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BRITISH STANDARD

BS EN 14324:2004

Brazing — Guidance on the application of brazed joints

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ICS 25.160.50

British Standards

National foreword

This British Standard is the official English language version of EN 14324:2004. It supersedes BS 1723-1:1986 and BS 1723-2:1986 which are withdrawn.

The UK participation in its preparation was entrusted to Technical Committee WEE/19, Brazing and bronze welding, which has the responsibility to:

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English version

Brazing - Guidance on the application of brazed joints

Brasage fort - Guide d'application pour les assemblages réalisés par brasage fort

Hartlöten - Anleitung zur Anwendung hartgelöteter Verbindungen

This European Standard was approved by CEN on 9 July 2004.

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Management Centre: rue de Stassart, 36 B-1050 Brussels

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Contents

Foreword

This document (EN 14324:2004) has been prepared by Technical Committee CEN/TC 121 “Welding”, the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by March 2005, and conflicting national standards shall be withdrawn at the latest by March 2005.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.

Introduction

The purpose of this document is to provide information and guidance to users whose knowledge of brazing is limited, either as regards the whole process or in some specific areas. It is not intended to replace textbooks but to make readily available certain important information and hopefully prevent some common errors.

Brazing techniques offer a wide field for joining, cladding, building up and comparable applications where brazing filler materials can be used. Structures similar to brazed joints can be achieved by arc brazing processes (MIG, TIG, plasma), infra-red brazing and electron beam brazing, which are better described as braze welding.

Where the word 'material' is used for components, they can be metallic or non-metallic, except when the component can only be metallic, when it is so described. The same usage applies to filler materials, although the use of non-metallic filler materials is very limited.

1 Scope

This document gives guidance on the application of brazing and the manufacture of brazed joints. This standard gives an introduction to brazing and a basis for the understanding and use of brazing in different applications. Because of the wide range of applications of brazing this standard does not give detailed guidance that might be product specific. For such information reference should be made to the appropriate product standard or, for applications where this does not exist, the relevant criteria should be clearly established before any brazing is undertaken.

This standard covers joint design and assembly, material aspects for both parent material and filler materials, brazing process and process variables, pre- and post-braze treatment and inspection.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 1044:1999, *Brazing — Filler metals.*

EN 1045, *Brazing — Fluxes for brazing — Classification and technical delivery conditions.*

EN 12797, *Brazing — Destructive tests of brazed joints.*

EN 12799, *Brazing — Non-destructive examination of brazed joints.*

EN 13133, *Brazing — Brazer approval.*

EN 13134, *Brazing — Procedure approval.*

EN ISO 18279, *Brazing — Imperfections in brazed joints (ISO 18279:2003).*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

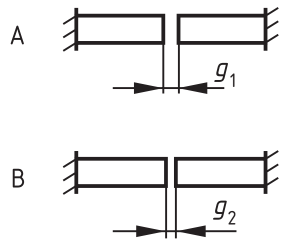
3.1
brazing
joining process in which a filler material is used which has a liquidus temperatur above 450 °C, but below the solidus of the parent material, and which is mainly distributed in the brazing gap by capillary attraction

NOTE Other joining methods exist (see E.6.3).

3.2
brazed joint
result of a joining process where the parent materials are not melted and the filling material and braze material have different chemical compositions compared to the parent materials

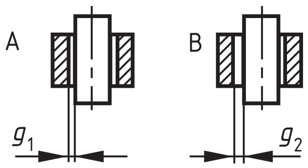
3.3
brazing gap
narrow, mainly parallel gap at the brazing temperature between the components to be brazed (see Figure 1 and 4.3.4)

3.4
assembly gap
fit up
narrow, mainly parallel gap at room temperature between the components to be brazed (see Figure 1 and 4.3.4)



$g_2 < g_1$

a) Constrained butt joint



$g_2 > g_1$

Shaded component has higher coefficient of expansion.

b) Tube joint (dissimilar materials)

Key

A Assembly at ambient temperature

B Assembly at brazing temperature

g_1 Assembly gap

g_2 Brazing gap

Figure 1 — Assembly gap and brazing gap

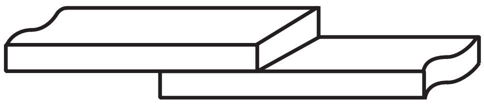
4 Joint design

4.1 Principle

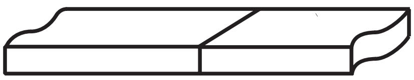
The brazing process depends upon capillary flow of a molten brazing filler material between parts separated by a narrow gap. The filler material has a different composition from the components to be brazed. This compositional difference may affect the properties of the assembly in service, e.g. at elevated temperature, in corrosive media or under fatigue loading. In addition the properties of the parent material of the components to be brazed can be affected by the brazing cycle.

4.2 Types of joint

There are basically two types of joint as shown in Figure 2. In practice very few assemblies are as simple as the basic types shown in Figure 2 (see annex A).



a) Lap



b) Butt

Figure 2 — Basic joint types

Lap joints are generally used because they are easier to fabricate and offer increased strength. Butt joints are used where adequate strength is readily obtained, e.g. where the mechanical properties of the parent materials are lower than those of the brazed joint, or where the thickness and/or length of a lap joint is undesirable.

It should be noted that the useful overlap for a lap joint in shear is related to the thickness of the thinner component; beyond the optimum overlap there is little to be gained in joint strength by increasing the overlap length.

4.3 Assembly gap and brazing gap

4.3.1 General

The areas of a brazed assembly are defined as shown schematically in Figure 3.

Perhaps the most critical feature in brazing is the control of the brazing gap, i.e. the gap at the brazing temperature, between the components to be brazed and through which the filler material has to flow by capillary action. There are several factors that influence the choice of the brazing gap and which have to be taken into consideration. It is essential to recognise that where joints are to be made between different parent materials, the assembly gap (fit up) will usually have to be different from the brazing gap (see 4.3.4).

NOTE The assembly gap may need to be larger or smaller than the brazing gap, depending on the thermal expansion coefficients of the materials, the configuration and the brazing process.

Different filler materials require different gaps even within the same group, as can be seen from the typical ranges given in Table 1, but the optimum gap may also be affected by a number of other joint parameters (see example in Figure 4), e.g.:

— parent material(s);

— geometry of the joint;

— surface finish of the faying surfaces;

— use of a flux or protective atmosphere;

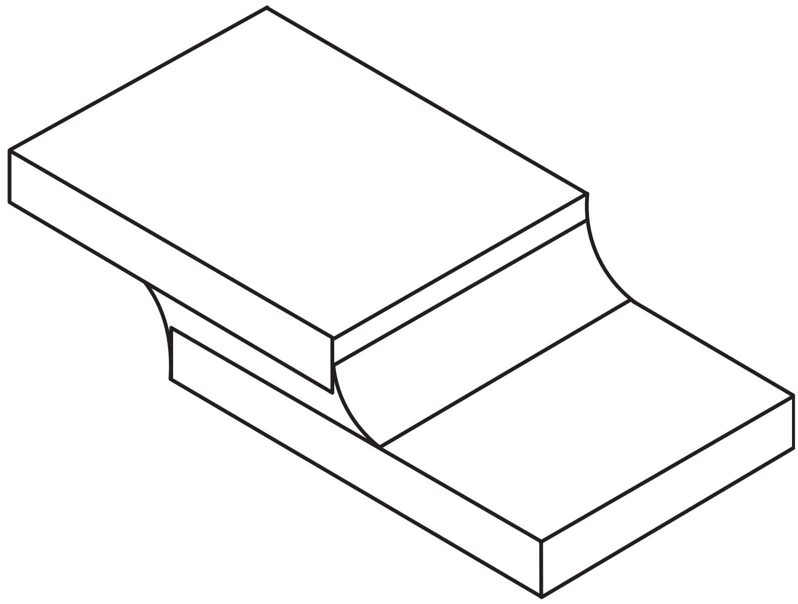
— careful control of brazing temperature and heating rate;

— brazing process.

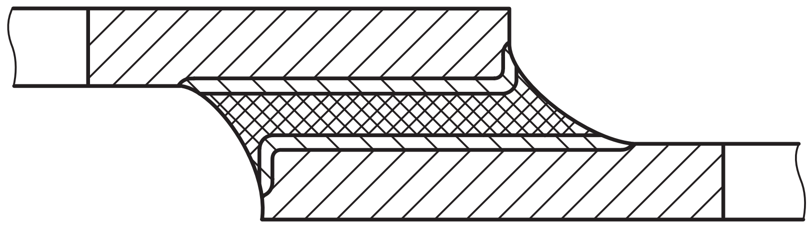
Table 1 — Typical brazing gaps

Filler material class according to EN 1044	Brazing gap[a] mm
AL	0,05 to 0,25
AG	0,05 to 0,30
CP	0,05 to 0,30
CU1XX CU2XX & CU3XX	Up to 0,15 0,05 to 0,20
NI	Up to 0,15
AU	Up to 0,10

[a] Brazing gap will depend on the selected filler materials, the brazing process and the brazing conditions.



a) Simple brazed assembly



Key

Parent material

Parent material affected by brazing (heat affected zone (HAZ))

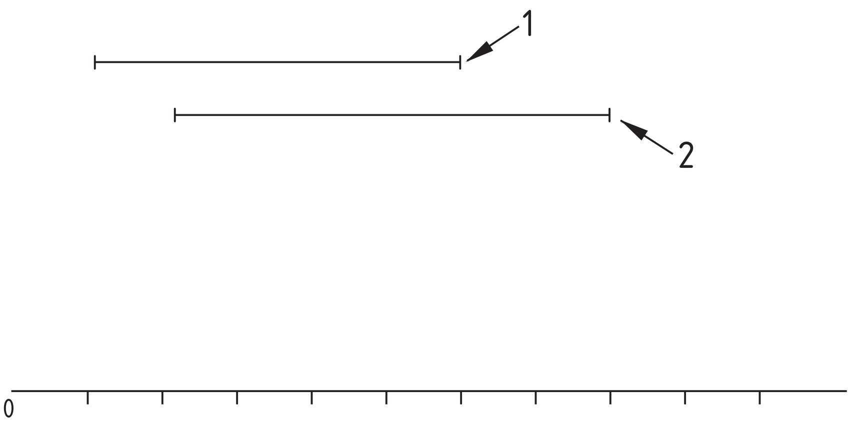
Diffusion-transition zone

Braze material

NOTE Extent of HAZ will vary with materials and brazing process.

b) Section through assembly in a)

Figure 3 — Schematic of brazed assembly



Key

1 Mechanized flame brazing with flux

2 Hand flame brazing with flux

Figure 4 — Schematic of differences in brazing gap ranges with different brazing processes (in this example for mild steel brazed with an AG filler materials)

4.3.2 Influence of brazing filler materials

Those types with the shortest melting range, often containing significant additions of temperature depressant elements (e.g. Si, B, P and Zn) exhibit enhanced fluidity and excellent capillary penetration. This also applies to most eutectic compositions and many pure metals. Conversely, those filler materials having wide melting ranges will generally have better wide gap filling characteristics and are more suitable for brazing when gaps are at the upper end of the stated range.

