British Standard

BRITISH STANDARD

BS 1723-2: 1986

Incorporating Amendment No. 1

Brazing —

Part 2: Guide to brazing

UDC 621.791.36

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Welding Standards Committee (WEE/-) to Technical Committee WEE/19 upon which the following bodies were represented:

BNF Metals Technology Centre
British Association for Brazing and Soldering
British Non-Ferrous Metals Federation
Electricity Supply Industry in England and Wales
Heating and Ventilating Contractors' Association
Joint Industry Board for Plumbing Mechanical Engineering Services in England and Wales
Ministry of Defence
Plumbing Trades Union
Society of British Aerospace Companies Limited
Welding Institute
Coopted member

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Contents

Foreword

This Part of BS 1723 has been prepared under the direction of the Welding Standards Committee. BS 1723 was originally published as one standard but the revision has been divided into four Parts as follows:

— *Part 1: Specification for brazing;*

— *Part 2: Guide to brazing;*

— *Part 3: Destructive testing and non-destructive evaluation (in preparation);*

— *Part 4: Procedure and operator approval (in preparation).*

This format has allowed the aspects covered in this guide to be widened and methods of testing together with procedure and operator approval are included for the first time. This is the first revision for which metric units have been used throughout.

It has been assumed in the drafting of this British Standard that the execution of its provisions is entrusted to appropriately qualified and experienced people.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 26, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

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1 Scope

This Part of BS 1723 gives guidance on the practice to be applied to the brazing process.

NOTE The titles of publications referred to in this standard are listed on the inside back cover.

2 Definitions

For the purposes of this Part of BS 1723 the definitions given in BS 499-1 and in BS 1723-1 apply. Where a definition given in BS 1723-1 differs from that given in BS 499-1, the definition in BS 1723-1 applies.

3 Principles

3.1 General

The brazing process has been defined[1] as a joining process in which a filler metal is used which has a melting point of above 450 °C, but below that of the parent material, and which is distributed in the joint by capillary attraction.

3.2 Design

For an assembly to be joined satisfactorily by brazing, the designer has to be aware of the advantages and constraints associated with the process. The main requirement is that the finished brazed assembly should be fit for its intended purpose. To this end the designer should take into account physical properties such as strength, ductility, leak tightness, electrical and thermal conductivity, distortion, appearance, etc., and possible hygienic criteria such as freedom from crevices and avoidance of toxic alloying elements, e.g. cadmium-bearing filler metals. Likewise it is necessary to consider life-limiting processes to which the assembly will be subjected. These include high temperature/corrosive environments and mechanical and thermal stressing. From the separate and cumulative effects of these, and in consultation with the brazing engineer, the design appraisal can be made.

The design should incorporate a gap between the component parts of the joint into which molten brazing filler metal will be drawn or distributed by capillary attraction. The optimum nominal size of this capillary gap will depend upon the composition of the parent materials and filler metal being used. Alloy suppliers will provide data for specific brazing filler metals and appropriate fluxes.

The capillary joint can be achieved either by machining the component parts of the joint to size or by such methods as knurling, expansion of one component, etc.

The preferred joint configuration is with the components overlapping. Whenever possible, for furnace and mechanized brazing, the designer should incorporate a loading groove of a suitable size within the joint in which filler metal is pre-placed.

The designer should be fully aware of inspection requirements, and provision should be made in the design so that inspection at intermediate and final stages of manufacture is possible. The selected inspection method should be compatible with the economics of the manufacturing route.

3.3 Brazing filler metal

The brazing filler metal should be selected bearing in mind the design requirements and the parent materials involved. If in doubt about compatibility with the environment and with the parent materials, advice should be sought from suppliers and other recognized sources of information.

The most commonly used filler metals are listed in BS 1845; other filler metals are listed in suppliers' catalogues.

3.4 Component 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 and 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 ground or polished. A roughened surface will assist filler metal flow particularly in the direction of the "lay" of machining. To improve the fit-up it may be necessary to modify the surface by methods such as knurling. To improve wettability of materials such as the nickel alloys containing titanium and aluminium, and ceramics, it may be necessary to plate the surfaces with a suitable material.

To prevent the flow of filler metal 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.

It should be noted that the degree of cleanliness required depends upon the ultimate quality required of the componene and also the brazing process to be used. The degree of preparation is most severe for high temperature flux-free controlled atmosphere brazing.

[1] BS 499-1.

3.5 Jigs and fixtures

The designer should endeavour to make the components self-jigging. If jigs are used, they should not impose stresses on the component during the brazing operation. Jigs are frequently expensive to manufacture and may distort at high temperatures and when thermally stressed. They impose a thermal load, and so their mass may be important when the brazing cycle is determined. The effects of the jig may have a considerable influence on process selection.

