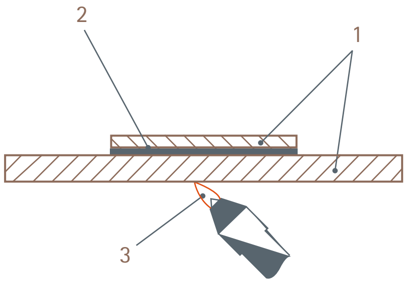
Figure 17 – Wave soldering (based on [10])

For the advantages and disadvantages of wave soldering, see the section on dip soldering or brazing.

4.5.3. Flame soldering or brazing

Flame soldering or brazing (or Torch soldering/brazing') can be performed by hand or by machine. The heat is applied by a flame of combustible gas (e.g. acetylene). The gas is fed to the torch head through a pressure regulator. The choice of torch depends on the workpiece, material and gas being used. The first stage involves applying flux to the surfaces to be joined. The joint gap must be dimensioned accordingly. The parts to be soldered or brazed must be fixed in position to prevent them from slipping. The workpiece should be pre-heated at the location of the joint and its immediate vicinity so that the solder or filler metal can flow easily. If the area to be soldered/brazed is not hot enough, the solder or filler metal will contract when it comes into contact with the cold surface and no wetting will occur. Pre-heating is done with a neutral or with a reducing or slightly reducing flame.

The solder or filler metal is fed to the joint in the form of a rod or wire. If the solder or filler metal is to be inserted into the joint (e.g. as a pre-form), consideration must be given to the right type of solder or filler metal and to the design of joint. In general, the soldering time or brazing time should not exceed three minutes. The flame should not be aimed directly at the joint as this could damage the flux. Most fluxes need to be removed once the soldering or brazing process is finished. Copper-copper joints are best made with phosphorus-containing solders or filler metals, as no flux is then required. Appropriate solders can be found in the following standards: DIN EN ISO 17672 (2010) for brazing filler metals; DIN 1707-100 (2011) and DIN EN ISO 9453 (2014) for soft solder alloys. Torch soldering and brazing are used in numerous industrial sectors, including refrigeration and air-conditioning, mechanical construction of small-scale and large-scale equipment, plumbing and heating installations, and gas and water installations. Information pertaining to gas and water installation work is available in the technical application notes GW 2 and GW 7 issued by the German Technical and Scientific Association for Gas and Water (DVGW). For example, drinking water installations are subject to special requirements: copper piping larger than 28 x 1.5 mm must only be joined by brazing [28] [29].



1. Components to be joined
2. Flux and solder 3. Flame

Figure 18 – Torch soldering (based on [10])

Advantages
- Process can be easily mechanised
- Low equipment costs

Disadvantages
- Working with a naked flame
- Components need to be held in place with a jig
- Time-consuming preparation and after-treatment of the workpiece

Table 23 - Advantages and disadvantages of torch soldering or torch brazing

4.5.4. Furnace soldering or brazing

Furnace soldering or brazing is nearly always carried out either in a protective gas atmosphere or in a vacuum; it is rarely done in an air atmosphere.

It offers a number of advantages over other soldering or brazing processes. If due consideration is given to the materials and workpiece geometries used, uniform heating and cooling can be achieved, thus reducing thermal stresses and distortion in the workpiece. The temperature-time profile is relatively easy to control. Workpieces with complex shapes and large numbers of joints can be soldered or brazed without difficulty. Additionally, heat treatment and soldering/brazing can be carried out in a single operation. The solder or brazing filler metals should have a narrow melting range in order to prevent liquation and erosion [6].

Furnace soldering or brazing carried out in a controlled atmosphere (using inert gases such as argon, helium or nitrogen, or reducing gases like hydrogen or carbon monoxide) is well suited to high-volume soldering or brazing jobs in which multiple joints need to be made, such as the fabrication of condensers, cooling units, heat exchangers and in automotive construction [6].

A variety of furnace types are available, including retort-type, batch-type and continuous-type furnaces. The temperature in the furnace should be approximately 50 °C above the relevant soldering or brazing temperature. It is important that the surfaces to be joined are thoroughly cleaned prior to furnace soldering or brazing. Furnace soldering or brazing of brass components is only possible if a flux is used [6].

Soldering or brazing in a vacuum furnace is a flux-free method of joining components that need to meet exacting quality specifications. It is commonly used in the aviation, aerospace, electronics, automotive, machine tool, plant equipment construction, and power engineering industries. Vacuum furnaces also come in a variety of types. Examples include radiation-heated glass vessels, resistance-heated and induction heated furnaces. Soldering or brazing is usually carried out under a low to moderate vacuum (1 mbar to 10-3 mbar) or high vacuum conditions (10-3...10-7 mbar). In the majority of cases, the heating power of a vacuum furnace lies between 50 kW and 500 kW. Before any soldering or brazing can take place, the heating chamber needs to be cleaned and the components carefully positioned within it. The temperature of the furnace is then increased rapidly to about 50 °C below the solidus temperature. The furnace is then held at this temperature for a short time to facilitate temperature equilibration. This is followed by rapid heating to approximately 20–30 °C above the soldering or brazing temperature of the solder or brazing filler metal. Depending on the work being carried out, the soldering or brazing temperature must be held for a period of 5–20 minutes. Process times can be shortened by heating and cooling under a protective gas atmosphere. In such cases, the vacuum in the furnace chamber is generated at higher temperatures [6].

Figure 19 – Vacuum soldering/brazing furnace [30]

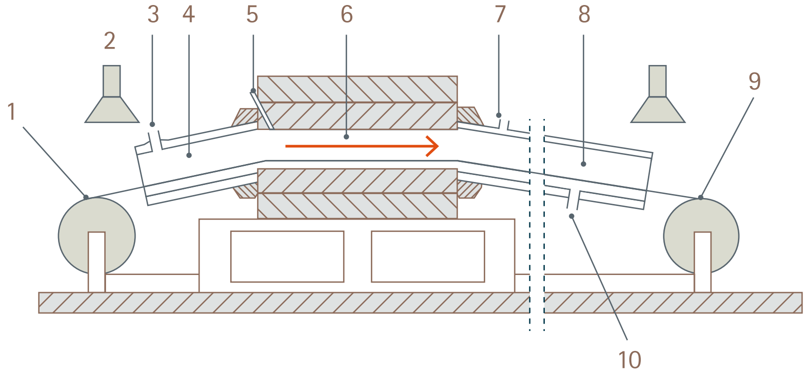
Another means of classifying furnace soldering or brazing processes is in terms of the process consumables used, such as:

- Flux
- Flux and protective gas
- Reducing protective gas (e.g. hydrogen)
- Inert protective gas (e.g. argon, helium) [6].