4.3.3 Influence of parent material

For those parent materials that are not readily soluble in the brazing filler material, or do not undergo mutual interaction to form alloy layers, gaps may, in general, be tighter than with those combinations where significant alloying occurs. Extensive inter-alloying will impair the fluidity of the brazing filler material and necessitate the use of wider brazing gaps to ensure complete penetration of the joint by the brazing filler material.

4.3.4 Influence of dissimilar parent materials

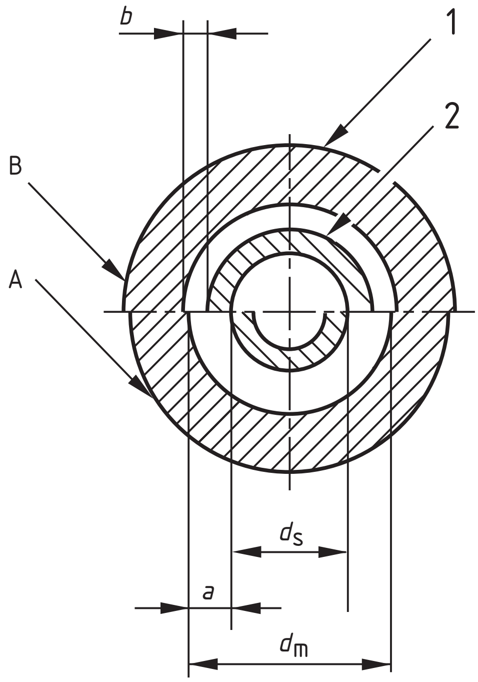
When dissimilar parent materials, of different coefficients of thermal expansion, are to be joined, care has to be exercised in designing the joint in order to obtain the correct brazing gap (see Figure 5). In extreme cases, joint gaps may close completely or open excessively at brazing temperature resulting in non-penetration or non-retention of the brazing filler material, respectively. Given that the brazing gap is the essential parameter, the assembly gap (to which the components will be machined) has to be calculated from the expansion coefficients of the parent materials, the sizes of the components and the brazing temperature.

This problem becomes greater:

— as the size of the brazed assembly increases;

— as the brazing temperature becomes higher;

— as the thermal expansion differential widens.



Key

1 Molybdenum

2 Steel

A Assembly at ambient temperature

B Assembly at brazing temperature

d_s Outer diameter of steel part (before brazing)

d_m Inner diameter of molybdenum part (before brazing)

a Assembly gap

b Brazing gap

Thermal expansion coefficient α
α steel > α molybdenum

Figure 5 — Influence on the brazing gap of dissimilar parent materials with different thermal expansion coefficients (schematic)

4.3.5 Influence of surface finish

Too coarse or too fine a surface finish will adversely affect the filling of the joint gap. The flow of the filler material may be influenced by the surface finishes of the joint materials.

4.3.6 Influence of atmospheres or fluxes

Processes using a protective atmosphere or a vacuum will tolerate tighter joint gaps, with given brazing filler materials, than an equivalent process where a flux is used. Unless joint gaps are adequate, flux and gas pockets will be by-passed and become entrapped in the finished joint.

4.4 Surface preparation

The component parts of a joint should be clean and properly fitting. When required by the brazing method, oxide, grease and oil should be removed by chemical, thermal and/or mechanical methods. This may involve degreasing, pickling, scratch brushing and other similar processes. The surface of the component within the brazed joint should not be polished. A roughened surface will assist filler materials flow particularly in the direction of machining. To improve the fit-up it may be necessary to modify the surface by methods such as knurling. To improve wettablilty of materials such as nickel alloys containing titanium and aluminium, and ceramics, it may be necessary to cover the surfaces with a suitable material, e.g. by plating or metallizing.

To prevent the flow of filler materials outside the joint area, it may be necessary to apply a 'stopping-off' agent. Care should be taken that this does not penetrate into the capillary joint gap and inhibit flow.

The degree of cleanliness required depends upon the ultimate quality required of the component and also the brazing process to be used. The degree of preparation is most severe for flux-free controlled atmosphere brazing at higher temperatures.

4.5 Stress distribution in service

Figure B.1 illustrates design modifications which endeavour to remove high stress concentrations from joint edges and distribute the stress more evenly in the parent materials.

4.6 Application of filler material

The brazing filler material is available in various forms (see 5.2.2).

For hand torch brazing applications, the brazing filler material is generally hand fed as rod or wire but may be pre-placed. In mechanized brazing applications, the brazing filler material is either pre-placed or automatically fed. In furnace brazing it has to be pre-placed. Examples of filler material placement are shown in Figure B.2.

The point at which the filler material is applied can greatly affect the quality of the joint. Internal pre-placement can also serve to demonstrate that capillary flow through the joint has occurred.

4.7 Assembly

It is essential, when designing joints, to ensure that the component parts will retain the required relationship during the brazing process. There are several effective methods of achieving this (see Figure B.3).

4.8 Good brazing design

Examples of good brazing design are given in Tables B.1 and B.2.

5 Materials

5.1 Parent materials

5.1.1 Basic considerations

The wide range of materials in current use precludes the listing of every grade which is amenable to joining by the brazing process. General categories are listed here for guidance purposes but other less common materials may well be applicable. If an unlisted material is specified, advice should be sought from the brazing filler manufacturer.

a) *Aluminium and its alloys.* Pure aluminium, aluminium-zinc (< 6 %), aluminium-manganese (< 2 %), aluminium-silicon (< 2 %), aluminium-magnesium (< 2 %).

b) *Coated materials.* Materials with electrodeposited or other coatings.

c) *Cobalt and its alloys.* Pure cobalt, hard facing alloys, corrosion-resistant alloys.

d) *Copper and its alloys.* Copper (unalloyed, phosphorus-bearing, silver-bearing), low alloyed copper alloys (formerly designated as e.g. beryllium-copper, chromium-copper and others), copper-zinc alloys (brasses), copper-tin alloys (tin-bronzes/ phosphor-bronzes, including some gunmetals), copper-tin-lead alloys (including some gunmetals), copper-nickel-zinc alloys (nickel-silvers), copper-nickel-alloys (cupro-nickel), copper-aluminium alloys (aluminium bronzes), copper-manganese-aluminium alloys.

e) *Ferrous metals.* Cast iron, malleable iron, mild steel, carbon and low alloy steels, alloy steels, high speed and tool steels, stainless, heat and corrosion-resistant steels.

f) *Nickel and its alloys.* Pure nickel, nickel-copper, nickel-iron, nickel-chromium-iron, nickel-chromium.

g) *Precious metals.* Gold, platinum, palladium, silver and their alloys.

h) *Refractory metals and alloys.* Titanium, zirconium, tantalum, niobium and their alloys.

i) *Tungsten and molybdenum.* Tungsten, molybdenum, cemented carbides, silver–tungsten, copper-tungsten.

j) *Non-metallic materials.* For example, ceramics, graphite, tungsten carbide, diamonds, cermets, glass, sapphire.

5.1.2 Special considerations

5.1.2.1 General

Some of the parent materials listed in 5.1.1 may have their properties adversely affected by the brazing process, either because of the effects of temperature or because of metallurgical interactions. In addition, consideration needs to be given to the effects that may arise in the brazing of dissimilar materials. Therefore, the points in 5.1.2.2 to 5.1.2.13 need to be considered when the brazing of such materials is proposed.

5.1.2.2 Dissimilar parent materials

One advantage of brazing is that many combinations of parent materials can be joined, but the effects of the brazing cycle on their physical and metallurgical characteristics always need to be considered.

The primary physical property to be considered is the coefficient of thermal expansion. This has two main effects. The gap between the components at brazing temperature will not be the same as the assembly gap (for which allowance has to be made in designing the joint). There may also be sufficient residual stress after brazing to cause mechanical failure. Depending on the form of the joint, this can cause severe distortion or even cracking, e.g. as sometimes occurs in the brazing of carbide tool tips to shanks, and allowance can be made for this by using the appropriate filler form or joint design to produce a thick compliant joint.

Metallurgical effects can influence the mechanical properties of the joint. In some cases brittle compounds may be formed but in other cases the joint may be strengthened.

5.1.2.3 Effects of brazing process on parent material properties

Where an alloy to be brazed depends for its strength on work hardening, hardening will be minimized by the brazing operation and this cannot be recovered. Precipitation hardenable alloys may be affected by the brazing operation: it may be possible to recover any loss in strength by suitable heat treatment. In some cases consideration needs to be given to changes in the corrosion properties caused by the brazing process. Information should be sought from the parent material supplier about these effects.