3.6 Flux

Fluxes assist brazing filler metal flow. They may form an active or a protective covering at the joint region. In the broadest sense, a suitable gaseous atmosphere or a vacuum can be regarded as a substitute for a flux. Fluxes are not intended for primary removal of oxide layers and grease, etc., and their use does not obviate the need for systematic cleaning of components prior to assembly.

The flux should have a lower melting temperature than the brazing filler metal, and be active or protective up to and above the brazing temperature; it should be so fluid that it is swept through the joint by the brazing filler metal and is not entrapped. The manufacturer of the brazing filler metal will recommend an appropriate flux for each application. This will have been tested and found compatible with the brazing operation. In general, fluxes are not used when brazing in controlled atmospheres at temperatures above 900 °C.

Flux residues are generally removed from components after brazing by chemical or mechanical methods. The residues should be disposed of in a suitable manner. It may not be acceptable to drain these into the public disposal system.

3.7 Inspection

Inspection will be used at all stages. The degree of quality control and inspection required will greatly affect the economics of the process, so methods should be agreed between the customer and the manufacturer at the design stage.

Acceptance criteria should be agreed, and any deviation from these should either be a matter of rejection or concessionary action. It is important however, that this is undertaken by persons with wide experience in the brazing field and not only by the inspection department.

3.8 Testing procedures

Tests on brazed joints may be any of three types:

a) visual examination;

b) non-destructive physical tests on completed work;

c) destructive tests on completed joints.

The purchaser, or his representative, should specify which of these tests are to be carried out. The sampling procedure and number of tests should be the subject of agreement between the purchaser, or his representative, and the contractor.

The purchaser may require the contractor to provide evidence that the brazing operators are suitable for the work upon which they will be employed. For this purpose, details of any approval(s) obtained by the operators under any appropriate standard laying down approval tests may be submitted as evidence of their proficiency, the names of all operators so qualified, together with particulars of any tests passed by each, being recorded and made available to the purchaser's inspector as and when required[2].

3.9 Defects

Defects occur in brazed joints as in all manufacturing processes. They may be caused by failure to comply with the details of an approved brazing process or because the effects of several interreacting variables are not fully appreciated or understood. The types of defect that may occur and can be observed by destructive and non-destructive methods of examination[3] are illustrated in Appendix A. No attempt is made to indicate whether these defect types are cause for rejection. This is part of the agreement between the contracting parties.

3.10 Health and safety[4]

In addition to the obvious hazards due to the heat required to carry out the brazing process, toxic fumes can be produced from the heated filler metals and fluxes and by flames. These fumes may contain cadmium and zinc from low melting temperature brazing filler metals or plated components, fluorides from fluxes, and carbon monoxide and oxides of nitrogen from flames. Of these, the most important are fumes of cadmium or cadmium oxide which are highly toxic, and filler metals containing more than 0.025 % of cadmium should only be used in conjunction with a purpose designed local exhaust ventilation system. Even with cadmium-free alloys, good ventilation of the brazing shop is still required.

[2] Further information will be given in BS 1723-4 which is in preparation.

[3] Further information will be given in BS 1723-3 which is in preparation.

[4] See Appendix B.

Operators should be aware of the hazards of fume emission and those of handling fluxes which can be corrosive and irritating to the skin. Suppliers should always be consulted regarding detailed precautions relating to brazing filler metals and fluxes.

4 Categories of brazed joints

Brazed joints are used for a multitude of applications and the demands made upon the joint range from the trivial to ensuring the integrity of an important structure. The most significant property of a joint may be its strength at room temperature or at elevated temperature, its corrosion resistance or its ability to act as a seal. Because of this wide range of applications, it is very difficult to draw up a system of joint categories based on joint properties such as strength or soundness; for example, if a seal is required, even on an important structure, it may well be possible for the actual braze area to be as low as 50 % of the nominal whereas, if strength is required for a less important structure, this might be totally inadequate.

Therefore, the following categories have been based not on the level of properties themselves but the consequences of failure and on the ways in which attainment of the required properties is demonstrated and their maintenance assured. Decisions as to which are the important properties and what level is required should be based on preliminary discussions between the purchaser and the supplier and, if necessary, other interested parties.

Category 1. This category is intended to cover those joints which will be used in the most important applications, where failure of the joint will lead to significant financial loss and, potentially, injury or loss of life.

Category 2. This category is intended to cover those joints which will be used in important applications, where failure of the joint will lead to significant financial loss but not, in general, injury or loss of life.