Medium	Vacuum	Reducing gas	Inert gas	Flux
Flux		X	X	X
Reducing gas			X	
Inert gas	O	X		
Vacuum	X			

X – can be used simultaneously
O – can be used sequentially

Table 24 - Surface activation in furnace soldering or brazing



1. Infeed 2. Extractor hood 3. Exit port for protective gas 4. Pre-heating zone 5. tube port
6. Soldering/brazing zone 7. Cooling water 8. Cooling zone 9. Exit 10. Entry port for protective gas

Figure 20 - Schematic diagram of a continuous-feed furnace with an inert gas atmosphere (based on [6])

Advantages
- Uniform heating and cooling ensures low-stress and undistorted components
- Soldering/brazing of complex assemblies
- Soldering/brazing and heat-treatment can be performed in a single step
- Process can be readily controlled
- Multiple joints can be made in a single step

Disadvantages
- All areas of the workpiece are subjected to heat treatment
- Long soldering/brazing times
- High equipment costs

Table 25 - Advantages and disadvantages of furnace soldering or brazing

Reflow soldering
Reflow soldering is an important technique in the electronics industry. It is a common method of attaching surface-mounted components to printed circuit boards. The technique makes use of solder pastes containing, for example, SnAgCu or SnAg alloys. In a reflow oven, the solder in the solder/flux paste melts creating a material bond between the electronic components and the circuit board (see figure 21).

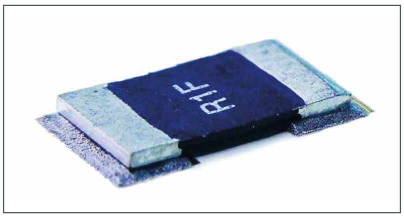


Figure 21 - Surface-mounted component shown before the solder in the solder paste melts [31]

	Radiation		Convection		Condensation (vapour phase)	Conduction
	Infrared	Laser	Air	Nitrogen		
Simultaneous process	X		X	X		
Simultaneous batch process					X	X
Sequential process		X				
Heat transfer to PCB assembly (inter–comparison)	Large energy density	Very large energy density	Homogeneous	Homogeneous	Homogeneous	Partially inhomogeneous if no planar contact to component
Maximum achievable temperature relative to the temperature T_P on the PCB assembly	Temperature can slightly exceed T_P	Temperature can slightly exceed T_P	T_P can be controlled very precisely (max. gas temp. ≤ 350 °C)	T_P can be controlled very precisely (max. gas temp. ≤ 350 °C)	T_P is limited by the choice of medium (max. temp. ≤ 260 °C)	T_P can be controlled precisely (max. hot-plate temperature ≤ 350 °C)
Flexibility in controlling the temperature profile	High	Low	Very high	Very high	Medium	Medium to low
Special requirements	No	Solder paste and substrate must be suitable	No	No	Component specifications must be taken into account	Requires a flat, bare contact surface

Table 26 - Comparison of the different reflow soldering heating modes [31]

The following heat sources may be used: light/radiation (e.g. infrared), convection (e.g. hot nitrogen), vapour-phase condensation (latent heat) and conduction. Table 26 lists some of the characteristic properties of the various heat sources.

Convection reflow soldering in a nitrogen atmosphere has gained in importance in recent years. The nitrogen partially displaces the air from the reflow oven thus reducing the oxygen content in the chamber. As nitrogen itself does not react chemically with the other elements present, it effectively prevents oxidation on the metallic surfaces to be soldered and therefore improves the solder wetting process. The convection of the hot gas is controlled externally by fans, blowers and injector nozzles. As can be seen in figure 22, a convection reflow oven has multiple process zones that can be controlled individually [31].

No matter which type of reflow soldering oven is chosen, the reflow process is always composed of the following steps: pre-heating, solder reflow, and cooling. To achieve pore-free soldered joints, reflow soldering can also be done under vacuum. Nevertheless, soldering faults can still arise, such as solder skips, tombstoning (unbalanced solder melting and wetting behaviour at the mounting pads on different sides of the component), solder bridges and solder balls [15] [31].

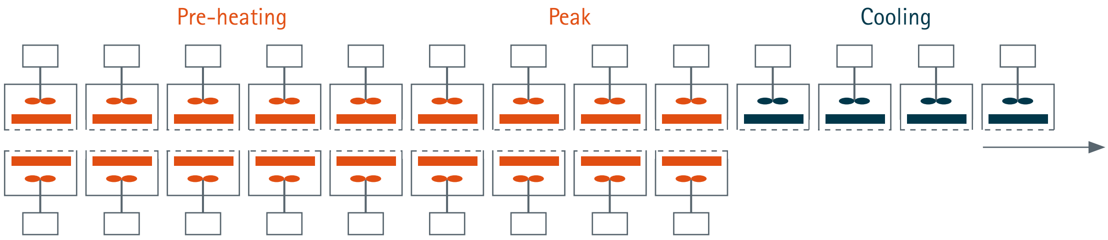
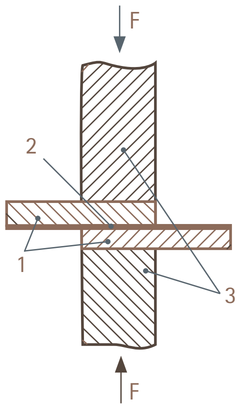


Figure 22 - Schematic diagram of a convection reflow oven [31]

4.5.5. Electric resistance soldering or brazing

Typical parent metals are copper, brass, unalloyed steel and aluminium, but all other metallic materials can be soldered or brazed by this technique.

The solder of filler metal is applied to or placed in the assembly gap before soldering or brazing begins. The electrodes (made, for example, from tungsten) are used to press the mating surfaces together. The electric current flowing in the secondary circuit of the transformer generates intense heat at the point of contact between the parts to be joined and causes the solder to melt. Depending on the particular application, a flux or a controlled atmosphere can be used. Soldering or brazing times range from a few milliseconds to a few seconds. There are two types of resistance soldering/brazing: direct resistance soldering/brazing, in which the electric current flows directly through the joint, and indirect resistance soldering/brazing, in which the current is introduced to the part to be joined via an electrode without flowing through the joint [6].