5.1.2.4 Alloys with tenacious surface oxides

Parent alloys containing additions forming tenacious oxide films are more difficult to braze than parent materials of the same system that do not. The most common additions are aluminium and titanium in stainless steels and nickel alloys. Such parent material will require special attention both in respect of surface preparation prior to brazing and the degree of protection provided by the flux or atmosphere used during the process, e.g. special fluxes or atmospheres or plating before brazing.

5.1.2.5 Porous metals

Components produced by powder metallurgical processes which have connected porosity (less than about 90 % of theoretical density) may prove difficult to braze because of capillary absorption of the filler materials. Sealing of the surface prior to brazing will be necessary in such cases.

5.1.2.6 Metals and alloys containing reducible oxides

Metals or alloys containing oxide inclusions or dissolved oxygen, which are easily reduced at the brazing temperature, shall not be brazed in a reducing atmosphere; the oxide inclusion can form steam causing porosity and loss of ductility.

5.1.2.7 Aluminium alloys

The filler materials used for brazing aluminium and its alloys are normally based on the Al-Si system. If the parent material contains magnesium as an addition, this reacts with the silicon in the brazing alloy to form an intermetallic compound at the interface. If the level of magnesium is more than 2 %, the amount of intermetallic compound at the interface may embrittle the joint.

5.1.2.8 Lead-bearing copper alloys

Lead is added to various copper alloys, e.g. to improve machinability, it being insoluble in copper and its alloys. If above about 2 %, lead may interfere with brazing

a) by forming an unwettable dross at the interface; and

b) by causing cracking.

These effects can be reduced by adequate fluxing and uniform heating without imposed stress.

5.1.2.9 Free machining carbon steels

Lead and sulphur are added to carbon steels to improve machinability. Lead additions below 0,35 % are not considered to reduce brazeability or joint strength, but higher levels may result in low joint strengths because of interaction with the filler material. When vacuum furnace brazing, it should be noted that lead will volatize from the surface of the steel.

Sulphur-bearing free machining carbon steels, which typically contain up to 0,6 % sulphur, are readily brazed. Joint strengths are comparable with sulphur-free grades.

5.1.2.10 Cast iron

Spheroidal graphite (s.g.) cast irons are fairly readily brazed with silver filler materials but flake graphite irons are more troublesome because the flakes interfere with wetting. One remedy is special surface treatments to remove the flakes, or an alternative may be to use a silver brazing filler material containing nickel.

5.1.2.11 Reactive and refractory metals and their alloys

Titanium, zirconium, niobium and tantalum and their alloys are not normally brazed and specialist advice should be sought before it is attempted. It is essential that an inert atmosphere is always used (argon or vacuum) and that hydrogen-bearing atmospheres are never used.

Molybdenum and tungsten can be brazed in hydrogen as well as in inert atmospheres. However, it is preferable that the brazing temperatures are below the recrystallization temperature, otherwise the parent material can be severely embrittled.

5.1.2.12 Metals prone to cracking during brazing

The main cause of cracking is the stressing of components while in contact with molten filler material. This stress may originate from work hardening of the parent material, from restraint imposed by a jig or from uneven heating. The cracking occurs at grain boundaries which tend to fill with brazing filler material. The phenomenon is sometimes called stress cracking or liquid metal penetration. To prevent this, annealed material should be used where applicable, even heating should be ensured and jigs designed to avoid restraint.

5.1.2.13 Non-metallic materials

Ceramics may be brazed either by previously metallizing the ceramic surface or by using reactive metal filler materials.

For glass materials special glass filler materials are available.

5.2 Filler materials

5.2.1 General

The principal filler materials covered by this standard are those detailed in EN 1044 and these fall into the classes shown in Table 2. Other commercially available filler materials can be used provided that they are acceptable to both the manufacturer and the user.

It is important that filler materials are stored and used under the conditions recommended by the manufacturer.

Melting ranges of the main filler material classes are shown in Figure 6.

Annex C gives details of the filler materials most commonly used for combinations of parent materials.

Annex D gives a guide to the suitability of various brazing filler material classes for the commoner brazing methods. Of necessity, it has been drawn up in very general terms. The suitability of the combination has to be decided in each case.

Table 2 — EN 1044 filler materials

EN 1044:1999 reference	Class	Composition
Table 2	AL	Aluminium brazing filler materials
Table 3	AG	Silver brazing filler materials
Table 4	CP	Copper-phosphorus brazing filler materials
Table 5	CU	Copper brazing filler materials
Table 6	NI	Nickel brazing filler materials
Table 6	CO	Cobalt brazing filler materials
Table 7	PD	Palladium bearing brazing filler materials
Table 8	AU	Gold bearing brazing filler materials
Table 1		Special 'vacuum application' versions of certain AG, PD and AU brazing filler materials

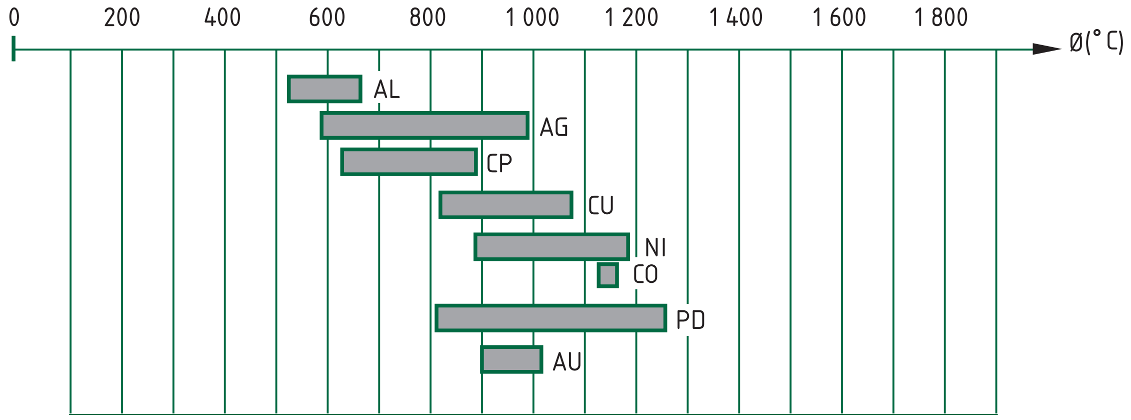


Figure 6 — Melting range of main filler material groups (schematic)

5.2.2 Forms available

The normal forms available include rod, wire, foil, preforms, powder, paste and clad sheet. A few brazing filler materials may also be sprayed, coated or vacuum deposited or blended from powders. The forms in which the brazing filler material are available should be determined at the design stage.

5.2.3 Applications

5.2.3.1 General

The choice of filler material for brazing a given combination of parent materials depends upon many factors, in some cases there will only be one possibility, in others, several. Not every filler material in a class can be used in a specific case.

5.2.3.2 Class AL

The filler materials in this class are used almost exclusively for the joining of pure aluminium and a restricted range of aluminium alloys.

5.2.3.3 Class AG

Silver brazing filler materials find wide application in the brazing of materials given in 5.1 with the exception of aluminium, magnesium and refractory metals and their alloys. Special grades are available for vacuum applications.

5.2.3.4 Class CP

These filler materials are usually restricted to joining copper and its alloys. With the exception of CP302, they are self-fluxing on copper, but a flux or protective atmosphere is required on most copper alloys. These phosphorus-bearing filler materials are not normally used for joining steel or nickel alloys, as brittle phases may be formed.

5.2.3.5 Class CU

These filler materials are generally used for brazing copper, cemented carbide and ferrous components (CU3XX with a flux) and for brazing of ferrous and some other high melting parent materials in a protective atmosphere or vacuum (CU1XX and CU2XX).

5.2.3.6 Class NI and CO

These filler materials are used almost exclusively for joining stainless steel and other heat and corrosion-resistant alloys in either vacuum or protective atmospheres.

5.2.3.7 Class PD and AU

These filler materials are used in protective atmospheres or vacuum to join metallized ceramics, copper alloys, nickel alloys and steels.

5.3 Fluxes

5.3.1 General

Fluxes are an essential requirement when brazing in air, with the general exception of the self-fluxing copper-phosphorus filler materials. Fluxes are also an integral part of all flux bath processes. In some circumstances they are used in protective atmosphere brazing operations.

The most commonly available forms are powder and paste. Alternatives include gases and liquids, flux-coated or cored filler materials and flux/filler material mixtures.

Fluxes are generally applied prior to heating.

Fluxes for brazing shall be as standardized in EN 1045.

5.3.2 Flux removal

5.3.2.1 General

Some flux residues are chemically active and their complete removal is essential if undesirable corrosion of the parent material is to be avoided.

The method of their removal will depend largely on the stage of exhaustion attained by the flux at the completion of the brazing cycle. This will depend upon the use of an adequate amount of the appropriate flux, avoidance of overheating and a heating time as short as possible. Provided that the assembly can sustain such treatment without damage, flux removal may be facilitated by quenching the assembly into water immediately after the brazing filler material has solidified.

Flux residues should be disposed of in accordance with the relevant regulations.

5.3.2.2 Fluxes for brazing ≥ 750 °C (e.g. FH21, FH30)

The fused residues from borax and similar high temperature fluxes are hard, glassy and relatively insoluble in water. Therefore they have to be removed mechanically, e.g. by grit or shot blasting or abrasive techniques.

5.3.2.3 Fluxes for brazing < 750 °C (e.g. FH10, FH11, FH12)

Residues from fluoroborate fluxes are relatively water soluble and may be removed in hot or boiling water. The efficiency of flux removal may be improved by agitation or ultrasonic vibration. Chemical or proprietary inhibited descaling solution may be used where complete removal of all residual discoloration is required. Non-immersion methods which are equally effective include steam lancing and wet or dry abrasive techniques.