Category 3. This category is intended to cover those joints whose failure would be inconvenient rather than important and not generally liable to lead to any loss of life.

Category 4. This category covers joints where the service requirements are minimal.

A summary of testing applied to different brazing categories is given in Table 1.

It will not always be easy to decide into which category a particular joint falls, but it is important to do this as accurately as possible. The risks involved in choosing too low a category for a given joint are obvious, but too high a category will impose an economic penalty because of the extra testing and inspection that are involved.

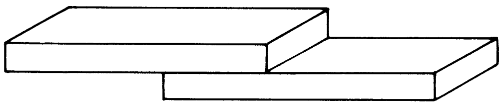
5 Joint design

5.1 Principle

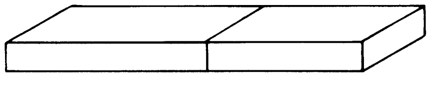
The brazing process depends upon capillary flow of a molten brazing filler metal between parts separated by a narrow gap. The filler metal melts at a lower temperature than the parts being joined and therefore it will be of a different composition. This composition difference has to be taken into account when considering the properties of the joint at service temperature, in corrosive media during service, and under fatigue loading. In addition, it has to be recognized that the parent material of the components to be joined can be affected by the brazing cycle.

5.2 Types of joint

There are basically two types of joint as shown in Figure 1. Lap joints are generally used because they are easier to fabricate, offer increased strength and can tolerate reduced joint soundness. Butt joints are used where adequate strength is readily obtained, e.g. where a parent material is weaker than the brazed joint, or where the thickness of a lap joint is undesirable.



(a) Lap



(b) Butt

Figure 1 — Basic joint types

It should be noted that the useful overlap for a lap joint in shear is approximately four times the thickness of the thinner component; beyond this limit there is little to be gained in joint strength.

Table 1 — Brazing quality category

Category	Procedure approval test	Post-braze inspection[a]	
		Visual	Other than visual
1	Required	100 % required	100 % non-destructive testing (NDT) required. Destructive tests by agreement
2	Required	100 % required	NDT required, but not up to 100 % of joints. Destructive tests by agreement
3	Required only by agreement	100 % required	Only required by agreement, on a spot check basis
4	Not required	Required on a spot check basis	Not required

[a] The details should be agreed between the interested parties. Test methods are described in BS 1723-3 (in preparation).

5.3 Brazing gap

5.3.1 *General.* Since each group of brazing filler metals has a preferred brazing gap range, the provision of the appropriate joint clearance is of fundamental importance in achieving efficient capillary penetration. The ideal brazing gap will vary according to the brazing filler metal type but may be modified by a number of other joint parameters.

These include:

the parent material(s);

length and geometry of the joint;

surface finish of the faying surfaces;

the use of a flux or protective atmosphere;

careful control of brazing temperature.

Typical brazing gaps are shown in Table 2.

5.3.2 *Brazing filler metal.* Those types with the shortest melting range, often containing significant additions of temperature depressant elements (Si, B, P, Zn and Cd) exhibit enhanced fluidity and excellent capillary penetration. This also applies to most eutectic compositions and many pure metals. For these filler metals, therefore, joint gaps at the minimum of the range shown in the table will be most suitable. Conversely, those filler metals having wide melting ranges will generally have better gap filling characteristics and will be most suitable for brazing when gaps are at the upper end of the stated range.

5.3.3 *Parent material(s).* For those parent materials which are not readily soluble in the brazing filler metal, 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 metal and necessitate the use of wider brazing gaps to ensure complete penetration of the joint by the brazing filler metal.

5.3.4 *Dissimilar parent materials.* Where 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. 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 metal, respectively.

If practicable, the material with the higher expansion should be the outer member of the assembly so that the joint is placed under compression on cooling. This becomes essential as the size of the brazed assembly increases, as the brazing temperature becomes higher and as the thermal expansion differential widens. With large components, the brazing gap may exceed recommended brazing tolerances at brazing temperatures.

5.3.5 *Surface finish.* Coarse surface finishes may generate irregularities in the joint gap and result in erratic filler metal flow, with reduced joint strength and soundness. Surface roughness should not, in general, exceed R_a 1.6 μm (CLA 63 μin) if the finish is directional.

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

5.4 Stress distribution

Figure 2 illustrates design modifications which endeavour to remove high stress concentrations from joint edges and distribute the stress more evenly in the parent materials.