1. Workpiece 2. Joint to be soldered
3. Electrodes

Figure 23 – Direct resistance soldering (based on [10])

Advantages
- Heat is applied only in the region of the joint, neighbouring areas remain unaffected
- Short soldering/brazing times
- Suitable for temperature-sensitive parts

Disadvantages
- Geometry of assembly must be taken into account

Table 27 - Advantages and disadvantages of electric resistance soldering or brazing

4.5.6. Induction soldering or brazing

Induction soldering or brazing can be used to join all types of metal and typically uses a flux in an air or controlled atmosphere. The technique is primarily used, however, for copper, brass, steel and aluminium. The solder or brazing filler alloy selected should have a narrow melting range or a fixed melting point and good flow properties. The cleaned joint is surrounded by a single-turn or multi-turn water-cooled induction coil. The induction coil must be shaped appropriately to fit the form of the workpiece. The technique is therefore particularly well suited for rotationally symmetric parts. An AC current flows in the coil, generating an alternating magnetic field that induces electric currents and therefore heat in the part being soldered or brazed [6].

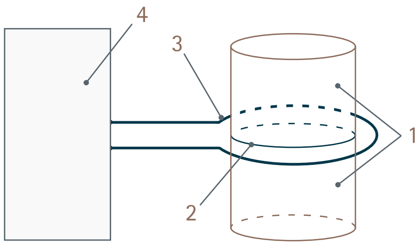
The technique requires a medium-frequency or high-frequency generator.

Table 29 shows how the heat penetration depth (or 'skin depth') in copper and brass varies with frequency. It is readily apparent that lower frequencies are more suited to heat generation at greater depths, while higher frequencies are better for processing at the workpiece surface.

Material	Temperature [°C]	Skin depth [mm] at the following frequencies:			
		50 Hz	500 Hz	10 kHz	1 MHz
Copper	600	17	5,5	1,2	0,12
Brass	600	26	8,5	1,8	0,18

Table 29 - Skin depth as a function of operating frequency [32]

Induction soldering/brazing offers a number of advantages over other soldering/brazing techniques. There is no exposure to high levels of light, heat or noise at the workplace, induction heating systems can be readily mechanised or automated, the process is energy efficient, heating is fast and localised, which is beneficial when dealing with temperature-sensitive parts. Drawbacks include the creation of an electromagnetic field during the soldering/brazing process and the high initial cost of the equipment, which makes the technique more suited to the mass production of assemblies [6].



1. Components to be joined 2. Brazing joint
3. Induction coil 4. Generator

Figure 24 – Induction brazing [10] (above)
Table 30 - Advantages and disadvantages of induction soldering or brazing (below)

	Medium frequency	High frequency
Frequency	1000 – 10.000 Hz	0.1 – 5 MHz
Size of copper parts [thickness t]	t = 4 – 12 mm	t = 0.3 – 3 mm
Output power	20 – 300 kW	2 – 30 kW
Soldering or brazing time	0,5 – 4 min	5 – 60 sec
Areas of application	Appliance manufacturing, automotive engineering	Precision engineering, electrical engineering, tool fabrication, aerospace engineering
Coupling gap between the coil and the part to be soldered or brazed	2 – 4 mm	for Cu: 1–2 mm
Gap width	0.05–0.25 mm (for narrow gaps in a controlled atmosphere; in all other cases: flux required)	

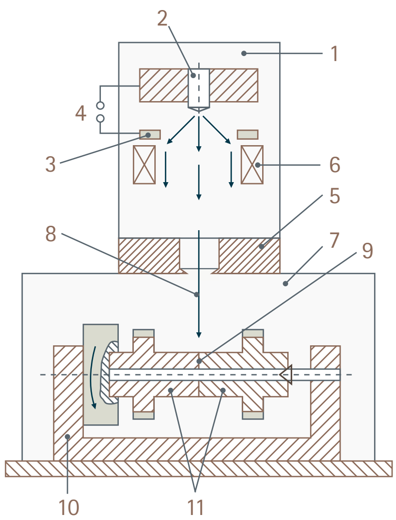
Table 28 - Characteristic features of induction soldering or brazing [6]

Advantages
- Contactless process
- Short soldering/brazing times
- High-quality soldered/brazed joints
- Uniform heating of the components

Disadvantages
- High investment cost
- Joint must be accessible to induction coil
- More suited for rotationally symmetric components
- Electromagnetic field

4.5.7. Electron beam brazing

Electron beam brazing is carried out in a medium or high vacuum environment. It is characterised by high power densities and a small beam diameter. The electrons are thermally emitted from the cathode and accelerated by the strong electric field that results from the high voltage (15–75 kV) applied between the cathode and anode. The electron beam exits the beam generator through a hole in the anode. When the tightly bundled electron beam impacts the target material, the kinetic energy of the fast-moving electrons is converted into thermal energy, generating heat in the material. In electron beam brazing, the parts to be joined must be pre-coated with filler-metal or filler metal preforms must be inserted at the location of the joint. Electron beam brazing is used for applications in which the joints have tight dimensional tolerances, where high-power, highly localised heating is required, or where heating has to be achieved extremely rapidly [6].



1.Vacuum chamber 2. Cathode 3. Anode
4. Power source connector terminals
5. Beam deflection system
6 . Focusing lens 7. Hartlötkammer
8. Electron beam 9. Brazing joint 10. Device for moving/positioning workpiece 11. Components to be joined

Figure 25 – Electron beam brazing [10]

Advantages
- Highly localised heating of parent material
- Good reproducibility
- Minimal distortion of components
- No complex preparation or after-treatment required

Disadvantages
- Process carried out in a vacuum
- Potential x-ray hazard
- Requires use of filler metal preforms or pre-coated parts

Table 31 - Advantages and disadvantages of electron beam brazing

4.5.8. Arc brazing

Electric arc brazing can be performed as a MIG or TIG process. The arc is created between a wire electrode and the parts to be brazed, transforming electrical energy into heat at the brazing joint. The filler metal is typically a copper-based alloy wire or rod whose melting range is below that of the parent metal. The solidus temperature of common filler metals of this type is in the range 830 °C to 1060 °C. Electric arc brazing is generally used for braze welding applications. The most important filler metals are listed in table 32.