5.3.2.4 Aluminium brazing fluxes

Type FL10 fluxes are highly corrosive and require very careful post-braze removal. The flux residues are water soluble and can be washed away. Type FL20 fluxes are generally non-corrosive and the residue can often be left *in situ.*

5.4 Atmospheres

5.4.1 Protective

Examples of types of protective atmosphere are listed in Table 3.

Users should understand that the effects of atmospheric purity, cycle time and temperature are interrelated and will affect the requirements for satisfactory brazing. The function of a protective atmosphere is to ensure the cleanliness of the parent and filler materials so that the latter can flow freely during brazing.

The choice of atmosphere will be influenced by the parent and filler materials and may be active or inert.

5.4.2 Vacuum atmospheres for brazing

A vacuum atmosphere is achieved in a vessel specifically designed for brazing or heat treatment by pumping out the furnace gases, usually air. The pumps are generally a carefully designed combination of mechanical and oil diffusion which are matched in pumping capacity, and of sufficient size to evacuate rapidly the furnace space. Outgassing of the charge of components and the interior of the furnace will occur during the heating cycle, and the pumps are frequently automatically interlocked with vacuum measuring instruments to accommodate this.

A vacuum of better than 10^{-3} mbar is easily achieved, but a low leak rate is equally important to control the residual atmosphere. 10^{-3} mbar is equivalent to a gas impurity content of approximately $1{,}1 \times 10^{-6}$ (parts per million) by volume.

5.5 Safety

The manufacturer's advice should be sought to ensure that the flux, atmospheres, filler material and parent materials are compatible.

Table 3 — Examples of protective atmospheres

No.	Source	Typical dew point of incoming gas °C	Approximate composition				Applications	
			H_2 %	N_2 %	CO %	CO_2 %	Filler material class	Parent materials
1	Combusted fuel gas[d] (low hydrogen)	Up to + 30	1 to 5	87	1 to 5	11 to 12	AG[a], CP, CU3XX[a]	Cu and some Cu alloys. Low and medium carbon steels
2	Combusted fuel gas[d] (decarburizing)	Up to + 30	14 to 15	70 to 71	9 to 10	5 to 6	AG[a] ,CP, CU1XX, CU2XX CU3XX[a]	Cu and some Cu alloys, low and medium C steel, Ni, Ni-Cu alloy
3	Combusted fuel gas[f], dried	- 40	15 to 16	73 to 75	10 to 11	-	AG[a],CP, CU1XX, CU2XX, CU3XX[a]	Cu and some Cu alloys, carbon steels, Ni-Cu alloy, Ni, Ni-Fe alloys
4	Combusted fuel gas[e], dried (carburizing)	- 40	38 to 40	41 to 45	17 to 19	-	AG[a] ,CP, CU1XX, CU3XX[a]	Cu and some Cu alloys, carbon steels, Ni-Cu alloy, Ni
5	Dissociated ammonia[g] (cracked ammonia)	- 54	75	25	-	-	AG, CP CU1XX, CU2XX, CU3XX, NI106, NI107	Cu and some Cu alloys, carbon steels, Ni-Cu alloy, Ni and Ni alloys, alloys containing Cr[b]
6	Cylinder hydrogen	Down to - 60	100	[d]	-	-	AG, CP, CU1XX, CU2XX, CU3XX, NI107	Cu and some Cu alloys, low and medium carbon steels, Ni and Ni alloys and alloys of Co, Cr and cemented carbides[b]
7	Inert gas[g], e.g. argon, nitrogen[c]	Below – 60	-	-	-	-	CP,CU1XX, CU2XX, NI	Cu and some Cu alloys, carbon steels, Ni and Ni alloys[b], alloys containing Cr

[a] Flux additionally required when filler materials containing volatile elements are used.

[b] Flux required in addition to atmosphere when appreciable quantities of aluminium, titanium, silicon or beryllium are present.

[c] It is essential that nitrogen is not used with refractory metals or aluminium or when the filler material contains boron or silicon.

[d] The combusted fuel gas (low hydrogen or decarburizing) may be referred to as exothermic. It may also be available as synthetic gas.

[e] The combustable fuel gas (carburizing) may be referred to as endothermic. It may also be available as synthetic gas.

[f] It may also be available as synthetic gas.

[g] Certain filler materials in EN 1044:1999 Tables 7 and 8, can be brazed in protective atmospheres 5 and 7

6 Methods of brazing

Annex E gives details of the different method of brazing, including the advantages and limitations of each method.

7 Heat treatment

Where the parent materials require heat treatment, it may be possible to carry this out as part of the brazing operation. In other cases it will be necessary to carry out heat treatment separately. If the subsequent heat treatment requires quenching, there is a risk of distortion and/or cracking.

8 Inspection

Where applicable, brazer qualification in accordance with EN 13133, brazing procedure qualification in accordance with EN 13134, non-destructive testing of brazed joints in accordance with EN 12797 and destructive testing of brazed joints in accordance with EN 12799 shall be used. Details of imperfections shall be as given in EN ISO 18279.

Specific requirements that are important to the purchaser and supplier should be established before any work is carried out, so that errors and misjudgements can be avoided. A list of relevant items is given below from which the purchaser/supplier can select those that are most applicable:

a) location where work is to be carried out (workshop or site);

b) design of assembly:

   1) interacting effects if subsequent processing is required, e.g. hardening or plating;

   2) jigs, fixtures, etc.;

   3) surface stop-off and protection of surfaces where filler material is not to flow;

c) inspection procedures, including sampling;

d) materials to be used and method of identification;

e) process and controls (if any) to be identified;

f) method of cleaning and oxide removal where necessary;

g) surface finish of components to be brazed and tolerances on fit-up;

h) achievement of satisfactory brazing cycles and means of avoiding overheating/overcooling;

i) post-braze cleaning and treatment to remove flux and surface finish requirements;

j) removal of surplus filler material;

k) repair of defective joints;

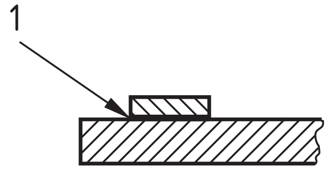
l) equipment controls and maintenance requirements;

m) recording of test results.

Annex A
(informative)

Examples of brazed assemblies

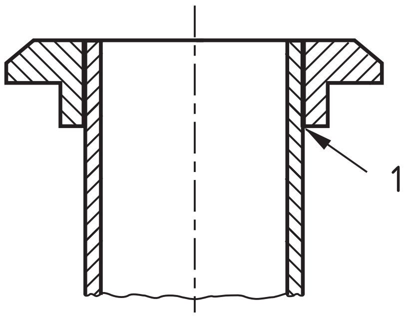
The figures in this annex illustrate examples of brazed assemblies. An electrical contact on a conductor (see Figure A.1) is one example, but more complicated assemblies may still have only a single joint, e.g. a flange on a pipe (see Figure A.2). However, one of the advantages of brazing is the ability to make several joints at the same time on an assembly such as a manifold (see Figure A.3). In addition, in some cases, with furnace brazing, it is possible to make very many joints at once as in a cross-flow heat exchanger that can be very large (see Figure A.4). In the case of metal-to-ceramic joints, cracking due to uneven thermal contraction can be a problem that can often be prevented by brazing a ceramic balance ring on the other side of the metal (see Figure A.5).



Key

1 Joint

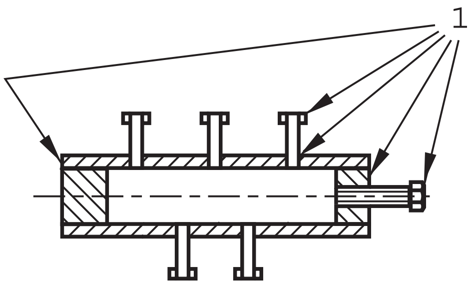
Figure A.1 — Electrical contact on conductor (schematic)



Key

1 Joint

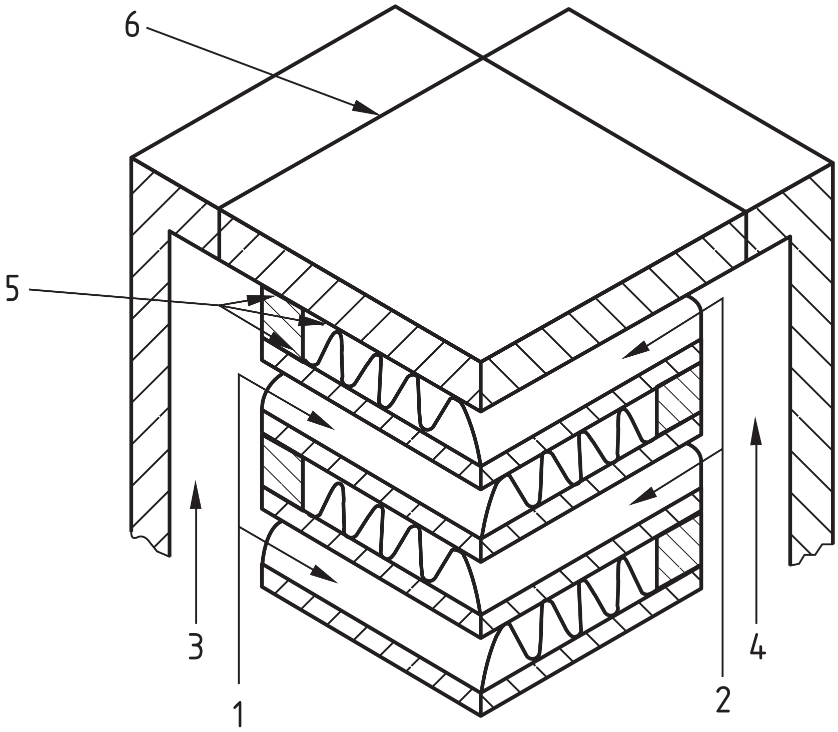
Figure A.2 — Flange on a pipe (schematic)