Table 2 — Typical brazing gaps

Filler metal (see clause **6**)	**BS 1845:1984 reference**	**Gap at brazing temperature**	**Comments**
		mm	
Group AL: aluminium	Table 1	0.05 to 0.25	Mineral fluxes
Group AG: silver	Table 2	0.05 to 0.150	Mineral fluxes
		0.025 to 0.125	Protective atmosphere
Group CP: copper-phosphorus	Table 3	0.025 to 0.125	No flux in air or protective atmosphere
		0.05 to 0.150	Mineral fluxes
Group CU: copper	Table 4	– 0.05[a] to 0.100	Protective atmosphere
Group CZ: copper-zinc	Table 5	0.05 to 0.150	Mineral fluxes
Group HTN: nickel and cobalt	Table 6	0.00 to 0.125	Protective atmosphere
Group PD: palladium bearing	Table 7	0.05 to 0.150	Mineral fluxes
		0.025 to 0.125	Protective atmosphere
Group AU: gold bearing	Table 8	0.025 to 0.125	Protective atmosphere

[a] "Positive interference" fit.

5.5 Pre-placement of filler metal

The brazing filler metal can be in the form of wire, shim, strip, foil, powder, paste and sheet or it may be sprayed, coated, plated or vacuum deposited.

For hand torch brazing application, the brazing filler metal may be hand fed. However, in automatic brazing operations, the brazing filler metal is either pre-placed or automatically fed. Examples of filler metal placement are shown in Figure 3.

5.6 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 4).

6 Materials

6.1 Parent materials

6.1.1 *General.* 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. In the event that an unlisted material is specified, advice should be sought from the brazing filler metal manufacturer and appropriate sources of technical information (see Appendix C).

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.* Pure copper and associated grades, tin-bronzes, phosphor-bronzes, gunmetals, brasses, nickel-silver, aluminium-bronzes, beryllium-copper, chromium-copper, cupro-nickel.

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

f) *Magnesium.* Magnesium and some of its alloys.

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

h) *Precious metals.* Gold, platinum, palladium.

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

j) *Tungsten and molybdenum.* Pure tungsten, pure molybdenum, cemented carbides, silver-tungsten, copper-tungsten, heavy metals.

k) *Other materials.* Ceramics, cermets, graphite, tungsten carbide, glass, diamonds and sapphire.