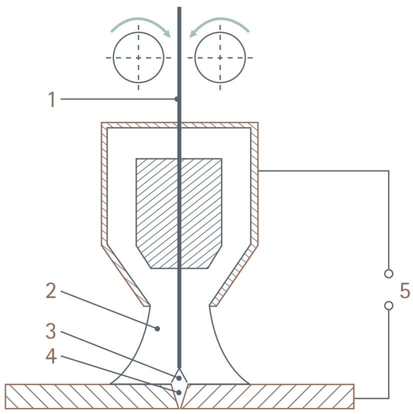
Filler metal alloy	DIN ISO 24373 (2009)		DIN EN ISO 17672 (2013)
	Designation	Material number	Material number
Silicon bronze	CuSi2Mn1	Cu 6511	Cu 521
Silicon bronze	CuSi3Mn1	Cu 6560	Cu 541
Tin bronze	CuSn6P	Cu 5180A	Cu 922
Tin bronze	CuSn12P	Cu 5410	Cu 925
Aluminium bronze	CuAl7	Cu 6100	Cu 561
Aluminium bronze	CuAl10Fe	Cu 6180	Cu 565
Manganese bronze	CuMn13Al8Fe3Ni2	Cu 6338	Cu 571

Table 32 - Overview of important filler metals used in laser and electric arc brazing

In recent years MIG brazing with consumable wire electrodes and plasma brazing have grown in importance, particularly when joining zinc galvanised sheet steel (thickness: less than 3 mm) in the automotive industry. Figure 26 shows a continuous peripheral MIG brazing seam on a motor bike fuel tank [33].

Figure 26 - Fuel tank from a Honda VT 1300CX with CuAl8 brazing filler metal [33]

Studies have shown that when electric arc brazing is carried out under a shielding gas, the commonly used copper-based (bronze) filler metals cause diffusion and partial dissolution to occur at the interface of the parent metal and the coating and filler metals. The metal surfaces that come into contact with the brazing filler alloy should be clean and bare so as to facilitate metallurgical interaction between the parent metal and the wetting filler metal. Fluxes are not required as the surfaces are activated by the burning arc. The DVS technical leaflet 0938-1 (2012) contains further information on the principles and details of the process as well as the equipment requirements. Application notes on arc brazing are available in DVS technical leaflet 0938-2 (2005). One of the advantages of electric arc brazing compared with laser beam brazing is the lower capital investment costs [6] [34] [35].



1. Wire electrode (filler metal) 2. Shielding gas
3. Arc 4. Brazing joint 5. Power source

Figure 27 - Electric arc brazing (MIG) (based on [6])

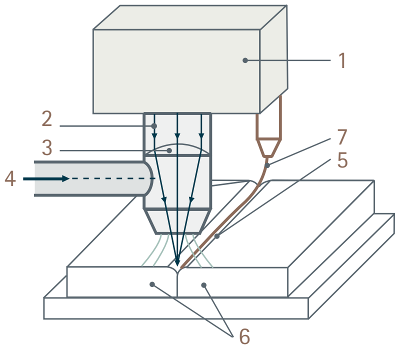
Advantages
- High productivity
- Little preparation or after-treatment required (no flux involved)
- Minimal distortion of components
- Can be readily mechanised
- High brazing speed
- Low investment costs
- Optically well-finished joints

Disadvantages
- Precision electrode feeding required
- Arc blow may need to be taken into account

Table 33 - Advantages and disadvantages of electron arc brazing

4.5.9. Laser beam soldering or brazing

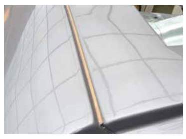
While both laser beam soldering and brazing techniques are used, most of the applications in the automotive industry involve laser beam brazing. The technique enables high temperatures to be reached so that high-melting copper-based filler metals can be processed without difficulty. A highly focused laser beam generates high power densities but only a small heat-affected zone. A particularly suitable radiation source for copper-based filler metals is a Nd:YAG solid-state laser as it generates laser radiation at a wavelength of 1.06 µm by the filler alloy. It is important that the parts to be joined are pre-coated with filler metal or that the filler metal is precisely positioned. Laser beam soldering and brazing techniques are used primarily in the electrical, automotive and precision engineering sectors. Very short soldering or brazing times are possible. For example, single soldering times in the millisecond range are possible for surface mounted electronic components [6].



1. Power source 2. Laser beam 3. Focusing lens
4. Shielding gas 5. Brazing joint
6. Components to be joined 7. Filler wire

Figure 28 – Laser beam brazing (based on [6])

Laser brazing is commonly used in the automotive industry to join zinc galvanised body panels, as it enables high brazing speeds to be achieved while the small heat affected zone minimises panel distortion issues [36]. The images in table 34 show a roof seam fabricated using laser brazing and a CuSi3Mn1 silicon bronze filler. Filler metals that are suitable for use in electron beam brazing (see table 32) can also be used for laser beam brazing [37].



Laser-brazed roof seam on a Volkswagen Passat CC (2008)

Laser-brazed roof seam on an AUDI Q5 (2008)

Table 34 - Examples of a laser brazed seam [33] (above)
Table 35 - Advantages and disadvantages of laser beam brazing (below)

Advantages
- Very high productivity
- Minimal preparation or after-treatment required (no flux involved)
- Can be readily mechanised
- Minimal distortion of components
- High brazing speed

Disadvantages
- High capital investment costs
- Positioning and feeding of filler wire has to be done very precisely

5. Quality assurance

Quality assurance is one of the main elements of a quality management system and is concerned with verification. The aim of quality assurance is to prevent the production or supply of defective products. As in welding, the quality of a brazing or soldering process depends on the skill and experience of the operator. Soldering and brazing are physicochemical processes in which a material bond is created through interactions between the solid parent material and the molten solder or filler metal. Phenomena such as capillary action and surface wetting are exploited in soldering and brazing processes. If the parent material and solder or filler alloy are properly matched, and if the joint is properly designed and made, a soldered or brazed joint can provide a more reliable join than that achievable by welding [38]. This section aims to provide an overview of quality assurance issues but does not claim to be complete.
The following faults and defects can arise in a soldering or brazing process:

- flux burning when the temperatures used are too high,
- inadequate wetting by the solder or filler metal alloy,
- wrong choice of solder/filler or flux,
- no preparation or improper preparation of the mating surfaces,
- de-wetting caused by oxidation at the joint because soldering/brazing times were too long.