Key

1 Joint

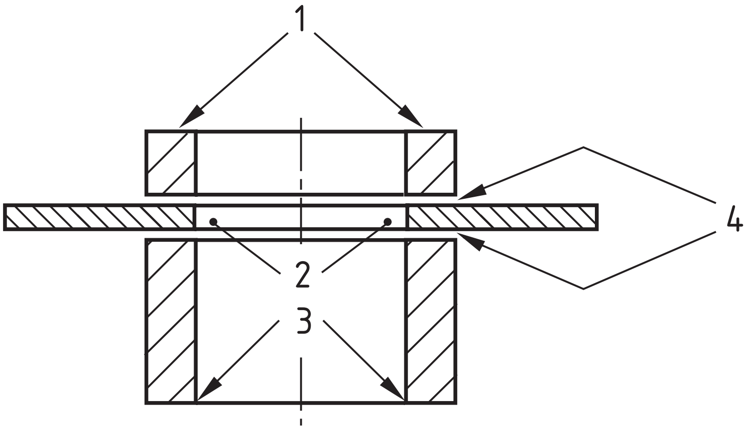
Figure A.3 — Manifold (schematic)



Key

1 A flow
2 B flow
3 A header
4 B header
5 Brazed joint
6 Welded joint

Figure A.4 — Cross-flow heat exchanger (schematic)



Key

1 Ceramic balance ring
2 Metal ring
3 Ceramic cylinder
4 Joint

Figure A.5 — Metal-to-ceramics (schematic)

Annex B
(informative)

Typical examples of joint design

Tables B.1 and B.2 illustrate some examples of brazing design. What is an unsuitable design for one application may be perfectly acceptable for another. The applicability should be verified in each case.

Table B.1 — Influence of filler material placement and/or joint design on flow (schematic drawings)

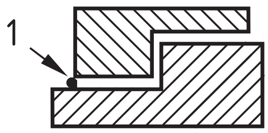
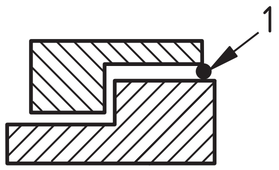
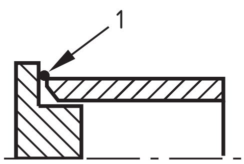
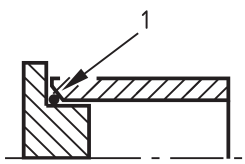
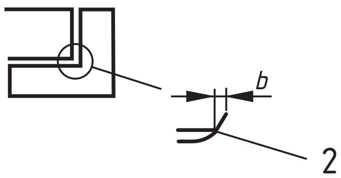
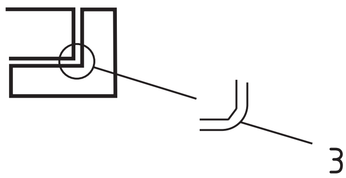
No.	Basic design	Improved design	Comments
1			1 – Filler material Where the gap varies, the filler material should be fed from the wider end.
2			1 – Filler material
3			2 – Barrier to flow 3 – Chamfer Chamfer added to aid filler material flow. This may also be aided by positioning filler material as shown in No. 2 of this table

Table B.1 — Influence of filler material placement and/or joint design on flow (schematic drawings) (*continued*)

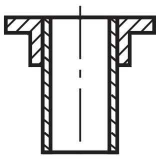
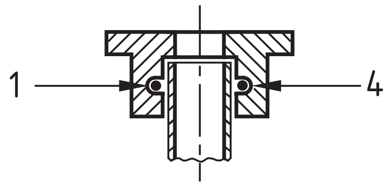
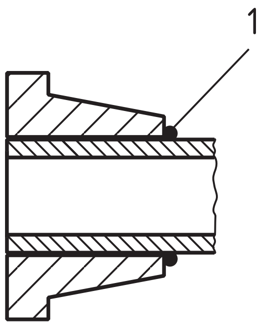
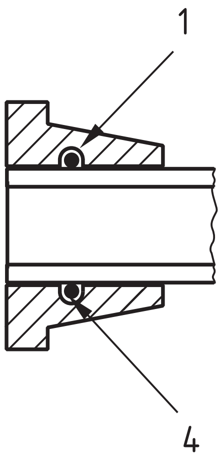
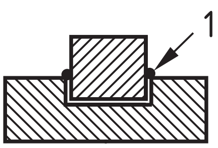
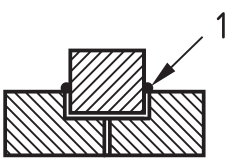
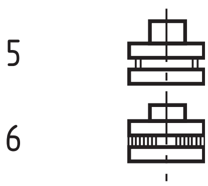
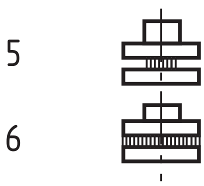
No.	Basic design	Improved design	Comments
4			4 – Filler material in loading groove If the assembly needs brazing in this position then a loading groove would be preferred as it is difficult to feed a flush joint.
5			4 – Filler material in loading groove The use of a loading groove will give a higher chance of joint soundness.
6			1 – Filler material When filler material is applied externally, the hole will permit the removal of flux residues.
7			5 – Before brazing 6 – After brazing Improved design prevents gas/flux entrapment.

Table B.2 — Influence of gap geometry

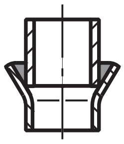
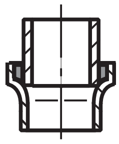
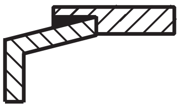
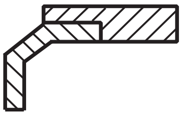
No.	Basic design	Alternative design	Comments
1			The alternative design illustrated is more suited to capillary brazing processes. The basic design illustration is more suited to processes that are less dependent on capillary flow.
2			
3			

Figure B.1 details some design modifications to deal with high service stresses, Figure B.2 gives more information about the advantages of pre-placement of filler material and Figure B.3 shows some common methods of locating components prior to brazing.

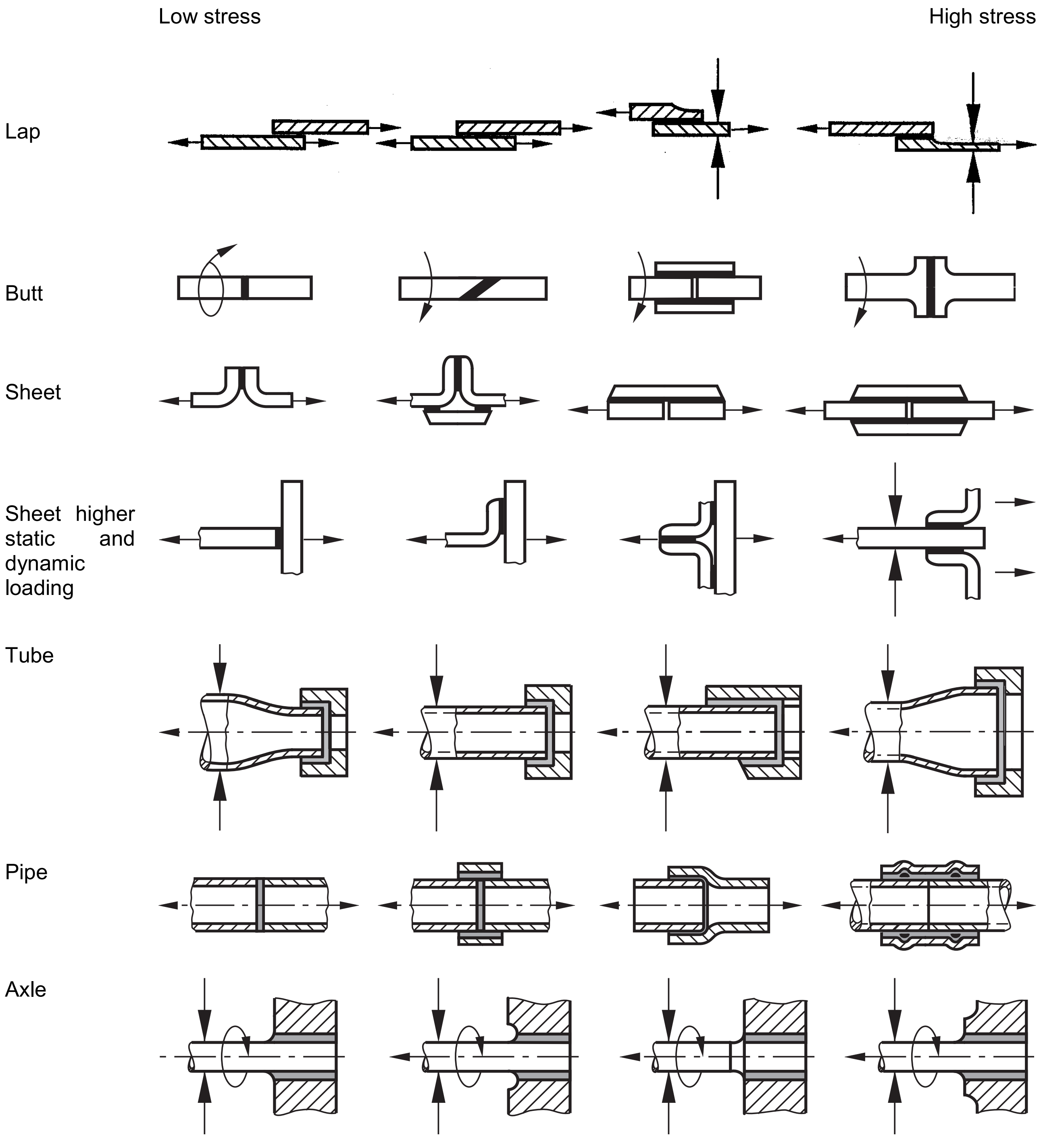
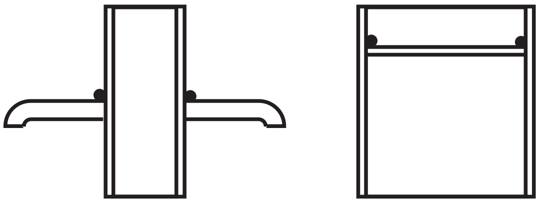
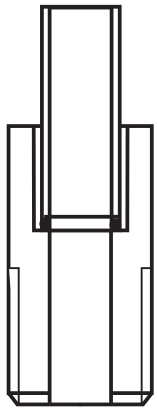