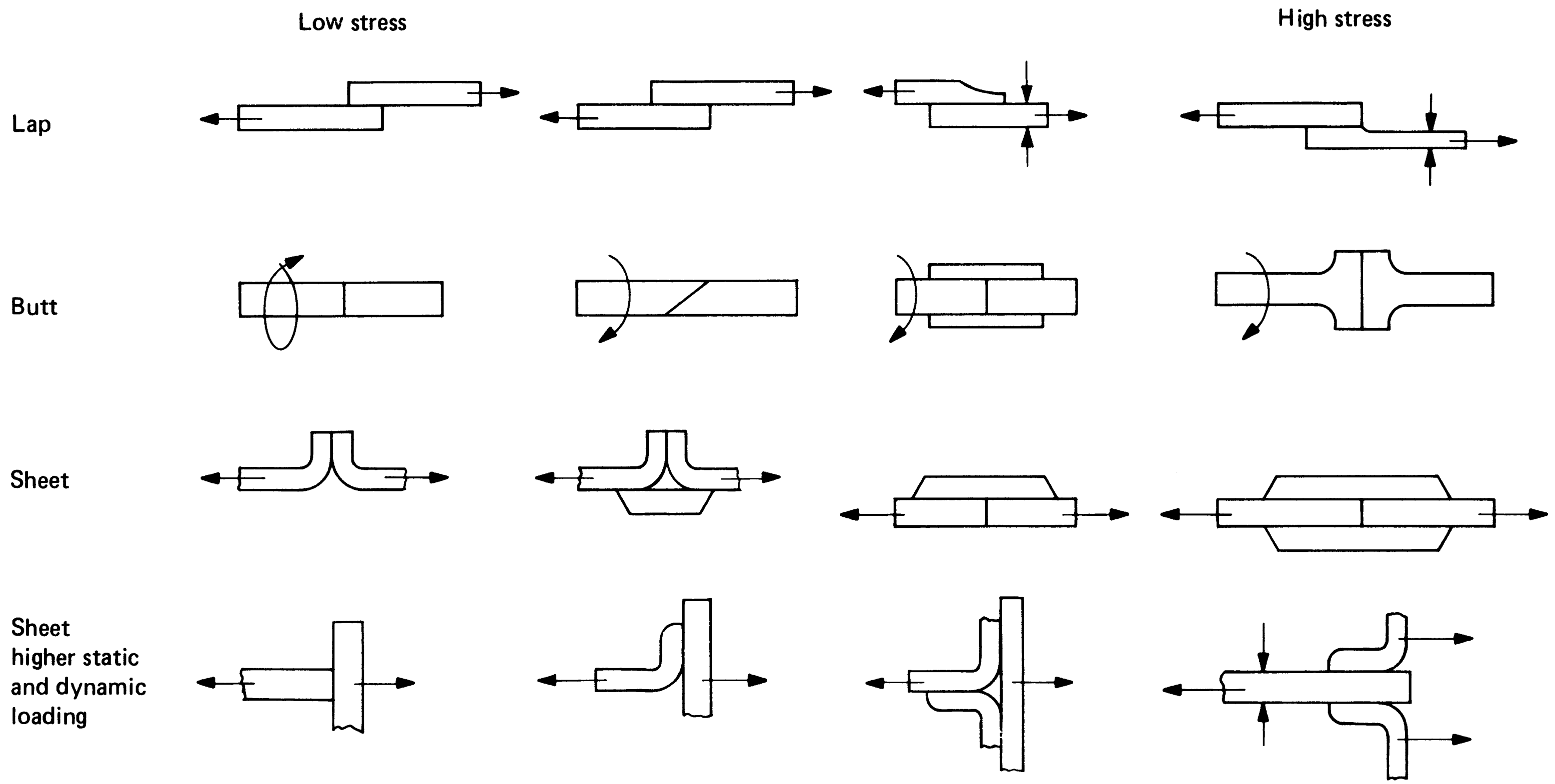


Figure 2 — Design modifications to deal with high stresses

6.1.2 *Special considerations.* Some of the parent materials listed in **6.1.1** 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 problems that may arise in the brazing of dissimilar metals. Therefore, the following points need to be considered when the brazing of such materials is proposed.

a) *Dissimilar parent materials.* Many combinations of parent materials present little difficulty, but the effects of the brazing cycle on their physical and metallurgical characteristics always need to be considered.

The most important physical difference is likely to be in coefficient of expansion. This has two main effects. The gap between components at brazing temperature will not be the same as at room temperature (for which allowance has to be made in designing the joint). There may also be a high residual stress after brazing; 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 again allowance has to be made for this in designing the joint.

Metallurgical effects are not necessarily as easy to predict. One possibility is the formation of brittle intermetallic components because both parent metals dissolve in the brazing filler metal and react. Alternatively, one dissolves and then forms a brittle intermetallic compound at the interface between the brazing filler metal and the second parent metal. This can happen, for example, if silver is used to braze titanium to copper; the copper dissolves in the silver and forms a brittle intermetallic layer on the titanium. A similar, although not identical, effect occurs in the brazing of aluminium bronze to steel; unless the steel is previously nickel plated, the joint very readily pulls apart at the steel-bronze metal interface.

b) *Mechanical properties.* Where an alloy to be brazed depends for its strength on precipitation hardening or work hardening, the strength will almost invariably be reduced by the brazing operation, often markedly so. Depending on the re-melt temperature of the joint in relation to the heat treatment temperatures, it may be possible to re-precipitation harden the assembly either subsequently or, in a few cases, as part of the brazing cycle.

c) *Corrosion resistance.* Many austenitic stainless steels suffer from a serious loss in corrosion resistance if they are taken through a thermal cycle which causes the precipitation of carbides in grain boundaries; this effect is usually called sensitization. This can occur during brazing, but the risk of it happening depends very much on the carbon content: the higher the carbon, the higher the risk. The normal grades of stainless steel are safe to braze, provided the cycle is rapid, but the high carbon grades are doubtful. The risk can be reduced by using a stabilized grade (containing titanium or niobium) or by using a low carbon grade. Some nickel alloys can also suffer from a similar loss in corrosion resistance due to precipitation of carbides or intermetallic compounds in grain boundaries.

Ferritic stainless steels are not normally affected by sensitization but they are vulnerable, when brazed with silver filler metals, to interfacial corrosion in aqueous service, the joint falling apart with remarkable rapidity. Although less vulnerable, austenitic stainless steels suffer from this type of corrosion, but it is not normally a risk. The choice of brazing filler metal has considerable influence on the degree of risk and the zinc-free nickel-bearing grades are preferred. A copper or nickel alloy filler metal, but not copper-zinc filler metal, avoids the risk.

d) *Materials with tenacious surface oxides.* Parent materials 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, and aluminium and beryllium in copper alloys. Such parent metals 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. For example, aluminium bronzes require a special flux whereas some stainless steels and nickel alloys are plated before furnace brazing to help wetting.

e) *Porous materials.* Metal parts 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 metal. Sealing of the surface will be necessary in such cases.