It is therefore important to produce and maintain quality assurance documentation. The documentation should provide safeguards against potential claims and provide the necessary proof that a fault or defect could not have occurred during the fabrication or production process. Important recommendations are contained in the standards governing quality management systems: DIN EN ISO 9001 (2008) and ISO/TS 16949 (2009). The DIN-DVS Manual 196 (Parts 1 and 2) also contains all of the relevant standards and DVS technical leaflets relating to soldering and brazing.

In addition to the standards, the German Welding Society DVS (Deutscher Verband für Schweißen und verwandte Verfahren e.V.) also issues technical leaflets and guidelines. There are fewer rules and accepted methods of quality assurance for soldering and brazing than for welding. The primary criteria are: appropriate qualification and training of operating personnel; production monitoring; checking on assessing the quality of the joints made.

The objective is to fabricate a high-quality soldered or brazed joint in a reproducible fashion while taking cost efficiency factors into consideration. The need for well-trained and skilled personnel is important not only for producing well-executed soldered or brazed joints, but also for fixing or jigging the components of the soldered or brazed assembly. The following guidelines and standards govern the procedures to be followed in training courses: DVS Guideline 1183 (2004), DIN ISO 11745 (2011) and DIN EN ISO 13585 (2012).

By identifying and, where necessary, correcting workflow irregularities early, monitoring procedures play an important role in ensuring that the soldering or brazing process meets the required quality specifications while remaining cost-effective. Monitoring involves capturing key process parameters (e.g. temperature time profile is) and observing the state of soldering is, the filler alloys and other auxiliary materials and consumables. Manual processes, such as hot iron soldering, demand highly trained operators with good manual dexterity as, in most cases, devices measuring and displaying the temperature at the workpiece are not used. Measuring instruments that can monitor process parameters and record process data are, however, essential when the soldering or brazing process is mechanised or fully automated, such as in a completely encased continuous-feed furnace.

Another important aspect when assessing the quality of a soldered or brazed connection concerns of the geometry and metallurgical structure of the joint. Dimensional and visual inspections are obligatory. The presence of cracks and pinholes (pores) are typically demonstrated using dye penetration and magnetic particle inspection techniques. If soldering or brazing defects are to be assessed and the wetted joint area determined, x-ray and ultrasonic testing are used. The different materials and the thicknesses of the parts must be taken into account if these non-destructive testing methods are deployed. Metallographic sections are prepared in order check the condition of the microstructure, the transition zone, the seam width and any erosion. If brazing is used in the construction of tanks, containers and piping, pressure and leak testing is required [6]. Destructive testing methods suitable for evaluating soldered joints are set out in the standard DIN 8526 (1977); those used to assess brazed joints are described in DIN EN 12797 (2000). Non-destructive testing methods must conform with DIN EN 12799 (2000).

Other defects that can occur include cracking, lack of fusion, and voids.The DIN EN ISO 18279 (2004) standard provides a comprehensive classification system for listing imperfections in brazed joints. Permissible defects and imperfections are detailed in DIN 65170 (2009). This standard also specifies permissible wetted joint areas, which are an important criterion for assessing the quality of a brazed joint [6].

6. Case studies

Quality requirements in soldering and/or brazing			
Operational and administrative aspects	Personnel	Fabrication / Production	Testing / Assessment
Quality management system DIN EN ISO 9001 (2008) ISO/TS 16949 (2009)	**Qualification testing of operators** DIN ISO 11745 (2011) DIN EN 13585 (2012) DVS-Richtlinie 1183 (2004)	**Soldering and brazing processes** DIN ISO 857-2 (2007)	**Non-destructive** DIN EN 12799 (2000) **Destructive** DIN 8526 (1977)DIN EN 12797 (2000) **Defects / Imperfections** DIN EN ISO 18279 (2004) DIN 65170 (2009)

Table 36 - Summary of a number of important quality requirements

6.1. Hot-air solder levelling of printed circuit boards

Hot-air solder levelling (also: hot-air levelling – HAL) is used to coat exposed copper surfaces on a PCB with solder. To make sure that the copper is wettable, it is crucial that all dirt or tarnish is removed from the PCB before HAL is performed. After pre-cleaning, the flux is applied at the fluxing station. To restrict flux contamination in the HAL system, the amount of flux applied should kept to the minimum needed. In semi- and fully automated systems, the solder application process can be carried out with the PCB oriented vertically or horizontally (see table 37). The horizontal process can be further classified into wave tinning systems, in which the solder is applied when the PCB passes through a solder wave bath, and roller tinning systems, in which the PCB passes through a set of pinch rollers [39].

If lead solders are used in the HAL process, the choice of solder is critical, as solders with a copper content of more than 0.3 % will result in uneven soldered surfaces. To ensure uniform reproducible results, solder analyses should be conducted at regular intervals. These analyses are generally carried out free-of-charge by the solder supplier [39].

HAL process		
vertical	· Fluxed PCB is dipped into a bath of hot solder · Board withdrawn after a short period · Excess solder is blown off by jets of hot air ('hot-air knives') · Result: some plated-through holes missed and non-uniform solder thickness on the PCB, horizontal HAL method is therefore preferred	
horizontal	**Wave tinning**	**Roller tinning**
	· PCB travels at constant speed over the entire length of the HAL machine · PCB is pulled though a solder wave bath · Excess solder removed by hot-air knives · Contact time with molten solder longer than in roller tinning	· PCB is accelerated after passing through the fluxing zone · PCB guided through up to three pairs of rollers · Excess solder blown off

Table 37 - Process steps in vertical and horizontal HAL systems

6.2. Strip tinning

Tinned strips of copper or copper alloys are the raw materials for plug-in connectors that are used in a wide variety of applications, such as connectors for vehicle wiring looms, for computers and other electronic devices. Component miniaturisation has placed increasingly tough demands on the quality of the strip tinning process. Meeting these quality specifications requires the strip to be hot-dip tinned with non-corrosive, no-clean fluxes (see table 15), which have to be carefully selected for the particular strip tinning line and for the copper alloy being tinned. Corrosive fluxes are rarely selected, as customers who use tinned strips frequently demand a chloride-free tinning process. Layer thicknesses can be adjusted individually to satisfy customer specifications [24].