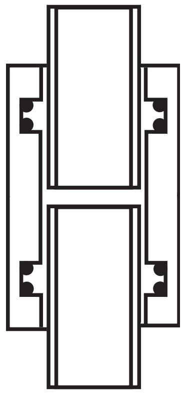
Figure B.1 — Design modifications to deal with high service stresses



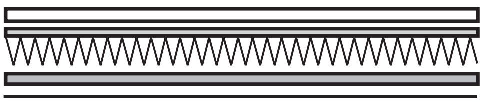
Rings are suitable for a wide range of tube/plate and tube/fitting assemblies



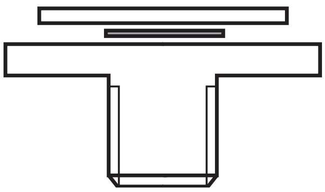
Internal pre-placement often assists visual inspection of brazed assemblies



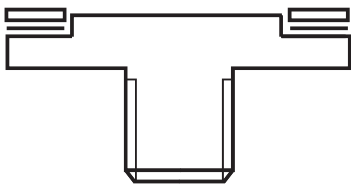
The use of loading grooves ensures that the filler material is in the correct position



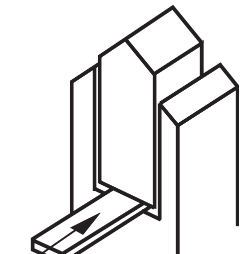
Foil is ideal for brazing corrugated or honeycomb cores to facing sheets



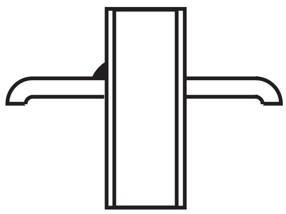
Brazing foil discs and shims are widely used for joining flat surfaces



When the filler material is pre-placed in the joint, washers may be preferred to wire rings since there is less displacement of the components

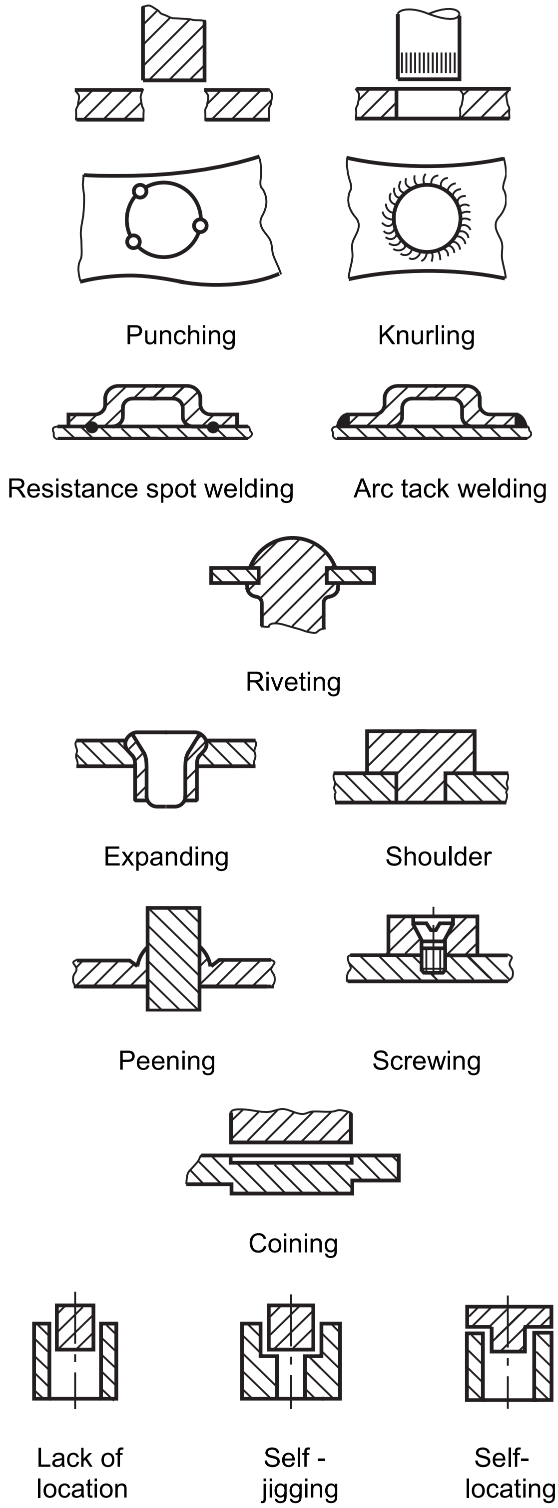


Cut lengths of wire, or strip often prove a convenient method of pre-placing filler material



Brazing pastes facilitate automatic application of filler material

Figure B.2 — Pre-placement of filler material



NOTE The required brazing gap is retained.

Figure B.3 — Common methods of locating components prior to brazing

Annex C
(informative)

Filler materials most commonly used for combinations of parent materials

Table C.1 — Filler materials most commonly used for combinations of parent materials

Parent materials	**Al & Al alloys**	**Cu & Cu alloys**	**Carbon & low alloy steels Cast iron**	**Stainless steel**	**Ni & Ni alloys**	**Ti & Ti alloys**	**Refractory metals**
	Filler material classes in accordance with EN 1044						
Al & Al alloys	**AL**						
Cu & Cu alloys		**AG** AU **CP** NI CU3XX					
Carbon and low alloy steels Cast iron		**AG** **CU3XX**	AG **CU** **CU3XX**				
Stainless steel	AL	AG NI AU P D	AG CU NI	AG AU **CU** **NI**			
Ni & Ni alloys		AG AU PD	**AG** CU NI	AG AU CU **NI**	AG **AU** CU **NI** PD		
Ti & Ti alloys	AL				AG	AG AL	
Refractory metals		AG PD AU					PD AU

NOTE Bold entries are those most commonly used.

Annex D
(informative)

Suitability of brazing filler material classes for the commoner brazing methods

Table D.1 — Suitability of brazing filler material classes for the commoner brazing methods

Filler material class in accordance with EN 1044	Brazing method							
	Flame	Induction	Resistance	Furnace		Immersion		Laser beam
				Protective/ reducing atmosphere	Vacuum	Flux bath	Dip bath	
AL	S	S	U	S [a]	S [b]	S	U	S
AG	S	S	S	S [c]	AG401 [e]	U	S	S
CP	S	S	S	S	U	U	U	-
CU1XX and CU2XX	U	S	S	S	S	U	U	S
CU3XX	S	S	S	U	U	U	S	S
NI & CO	U	S	U	S	S	U	U	-
PD	U	S	U	S	S [d]	U	U	-
AU	U	S	U	S	S	U	U	-

Key

S Suitable

U Unsuitable

[a] Only with flux.

[b] Not all filler metals in the class are suitable .

[c] With flux in some cases.

[d] Not PD202.

[e] AG401 is suitable for vacuum furnace brazing.

Annex E
(informative)

Methods of brazing

E.1 Flame brazing

E.1.1 General

Various fuel gas mixtures may be used for flame brazing. The main factors affecting the choice of mixture are heating power, fuel and equipment investments and availability of gas supply.

The heating torch or blowpipe generally consists of either a single fuel gas delivery tube with adjustment valve and a port system to allow naturally aspirated air to mix with the fuel prior to combustion, or two delivery tubes, one supplying the fuel gas and the other the oxidant via adjustment valves and a pre-mixing chamber.

E.1.2 Hand torch brazing

E.1.2.1 Process

In this method the heat is generally applied using a single torch (blowpipe) held in the operator’s hand. For large work pieces multiple torches may be used.

In decreasing order of heating energy the gas systems generally employed are:

— oxy-acetylene;

— oxy-methyl acetylene mixtures (proprietary);

— oxy-propane;

— oxy-natural gas (methane);

— compressed air-acetylene;

— compressed air-propane;

— compressed air-natural gas (methane);

— aspirated air-acetylene and propane.

(Overlap occurs at the interface of the respective ranges.)

The choice of system will depend on many factors such as material melting temperature, manual skills available, production rate requirements, cost of fuel/oxidant combination, etc.

E.1.2.2 Application

After adjustment to achieve optimum flame conditions and manipulation of the burner tip to concentrate heat at the optimum working distance (immediately outside the inner combustion cone) within the more massive of the component parts, flux can be applied dry by means of a hand held filler rod until the melting temperature is achieved and the rod is then normally allowed to dwell on the joint until fusion of the filler material occurs.

The process may however, with advantage, also be used with pre-placed paste-flux and filler material rings, or with brazing paste, or with self-fluxing brazing filler material.

Alternatively a gas flux can be added through the flame (flux processes). Clean and bright surfaces can be achieved and pickling is not necessary.

E.1.2.3 Advantages/limitations

The main advantages of the process are:

a) apparatus is simple and its operation is easily understood;

b) moderately rapid heating rate;

c) maximum flexibility of shape, size, heat pattern and consumables allowing simple and complex assembly operations;

d) minimum capital investment;

e) minimum maintenance.

Limitations of the process are:

1) high labour content (investment);

2) training is required to achieve consistent results;

3) relatively low production rate;

4) health and safety factors are more difficult to control.