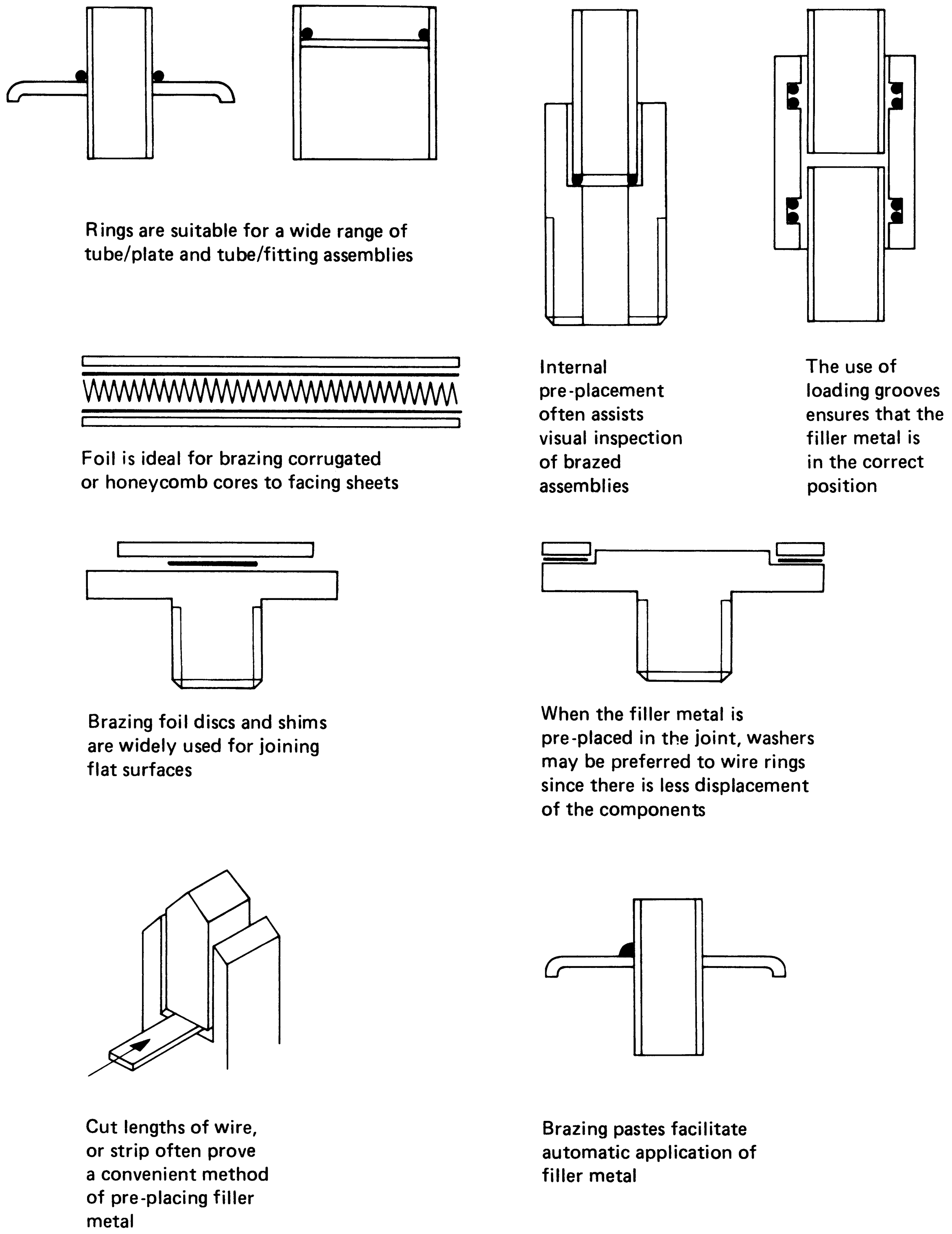
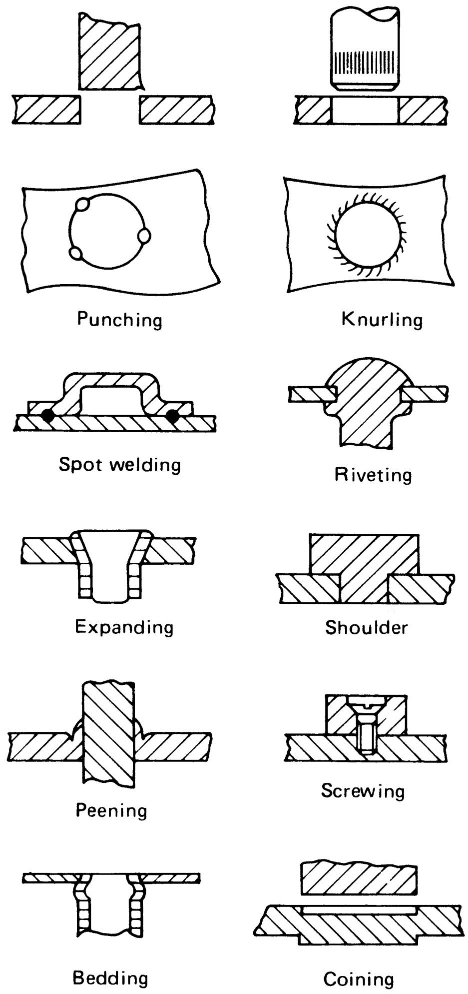