6.3. Fabricating heat exchangers from copper

Thanks to their good thermal conductivity and their high mechanical stability, heat exchangers made from copper/brass are commonly used for air-conditioning systems in utility vehicles, for radiators in construction machinery, or for industrial cooling equipment. They are manufactured in four steps. The initial stage involves machine-tinning brass strip by hot-dipping in a tinning bath and then drawing into tubes. The tubes are then brazed with copper fins in a furnace. Dip brazing is then used to join the tubes to the tube sheet. Finally, the water tank is manually brazed to the tube sheet. Non-corrosive or no-clean fluxes are preferred for all steps of the production process. To achieve the best possible brazing results, the fluxes are selected for the particular brazing operation. Corrosive fluxes are only used in exceptional circumstances as they require additional rinsing operations that drive up process costs [24].

The adapter tube on a heat exchanger can be fabricated by brazing a flexible inner copper tube with a protective woven bronze shield using fluxless electric arc brazing (TIG). Appropriate filler materials are the high-tin bronze rods, such as CuSn12P. In TIG brazing, the arc burns above a sharp-tipped tungsten rod and the filler metal is fed to the joint by hand. Well-executed brazes have a visually appealing appearance [33].

Figure 29 – Heat exchange tube [33]

6.4. Manufacture of compact high-performance radiators from copper

The CuproBraze® process is used to manufacture compact high-performance heat exchangers from copper and non-ferrous metals. The compact highly efficient design of these heat exchangers makes them particularly well suited for applications in the automotive and aviation industries, but also for coolers, condensers or evaporators in the refrigeration and electrical engineering sectors. One of the advantages of radiators made from copper or copper alloys over those made from aluminium is that they prevent biofouling and thus eliminate the bad odours that would otherwise be generated by fungus and bacteria in the cooling channels. In the CuproBraze® process joints are created by brazing with the filler alloy CuNiSnP. Once the tubes and fins have been fabricated, a filler metal paste is applied to them. Once brazed, the elements are then assembled to make the heat exchanger and held in position by a jig. Brazing paste is then applied again and the assembly is brazed in a continuous-feed furnace. There is no need for fluxes and subsequent rinsing procedures [40] [41].

Figure 30 – Compact high-performance radiator [12]

7. Terminology

Cooling time
Time span during which the joint cools down from the soldering/brazing temperature to ambient temperature [10].

Heating time
Time during which the soldering/brazing temperature is reached. It includes the equalising (preheating) time and can also include other times, e.g. the degassing time [10].

Wetting
Spreading and adhesion of a thin continuous layer of molten filler metal on the surfaces of the components being joined [10].

Diffusion zone / Transition zone
Layers formed during soldering or brazing with a chemical composition that is different from that of the parent material(s) and that of the solder or braze metal [10].

Equalising temperature
Temperature at which the components being joined are held so that they are uniformly heated through [10].

Equalising temperature
Time during which the components to be soldered or brazed are held at the equalising/preheating temperature [10].

De-wetting
Separation of solid filler material which, although it had spread over the surfaces of the components to be joined, had failed to bond to them because of e.g. inadequate cleaning or fluxing [10].

Soldered or brazed assembly
Assembly formed by soldering or brazing two or more components together [10].

Total time
Period which includes the heating time, the holding time and the cooling time [10].

Parent material
Material being brazed/soldered [10].

Holding time
Time during which the joint is kept at the soldering or brazing temperature [10].

Capillary attraction
Force, caused by surface tension, which draws the molten filler metal into the gap between the components being joined, even against the force of gravity [10].

Liquidus temperature
Temperature above which a material is completely liquid.

Solderability/Brazeability
Property of a component that enables it to be produced by soldering or brazing so as to meet the requirements of its intended use [2].

Material suitability for soldering/brazing
Property of a material that is influenced by the manufacturing process and, to a lesser extent, by its design [2].

Solder metal or braze metal
Metal formed by the soldering or brazing process [10].

Soldering / Brazing
Joining processes in which a molten filler material is used that has a lower liquidus temperature than the solidus temperature of the parent material(s), which wets the surfaces of the heated parent material(s) and which, during or after heating, is drawn into (or, if pre-placed, is retained in) the narrow gap between the components being joined [10].

Manufacturing suitability for soldering/brazing
Property of the manufacturing process that is primarily influenced by design factors and less by the material itself [2].

Soldering or brazing seam
Region of the joint comprising the solder/braze material and the diffusion/transition zones [10].

Design suitability for soldering/brazing
Property of the design that is determined in equal measure by the material and the manufacturing process [2].

Closed joint
Joint in which the gap is filled principally by capillary action with filler metal, i.e. either a butt joint or a lap joint between parallel faces of the components to be soldered or brazed [10].

Soldering or brazing temperature
Temperature at the joint where the filler metal wets the surface or where a liquid phase is formed by boundary diffusion and there is sufficient material flow [10].

Soldering or brazing time
Time period for the soldering or brazing cycle [10].

Filler material
Added metal required for soldered or brazed joints, which can be in the form of wire, inserts, powder, pastes, etc [10].

Soldering or brazing paste
Metal powder combined with a binder and in some cases a flux. Soft solder pastes are used, for example, in reflow soldering; brazing pastes are used, for example, in the brazing of pipes made of copper or galvanised steel.

Solidus temperature
Temperature below which there is no liquid phase

Parent material affected by the soldering/brazing process
Material with properties different from those of the parent material due to the influence of the soldering/brazing process [10].

Heat-affected zone
Zone of parent materials affected by the soldering/brazing process [10].

Effective temperature range
Temperature range within which a flux or a protective atmosphere is effective [10].