E.1.2.4 Size limitations

The only limits imposed are the size of the available equipment and/or gas supply to deliver the required heating energy level and the means available for disposing of surplus energy and pollution (heat splash and fume).

E.1.2.5 Safety

Torches for hand torch brazing for fuel gas – oxygen and fuel gas – compressed air should be in accordance with EN ISO 5172. Fuel gas – aspirated air torches should be in accordance with EN 731.

Care has to be taken to operate the burner equipment and the gas installations strictly in accordance with the manufacturer’s instructions, because all fuel/gas oxidant mixtures are potentially explosive, as well as being fire hazards. No modifications or repairs may be carried out on the equipment other than by experts and trained personnel.

All hoses should be regularly checked for integrity, signs of chaffing and cracking and replaced as necessary.

Non-return valves and flashback arrestors should comply with EN 730-1 and EN 730-2.

Adequate ventilation should be ensured.

E.1.3 Mechanized flame brazing

E.1.3.1 Process

Assemblies to be brazed are presented in a jig, mounted on a trolley, rotary table or conveyor belt to a suitably designed burner system.

Burners with various profiles are available. They enable heat patterns to be designed to suit all assemblies of all shapes and sizes.

Various fuel gas mixtures are used for mechanized flame brazing. The main factors affecting the choice of mixture are heating power, fuel and equipment costs and availability of gas supply. In order of descending heating power, the typical gas mixtures used for mechanized flame brazing are:

- oxy-acetylene;
- oxy-propane;
- compressed air-acetylene;
- compressed air-propane;
- compressed air-natural gas.

E.1.3.2 Application

The process is widely used for brazing at temperatures up to 1 000 °C and is applicable to all materials not adversely affected by heating in air.

Brazing fluxes which are necessary in all cases, other than the application of the self-fluxing copper-phosphorus based brazing filler materials to copper, can be applied manually by brushing or dipping, or automatically using specialized equipment.

Alternatively a gas flux can be added automatically through the flame. Clean and bright surfaces can be achieved and pickling is not necessary.

Brazing filler materials can be applied as hand-fed rod, but in mass production are normally applied either as a preform, or automatically as a paste, or wire. The filler materials generally used are as specified EN 1044:1999, Tables 3 and 4.

E.1.3.3 Advantages/limitations

The main advantages of the process are:

a) moderate equipment investment;

b) simple maintenance;

c) high quantity;

d) flexibility regarding component shape and size and jigs;

e) suitable for continuous or indexing machines;

f) suitable for multiple joints that need to be made individually;

g) automatic feeding of filler materials, paste and flux.

Limitations of the process are:

1) heat input less rapid than induction heating;

2) local extraction of fumes hampered by velocity and volume of burnt gas;

3) not suitable brazing at high temperatures, e.g. above 1 000 °C;

4) complex assemblies subject to more distortion/local overheating than in a furnace;

5) more noise and heat dissipation compared with induction heating.

E.1.3.4 Size limitation

The only limits imposed are the size of the available equipment and/or gas supply to deliver the required heat energy level and the means available for disposing of surplus energy and pollution (heat splash and fume).

E.1.3.5 Safety

Adequate ventilation is necessary. It is essential that maintenance and modification of burners and gas supply is only carried out by competent personnel.

Fixed torches should always be lit from the side, or below, and not by reaching over an unlit torch to light another, since all burners in a system ignite simultaneously.

E.2 Induction brazing

E.2.1 Process

When alternating current is passed through a work-coil adjacent to or around a metal component, a secondary current is induced into the components, and heat is produced. When a high frequency (300 kHz) current is applied for heating steels the heat is concentrated at the surface; with a lower frequency (10 kHz) current a greater depth of penetration is achieved. Intermediate susceptors may be used to heat irregularly shaped components by radiation.

E.2.2 Application

The process can be used for brazing in all temperature ranges and on all electrically conducting materials. It is versatile and can be used either in 'one-off' operations or in equipment designed to mass produce components of the same shape. Either flux or controlled atmosphere can be used to aid the brazing process.

The filler material should be pre-placed, and the flux generally incorporated at the same time.

For high technology applications, the component may be processed in a vacuum or under the cover of a suitable gaseous atmosphere. For details regarding power sources, coil design, processes, and automation, manufacturers competent in the design and manufacture of suitable equipment should be consulted.

E.2.3 Advantages/limitations

The main advantages of the process are:

a) rapid heating;

b) closely controlled reproducible heat pattern for simple shapes;

c) economical to run;

d) the heat is concentrated in the joint areas.

Limitations of the process are:

1) high capital investment;

2) less efficient for materials which are non-ferromagnetic, particularly if of high thermal conductivity;

3) coil design is difficult for irregularly shaped or complex components.

E.2.4 Size limitations

In general, the method is used to heat only the area to be brazed and so, by careful design, very large assemblies can be brazed. At the other extreme of the size range, very small components can be processed by this method.

E.2.5 Safety

It is essential that care is taken when high frequency current is passed through the coil. Due to induction, metallic objects (including rings and watches), can be heated causing severe burns (not electric shock). Skin contact with the coil will also cause a r.f. burn. The manufacturer's instructions should be carefully observed and the equipment should be maintained, according to the manufacturer's instructions, by authorized personnel.

Adequate ventilation should be ensured.

E.3 Resistance brazing

E.3.1 Process

The parts to be joined are raised to the brazing temperature by the passage of a high current at a low voltage. Suitably shaped electrodes are used to establish good electrical contact and to apply sufficient force to hold the component parts in the correct position for brazing. Heat may be generated indirectly within the body of the electrode (usually graphite) from where it is transmitted by thermal conduction to the joint assembly. Alternatively, heat may be generated directly by the combined effect of the various interfacial and bulk resistances of the parts themselves. In this case, water cooled metal electrodes of relatively high electrical conductivity are used to transmit current to, and maintain the appropriate holding force on, the joint assembly.

E.3.2 Application

The process is best suited to applications where joints of limited area and relatively simple geometry permit the ready access of electrodes to the assembly. It is particularly suitable for the repetitive brazing of flat symmetrical components using both manual and automated techniques.

Temperatures attained by the process vary according to the mode employed; indirect heating is usually restricted to temperatures below 800 °C, because of excessive burning and wastage of the graphite electrode, whereas such limitations do not apply to direct heating.

The use of flux in resistance brazing applications requires considerable care due to its non-conducting characteristics and the risk of explosion. In consequence, self-fluxing brazing filler materials are preferred or, less commonly, a localized protective atmosphere. Where the use of a flux cannot be avoided, a small quantity of thin paste (to be preferred) or liquid flux is employed.

E.3.3 Advantages/limitations

The main advantages of the process are:

a) extremely rapid localized heating;

b) low running investment;

c) low capital investment;

d) closely controlled reproducible heat pattern.

Limitations of the process are:

1) higher capital investment than hand torch brazing;

2) severe limitations on shape and size;

3) high wear of graphite electrodes;

4) potentially poor repeatability if flux is used;

5) not suitable for high temperature parent materials.

E.3.4 Size limitations

Energy requirements increase rapidly with increasing size of the joint, so restricting the use of the process to small joint areas.

E.3.5 Safety

Health hazards are limited to a spatter risk caused by dirty or high resistance parts, flux films or insufficient holding pressure. The time cycles are short and the volume of fume producing material small.

Adequate ventilation should be ensured.

E.4 Furnace brazing

E.4.1 Process variants

There are two main variants of the process; protective atmosphere or vacuum furnace brazing. The first can be continuous or batch operated. The second can generally only be batch operated. These variants are individually discussed in greater detail in E.4.2 to E.4.3, but certain aspects are common to all of them and are therefore considered in this sub-clause.

Many small components or one large one may occupy the available furnace space. It is essential to realise that the components are not accessible during brazing. Therefore, preparation before loading should include adequate jigging if the components are not self-aligning as well as the pre-placement of brazing filler material and (where relevant) flux. The joint should be designed to ensure correct positioning of the brazing filler material and its retention in the joint when molten. The process variables, e.g. heating and cooling rates, intermediate dwell and peak temperatures and times at temperature should be determined by preliminary trials and recorded in the procedure instructions. Since the brazing times are generally longer than with most other brazing processes, it is advisable to pay greater attention to the possible effects of the thermal cycle on the properties of the parent materials. Some advantages and limitations are also common to all furnace brazing processes as follows.

Advantages of the processes are:

a) minimal distortion, even on complex parts;

b) simultaneous brazing of multiple and/or multi-joint assemblies;

c) good control of process variables and therefore particularly suited to high integrity components.

Limitations of the processes are as follows:

1) through heating of the components is inevitable, which cannot be acceptable in some applications;

2) when the heating rates are slow, filler materials with wide melting ranges may be unsuitable because of liquation;

3) furnace contamination can occur from metallic vapours, metallic oxides or flux residues.

E.4.2 Protective atmosphere brazing

E.4.2.1 General

It is unusual to use flux in a protective atmosphere furnace as, to prevent oxidation, a suitable gas atmosphere is provided within the furnace.

The atmosphere most commonly used in a continuous furnace is exothermic, derived from partially burnt natural gas or propane, and is reducing. Cracked ammonia, hydrogen and nitrogen mixtures and endothermic atmospheres are also used. The selection of protecting gas, filler material and flux, if necessary, should be done taking the advice of the supplier of the filler material.

E.4.2.2 Continuous furnace brazing

E.4.2.2.1 Process

Components are progressively conveyed through a continuously heated tunnel furnace, then through a cooling zone. The heating and cooling cycle depends upon the conveyor speed and temperature setting.

E.4.2.2.2 Application

Although applied to many materials, the major application of continuous heated furnace brazing is for the joining of mild steel with copper filler material.

It is important that the assemblies are secure and that parts are self-locating and will not be disturbed by the movement of the conveyor.