Figure 3 — Pre-placement of filler metal



NOTE The required brazing gap should be maintained.

Figure 4 — Common methods of locating components prior to brazing

f) *Metals and alloys containing reducible oxides.* It is essential that metals or alloys containing oxide inclusions, which are easily reduced at the brazing temperature, are not brazed in a reducing atmosphere; the oxide inclusions can form steam causing porosity and loss of ductility. By far the commonest example is tough pitch copper.

g) *Aluminium alloys.* The filler metals used for brazing aluminium and its alloys are based on the Al-Si system. If the parent metal 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 about 2 %, the amount of intermetallic compound will be sufficient to embrittle the joint.

h) *Magnesium alloys.* It is not possible to braze many magnesium alloys and specialist advice should always be sought if this is being considered.

i) *Lead-bearing copper alloys.* Lead is added to various copper alloys, e.g. to improve machinability, it being insoluble in copper. If above about 2 %, lead may interfere with brazing:

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

2) by causing cracking.

These effects can be reduced by adequate fluxing and uniform heating without imposed stress, but the risk always needs to be borne in mind and satisfactory joints on alloys with high lead contents may be impossible to achieve.

j) *Free machining steels.* Lead and sulphur are added to steels to improve machinability. Lead additions below 0.35 % are not considered to have a deleterious affect on brazeability, or joint strength, but higher levels may result in low joint strengths because of interaction with the filler metal. When vacuum furnace brazing, it should be noted that lead will volatilize from the surface of the steel.

Sulphur-bearing free machining steels, which typically contain up to 0.6 % sulphur, are readily brazed and joint strengths are comparable with sulphur-free grades.

k) *Cast iron.* Spheroidal graphite (s.g.) cast irons are fairly readily brazed with silver filler metals but flake graphite irons are more troublesome because the flakes interfere with wetting. One remedy is special surface treatment to remove the flakes, but this is not simple and a better remedy is to use a brazing filler metal containing nickel, such as BS 1845, AG9 or AG18.

l) *Cracking during brazing.* The main cause of cracking is the stressing of components while in contact with molten filler metal. This stress may originate from work hardening of the parent metal, from restraint imposed by a jig or from uneven heating. Nickel alloys, some steels and a few copper alloys are sensitive to cracking when brazed with silver filler metal. In the case of steels, cracking may also occur when using some copper zinc filler metals. It will only occur in steels if they are austenitic and not ferritic at the temperature involved. In the case of copper alloys, 70/30 cupro-nickel is the most important alloy to be sensitive to this phenomenon; 90/10 cupro-nickel is virtually immune. The cracking occurs at grain boundaries which tend to fill with brazing filler metal. 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.

m) *Reactive and refractory metals.* Titanium, zirconium, niobium and tantalum are not normally brazed and specialist advice should always 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 essential that the brazing temperature is below the recrystallization temperature, otherwise the parent material will be severely embrittled.

n) *Brazing alloys containing phosphorus.* If phosphorus-bearing copper brazing filler metals (BS 1845, CP series) are used to join steel or nickel alloys, the joints will be brittle (because of the formation of phosphides). Therefore, it is not normal to use these filler metals in such applications.

The phosphorus-bearing nickel brazing filler metals (BS 1845, HTN6 and HTN7) also give brittle joints if the cycle time is short. If the cycle time is lengthened, it is possible to diffuse sufficient phosphorus away from the joint to improve the ductility, because the temperature is higher than would normally be used with the copper alloys.

6.2 Filler metals

6.2.1 *BS 1845 materials.* The principal filler metals covered by this standard are those detailed in BS 1845 and fall into the groups shown in Table 3. Alternatives may be used provided that they meet the commercial requirements, subject to their acceptance by both manufacturer and user.