8. Appendix

The tables below present a selection of standards and guidelines relating to soldering and brazing

	Standard	Title / (Year of publication)
General	DIN 8514	Brazeability, solderability (DIN 8514:2006-05)
	DIN ISO 857-2	Welding and allied processes – Vocabulary – Part 2: Soldering and brazing processes and related terms (ISO 857-2:2005)
Engineering desig	DIN 1912-4	Graphical Representation of Welded, Soldered and Brazed Joints – Concepts and Terms for Soldered and Brazed Joints and Seams (DIN 1912:1981)
	DIN EN ISO 2553	Welding and allied processes - Symbolic representation on drawings - Welded joints (ISO 2553:2013); German version EN ISO 2553:2013
	DIN 65169	Aerospace – Brazed and high-temperature brazed components – Directions for design (DIN 65169:1986)
Processes / Manufacturing	DIN EN 14324	Brazing – Guidance on the application of brazed joints (German version EN 14324:2004)
Parent materials / Solders and filler metals / Fluxes	DIN CEN/TS 13388	Copper and copper alloys – Compendium of compositions and products (DIN CEN/TS 13388:2013
	DIN EN ISO 3677	Filler metals for soft soldering, brazing and brazewelding– Designation (ISO 3677:1992; German version EN ISO 3677:1995
	DIN EN ISO 17672	Brazing – Filler metals (ISO 17672:2010; German version EN ISO 17672:2010
	DIN 1707-100	Soft solder alloys – Chemical composition and forms (DIN 1707-100:2011-09)
	DIN EN ISO 9453	Soft solder alloys – Chemical compositions and forms (ISO 9453:2014; German version EN ISO 9453:2014)
	DIN EN 1045	Brazing – Fluxes for brazing – Classification and technical delivery conditions (German version EN 1045:1997)
	DIN EN 29454-1	Soft soldering fluxes – Classification and requirements – Part 1: Classification, labelling and packaging (ISO 9454-1:1990; German version EN 29454-1:1993)
	DIN EN ISO 9454-2	Soft soldering fluxes – Classification and requirements – Part 2: Performance requirements (ISO 9454-2:1998; German version EN ISO 9454-2:2000)
Test procedures	DIN EN ISO 13585	Brazing – Qualification test of brazers and brazing operators (ISO 13585:2012; German version EN ISO 13585:2012)
	DIN EN 13134	Brazing – Procedure approval (German version EN 13134:2000)
	DIN ISO 11745	Brazing for aerospace applications – Qualification test for brazers and brazing operators – Brazing of metallic components (ISO 11745:2010; DIN ISO 11745:2011-01)
	DIN EN 12797	Brazing – Destructive tests of brazed joints (German version EN 12797:2000)
	DIN 8526	Testing of soldering joints – Gap soldered joints, shear test, creep shear test (1977)
	DIN EN 12799	Brazing – Non-destructive examination of brazed joints (German version EN 12799:2000)
	DIN EN ISO 18279	Brazing – Imperfections in brazed joints (ISO 18279:2003; German version EN ISO 18279:2003) (2004)
	DIN 65170	Aerospace series – Brazed and high-temperature brazed metallic components – Technical specifications; Text in German and English (2009)
	DIN 1900	Specification and qualification of brazing procedures for metallic materials – Procedure test for arc brazing of steels (DIN 1900:2010-04)

Table 38 - Selected standards covering soldering and brazing processes

Regulations / Technical guidelines / Technical leaflet	
BGV D1	Berufsgenossenschaftliche Vorschrift für Sicherheit und Gesundheit bei der Arbeit [Accident prevention regulations governing welding, cutting and allied processes; published by the German Employers' Liability Insurance Association] (04/2001)
Richtlinie DVS 1903-1	Löten in der Hausinstallation – Kupfer – Anforderungen an Betrieb und Personal [Technical guidelines: Soldering/ brazing in domestic installation work – Copper – Requirements to be met by companies and their employees] (10/2002)
Richtlinie DVS 1903-2	Löten in der Hausinstallation – Kupfer – Rohre und Fittings – Lötverfahren – Befund von Lötnähten [Technical guidelines: Soldering/brazing in domestic installation work – Copper – Pipes and fittings – Soldering/brazing procedures – Inspecting soldered/brazed joints] (10/2002)
Merkblatt DVS 0938-1	Lichtbogenlöten – Grundlagen, Verfahren, Anforderungen an die Anlagentechnik [Technical leaflet: Electric arc brazing – Principles, methods and technical requirements] (08/2012)
Merkblatt DVS 0938-2	Lichtbogenlöten – Anwendungshinweise [Technical leaflet: Electric arc brazing – Application notes] (05/2005)
Merkblatt DVS 2602	Hartlöten mit der Flamme [Technical leaflet: Torch brazing] (04/2011)
Merkblatt DVS 2604	Öfen für das Hart- und Hochtemperaturlöten unter Vakuum [Technical leaflet: Furnaces for brazing and high-temperature brazing under vacuum] (02/2008)
Merkblatt DVS 2606	Hinweise auf mögliche Oberflächenvorbereitungen für das flussmittelfreie Hart- und Hochtemperaturlöten [Technical leaflet: Information on surface preparation methods for flux-free brazing and high-temperature brazing] (12/2000)
Merkblatt DVS 2607	Prozesskontrolle beim Hochtemperaturlöten [Technical leaflet: Process control during high-temperature brazing] (02/2008)
Merkblatt DVS 2608	Reparatur von Hochtemperaturlötverbindungen [Technical leaflet: Repair of high-temperature-brazed joints] (02/2008)
Merkblatt DVS 2611	Visuelle Beurteilung von Weichlötstellen – SMD auf Leiterplatte – Kriterien im synoptischen Vergleich [Technical leaflet: Visual assessment of soldered joints – SMDs on printed-circuit boards –Comparison criteria] (05/1993)
Merkblatt DVS 2612-1	Flussmittel für das Weichlöten in der Elektronik – Hinweise für den Praktiker [Technical leaflet: Fluxes for electronic soldering applications – Information for soldering operators]
Merkblatt DVS 2617	Neueinstufung und Etikettierungsvorschriften für Flussmittel zum Hartlöten, die Borsäure, Boraxpentahydrat oder di-Bortrioxid enthalten [Technical leaflet: Reclassification and labelling rules for fluxes containing boric acid, borax pentahydrate or boron trioxide] (09/2012)
DVGW GW 2 (A)	Verbinden von Kupfer- und innenverzinnten Kupferrohren für Gas- und Trinkwasser-Installationen innerhalb von Grundstücken und Gebäuden [Technical application note: Joining copper pipes and internally tinned copper pipes for gas and drinking water installations in buildings and property] (2012)
DVGW GW7	Flussmittel zum Löten von Kupferrohren für Gas- und Wasserinstallationen [Technical application note: Fluxes for soldering/brazing copper pipes in gas and water installations]