Conveyor speeds vary, according to the mass of components, giving typical process cycle times of 15 min to 2 h.

E.4.2.2.3 Advantages/limitations

The main advantages of the process are:

a) high production throughputs;

b) usually fluxless with no post-cleaning requirements;

c) components need not be as clean as for vacuum brazing;

d) can use low cost brazing filler materials.

Limitations of the process are:

1) high capital investment (but lower than vacuum furnaces per unit of output);

2) not practical to switch on and off repeatedly.

E.4.2.2.4 Size limitations

The maximum size of component is limited only by the furnace cross-sectional area.

E.4.2.2.5 Safety

Fumes need to be extracted. There is an explosion risk with highly reducing atmopheres, as with any hydrogen-rich gas.

E.4.2.3 Batch furnace brazing

E.4.2.3.1 Process

Components are loaded into a heated space, normally within a retort to hold the protective atmosphere.

The heating cycle is controlled by varying the furnace temperature. Rapid cooling is normally possible by removing the retort from the furnace.

E.4.2.3.2 Applications

Batch furnace brazing is principally used in the electronic and electrical industries.

E.4.2.3.3 Advantages/limitations

The main advantages of the process are:

a) usually fluxless with no post-cleaning requirements;

b) components generally need not to be as clean as for vacuum brazing;

c) larger components can be processed than in a continuous furnace.

Limitations of the process are:

1) long cycle time;

2) limited retort life at higher temperatures;

3) high energy consumption.

E.4.2.3.4 Size limitations

Large components can be processed.

E.4.2.3.5 Safety

Fumes need to be extracted. There is an explosion risk with highly reducing atmospheres as with any hydrogen-rich gas.

E.4.3 Vacuum brazing

E.4.3.1 Process

The furnace has a chamber (usually water cooled), with a sealable door, inside which are heat shields. The furnace is heated by resistance heaters on the inner faces of the heat shields.

The furnace is continually pumped during heating, normally to pressures of the order of 1×10^{-3} mbar to 1×10^{-5} mbar and this removes any evolved gases. Other pressure ranges may be specified for special purposes. The function of the vacuum is to preserve surface cleanliness and permit filler material flow. Low leakage rates are as important as pumping speed and ultimate pressure.

Accurate means of regulating temperature, heating and cooling rates are normally available. To speed cooling after brazing, provision is made to circulate through the furnace cooled gas that is inert to the materials being brazed.

E.4.3.2 Application

Although in principle widely applicable, vacuum brazing is normally used for brazing at high temperature of the corrosion and heat resisting types of alloys.

Heating is slow and this results in total floor-to-floor cycle times in the range 2 h to 10 h.

E.4.3.3 Advantages/limitations

The main advantages of the process are:

a) high alloy steels, nickel alloys containing titanium and aluminium and reactive metals can be brazed;

b) flux-free brazing with no post-braze cleaning required;

c) precise heating cycles and thermal control;

d) brazing combined with heat treatment of parent materials to be joined.

Limitations of the process are:

1) high capital investment;

2) surfaces of components have to be clean (more critical than with other processes);

3) heating and cooling rates may be slower than optimum for certain materials;

4) it is essential that volatile metals are excluded from the furnace charge (except when brazing aluminium).

E.4.3.4 Size limitations

Production furnaces with ruling dimensions of 300 mm to 1 000 mm are common, but larger furnaces are available.

E.4.3.5 Safety

There are few hazards except from residual backfill gases in larger furnaces.

Adequate ventilation should be ensured.

E.5 Immersion brazing

E.5.1 General

The assembly is raised to the brazing temperature by partial or total immersion in a molten heat transfer medium. Three types of process are used:

a) flux bath brazing;

b) dip bath brazing;

c) salt bath brazing.

E.5.2 Flux bath brazing

E.5.2.1 Process

Flux bath brazing (also known as flux dip brazing) is the most widely used and involves the submersion of the components in a bath of suitably active molten flux. Filler material preforms are placed adjacent to the joint area prior to immersion.

E.5.2.2 Application

The process is restricted to the brazing of aluminium and a limited range of aluminium alloys over a relatively narrow range of temperatures around 600 °C. The technique is particularly suitable for the simultaneous brazing of multiple joints in complex assemblies such as heat exchangers.

E.5.2.3 Advantages/limitations

The main advantages of the process are:

a) provides precise and even heating of complex assemblies;

b) simultaneous heat treatment can be carried out.

Limitations of the process are:

1) need for careful preheating;

2) need for control of flux bath composition;

3) provision needs to be made for flux access and drainage;

4) need for meticulous removal of corrosive flux residues;

5) tendency for distortion of parts heated close to their melting temperature.

E.5.2.4 Size limitations

Flux bath brazing will accommodate a wide range of sizes including thin sections. The maximum dimension which can be handled will depend on the flux bath size but may be of the order of 1 m.

E.5.2.5 Safety

There is a significant risk of explosion if pre-heating is not carried out efficiently. Irritant fumes are emitted by the molten flux and require adequate extraction. Splashing by molten flux is an ever present risk.

E.5.3 Dip bath brazing

E.5.3.1 Process

Dip bath brazing involves immersion of the immediate joint area in a molten filler material bath, the surface of which is usually protected by a layer of molten flux. This process is mainly restricted to the joining of the ends of light section assemblies of limited heat capacity.

E.5.3.2 Application

Filler materials with melting temperatures in excess of 900 °C are seldom used and operating temperatures are usually below 750 °C due to problems of limited flux stability at operating temperatures. For wire terminations and junctions of appropriate geometry it offers a rapid means of achieving high integrity joints.

E.5.3.3 Advantages/limitations

The main advantages of the process are:

a) wide brazing gaps can be accommodated;

b) good standard of joint;

c) rapid heat transfer.

Limitations of the process are:

1) compositional drift of the bath which needs to be monitored;

2) need for frequent flux replenishment;

3) need to preheat components;

4) surfaces of components are coated with brazing filler material which is wasteful.

E.5.3.4 Size limitations

Components brazed by the process will seldom exceed 5 mm in cross section and a few centimetres in length due to the chilling effect of more massive parts.

E.5.3.5 Safety

With this process, the risks are as follows:

— explosion with damp assemblies;

— splashing of molten metal and flux;

— evolution of toxic metal oxide.

Cadmium-bearing AG series filler materials and their associated fluxes are the most hazardous combination in this last respect.

Adequate ventilation should be ensured.

E.5.4 Salt bath brazing

E.5.4.1 Process

Now largely outmoded, this process involves submerging the assembly to be brazed in a fused salt bath. Brazing filler material preform and a suitable brazing flux are applied to the joint area prior to immersion.

E.5.4.2 Application

Application is restricted to ferrous components where brazing and heat treatment may often be combined in a single operation. In this case only those EN 1044, AG and CU3XX filler materials with melting temperatures in excess of 750 °C will be suitable.

E.5.4.3 Advantages/limitations

The main advantages of the process are:

a) uniform temperatures and rapid heating rate;

b) components remain scale free;

c) combined heat treatment and brazing operations are possible.

Limitations of the process are:

1) need to preheat to dry flux;

2) not suitable for light section parts due to floatation surface tension effects of salt;

3) salt removal and its safe disposal cause problems.

E.5.4.4 Size limitations

It is not a practical process for small parts of low mass. Maximum dimensions are limited only by the size of salt bath available.

E.5.4.5 Safety

Health hazards emanate largely from the molten salt and include the danger of explosion from damp components, splashing by molten salts and fumes emanating from the bath surface.

Adequate ventilation should be ensured.

E.6 Special methods

E.6.1 Laser beam brazing

E.6.1.1 Process

A continuous wave laser beam is used as the heat source. With a defocused beam it is possible to heat the pre-placed or automatically fed brazing filler material to its melting temperature as well as heating the joint surfaces of the components to a temperature sufficiently high for localized filler material wetting and flow to occur. The laser beam is absorbed in the top surface of the joint only. The variables for the process are the power of the laser beam, focussing, traverse and details of wire supply.

E.6.1.2 Application

The process is suitable for components that require a minimal or a very localized amount of heat input to the joint.

E.6.1.3 Advantages/limitations

The main advantages of the process are:

a) localized heat source;

b) suitable for sealing joints where uniform heating of the whole joint is impractical.

Limitations of the process are:

1) only for thin sheets;

2) high capital cost;

3) limited capillary flow;

4) for some metals, e.g. copper, beam reflection can cause operating difficulties;

5) impractical to switch on and off repeatedly.

E.6.1.4 Safety

As for all laser applications, the safety rules for this type of equipment have to be followed. It should only be used by competent personnel.

E.6.2 Brazing/braze welding with an arc

E.6.2.1 Process

Arc brazing/braze welding processes can be divided into gas-shielded metal arc (MIG) and tungsten inert gas (TIG) brazing/braze welding.

The principle of brazing/braze welding with an electric arc is mainly similar to MIG and plasma arc welding with wire consumables. Copper alloy filler materials are used.

E.6.2.2 Application

This process is suitable for surface coated or uncoated thin sheet, e.g. galvanized sheet.

E.6.2.3 Advantages/limitations

The main advantages of the process are:

a) reduced damage of the coating and a lower thermal load can be achieved because of the lower melting temperature of the filler materials;

b) the filler materials used are largely corrosion resistant;

c) there is no important melting of the parent materials;

d) working under local shielding gas atmospheres and without fluxes.

Limitations of the process are:

1) joint has to be accessible for shielded gas torch (plasma gas torch);

2) thickness of sheet usually up to 3 mm.

E.6.2.4 Safety

Adequate ventilation should be ensured. If necessary, torches with localized ventilation should be used.

With this process metal vapour and dust can be generated. All safety regulations should be observed.

E.6.3 Other methods

Other methods are possible, e.g. infra-red brazing and electron beam brazing, which are better described as braze welding.

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