Table 39 – Regulations, technical guidelines and leaflets covering soldering and brazing processes

Temperature in acc. with DIN ISO 857-2 (2007)	Process	Filler materials	Soldering / brazing method	Example applications
≤ 450 °C	Soldering	Soft solders mostly tin-based; commonly used in combination with a flux: joint strength is relatively low	Hot-iron soldering, wave soldering, dip soldering	Manufacture of condensers, cooling units and metal vessels; Electronics; Fabrication of PCBs; Tinning
> 450 °C	Brazing	Typically used with a flux; suitable brazing filler metals (BFMs) are: silver-based BFMs, brass BFMs, copper alloy BFMs; copper and copper alloys can be brazed in air without a flux using phosphorus-containing BFMs; high-strength joints	Torch brazing, induction brazing, electric resistance brazing, furnace brazing	Refrigeration and air-conditioning; Gas and water installations; Mechanical construction of small-scale and large-scale equipment; Plumbing and heating installations; Cooling systems; Heat exchangers; Automotive and aviation construction; Power engineering; Electrical engineering / electronics

Table 40 - Examples of soldering and brazing applications

Parent material	Solder / Brazing filler metal (BFM)							
	Lead solders	Tin-lead solders	Silver-alloy BFMs	Copper-phosphorus BFMs	Silver-copper-palladium BFMs	Copper-zinc BFMs	Copper-nickel BFMs	Copper alloy BFMs
Aluminium alloys		x		x				
Beryllium					x			
Gold					x			
Cast iron				–		x	x	
Grey cast iron				–			x	
Malleable iron				–		x	x	
Carbide						x	x	
Copper	x	x	x	x		x		
Copper alloys	x	x	x	x		x		
Brass	x			x				
Molybdenum					x			
Nickel		x	x		x	x	x	x
Nickel alloys		x				x	x	x
Unalloyed steel		x	x	–		x	x	x
Alloyed steel		x	x	–		x	x	x
High-strength steel			x	–			x	
Corrosion-resistant steel			x	–	x	(–)		
Creep-resisting steel				–	x			
Titanium					x			
Tungsten					x			
Zirconium					x			

x common combination; **–** unsuitable combination

Table 41 - Matrix for selecting commonly used combinations of parent metals and solders or brazing filler metals

	Solder or brazing filler metal	Advantages	Disadvantages
Soft solders	Tin-lead solders	· good engineering properties · good plasticity	· low creep resistance · allotropic transformation of tin at low temperatures (risk of tin pest) · risk of low-temperature embrittlement · enhanced corrosion under damp or tropical conditions
	Lead solders	· high plasticity · good processability · better thermal stability than tin-lead solders · good low-temperature stability	· poor resistance to corrosion · toxicity concerns (harmful to health and the environment)
	Lead-free solders	· recyclable	· longer soldering times · slower surface-wetting rate · elevated operating temperatures · risk of metal whiskering · Tip corrosion on hot-iron soldering irons
Brazing filler metals	Silver alloy BFMs	· good thermal conductivity · good electrical conductivity · high plasticity · high strength · good corrosion resistance · good wettability · oxides exhibit low strength/stability · good buffer between materials with differing thermal expansion coefficients	· high purchase price
	Copper-phosphorus BFMs	· very low viscosity · low brazing temperature · self-flowing · good plasticity	· risk of liquation · Risk of increased porosity through phase separatio
	Silver-copper-palladium BFMs	· elatively low melting temperature, which is useful for parent materials that are susceptible to grain coarsening at elevated temperatures · good wetting and flow properties	· Low strength at high temperatures compared with other palladium-containing filler metals · high purchase price
	Copper-zinc BFMs	· good plasticity · high strength · high thermal stability	· plasticity decreases as zinc content rises · zinc vaporises at elevated brazing temperatures leading to porous joints · not suitable for brazing in a protective gas atmosphere or in a vacuum
	Copper-nickel BFMs	· good heat resistance · good creep-resistance	
	Copper BFMs	· Lowest vapour pressure of all brazing filler metals · good viscosity · good flow behaviour	· risk of gas entrapment and solidification cracking with oxygen-containing coppers and an oxidising atmosphere

Table 42 – Summary of some advantages and disadvantages of selected solders/brazing filler metals

	Regulation / Directive / Technical rules	Hazardous substance	Notes
since 2006	RoHS Directive 2011/65/EU – (earlier Directive: 2002/95/EG)	Lead	Frequently contained in solders
since 2009	TRGS 528	Solder fumes	
since 2006	TRGS 900	Workplace exposure limits	
since 2012	Regulation (EC) No. 1272/2008 ('CLP Regulation'); 67/548/EEC (30th/31st DVS technical leaflet 2617	· Boric acid · Boron trioxide · Borax (sodium borate, anhydrate) · Borax decahydrate · Borax pentahydrate	Frequently contained in fluxes
since 2011	Commission Regulation (EU) 494/2011	Cadmium	Brazing fillers that contain a cadmium concentration greater than 0.01 % by weight are prohibited

Table 43 – Hazardous substances

Conversion tables

Sn50Pb49Cu1 (162)	L-Sn50PbCu
Sn50Pb32Cd18 (151)	SnPb32Cd18
Sn96Ag4 (701)	L-SnAg5
Sn97Ag3 (702)	L-SnAg5
Sn95Sb5 (201)	L-Sn95
Sn97Cu3 (402)	L-SnCu3
Pb98Ag2 (181)	L-PbAg3

Table 44 - Soft solders

DIN EN 29454-1	DIN 8511
1.1.1	F-SW31
1.1.2	F-SW26
1.1.3	F-SW27 F-SW32
1.2.2	F-SW28
1.2.3	F-SW33
2.1.1 2.1.3 2.2.3	F-SW24
2.1.2 2.2.2	F-SW25
2.1.3 2.2.1 2.2.3	F-SW23
2.2.3	F-SW34
3.1.1	F-SW12 F-SW21
3.1.2	F-SW22
3.2.1	F-SW13
3.2.2	F-SW11

Table 45 – Flux designations

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Bilder Deckblatt:
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Index of figures

Index of tables

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