Table 3 — BS 1845 materials

BS 1845:1984 reference	Group	Composition
Table 1	AL	Aluminium brazing filler metals
Table 2	AG	Silver brazing filler metals
Table 3	CP	Copper-phosphorus brazing filler metals
Table 4	CU	Copper brazing filler metals
Table 5	CZ	Copper-zinc brazing filler metals
Table 6	HTN	Nickel and cobalt brazing filler metals
Table 7	PD	Palladium bearing filler metals
Table 8	AU	Gold bearing brazing filler metals
Appendix A		Special “vacuum application” versions of certain AG, PD and AU brazing filler metals

6.2.2 *Forms available.* The normal forms available include rod, wire, foil, preforms, powder, paste and clad sheet. A few brazing filler metals may also be deposited. The forms in which the brazing filler metal are available should be determined at the design stage.

6.2.3 *Applications.* The choice of filler metal for brazing a given combination of parent materials depends upon many factors, in some cases there will be only one possibility, in others, several. Table 4 gives a very general guide to the groups of filler metals (as given in BS 1845) which could be used for the various categories of parent material discussed in **6.1**, or combinations thereof. Not every filler metal in a group could necessarily be used in a specific case, depending upon circumstances.

Group AL. The filler metals in this group are used almost exclusively for the joining of pure aluminium and a restricted range of aluminium alloys.

Table 4 — Choice of brazing filler metal groups for different parent materials

	Mg	Al and its alloys	Cu and its alloys	Precious metals	Cast irons	Stainless steels	Steels and tool steels	Ni and its alloys	Co and its alloys	W and Mo	Refractory metals and alloys	Other materials	Coated material
Coated materials	NR	NR	AG, CP([b]) CZ([b])	AG, PD([b]) AU([b]), CU([b])	AG([b])	AG([c]), PD AU, CU	AG, CU CZ	AG([c]), PD AU, CU	AG, PD AU, CU	AG, CU PD, AU	NR	AG, CU PD, AU	AG, CU PD, AU
Other materials	NR	NR	AG, CP([b]) CZ([b])	AG, PD AU	AG([c])	AG([c]), HTN PD, AU, CU	AG, HTN CU	AG([c]), HTN CU, PD, AU	AG, HTN CU, PD, AU	AG, CU PD, AU	[a]	[a]	
Refractory metals and alloys	NR	NR	[a]	[a]	NR	NR	NR	NR	NR	[a]	[a]		
W and Mo	NR	NR	AG, PD AU,	AG, PD([b]) AU([b])	NR	AG([c]), CU PD, AU	AG, CU	AG([c]), CU PD, AU	AG, CU PD, AU	AG, CU PD, AU			
Co and its alloys	NR	NR	AG	AG, PD AU	AG([c])	HTN, AG([c]) CU	HTN, AG CU	HTN, AG([c]) CU	HTN, AG CU				
Ni and its alloys	NR	NR	AG([b], [c]) PD	AG([b], [c]) PD, AU	AG([c])	HTN, AG([c]) CU, PD, AU	HTN, AG([c]) CU, PD	HTN, AG([c]) CU, PD, AU					
Steels and tool steels	NR	NR	AG, CZ([b])	AG, PD AU	AG([c]) CU	HTN, AG([c]) CU	AG, CU, CZ HTN						
Stainless steels	NR	NR	AG([c]), AU	AG([c]), PD AU	NR	HTN, AG([c]) CU, PD, AU							
Cast irons	NR	NR	AG([c])	NR	AG([c]) CU								
Precious metals	NR	NR	AG, PD([b]), AU([b])	AG, CU PD, AU									
Cu and its alloys	NR	NR	AG, CP([b]) CZ([b]), PD AU										
Al and its alloys	NR	AL											
Mg	[a]												

NR = Not recommended.

[a] Brazing only possible under limited circumstances, specialist advice should be sought.

[b] This filler metal group can only be used for some parent materials.

[c] See **6.1.2** for specific discussion.

Table 5 — Choice of AG brazing filler metals for some combinations of parent materials

NOTE This table indicates the preferred brazing filler metals, based on technical and economic considerations. Other filler metal grades may be suitable for some applications.

	Cu and its alloys	Tool steels	Stainless steels	Cast irons[a]	Ni and its alloys	Co and its alloys	Mo and W	Tungsten carbide
Tungsten carbide	—	AG 1, 2, 3, 9, 14, 18	AG 9, 18[c]	AG 9, AG 18	AG 9, 18[d]	—	AG 9, 18	AG 9, 18
Mo and W	AG 9, 18	AG 9, 18	AG 9, 18[c]	AG 9, 18	AG 9, 18[d]	AG 9, 18	AG 9, 18	AG 9, 18
Co and its alloys	All except AG 5, 9, 13 18, 19	All except AG 7, 13	All except AG 7, 13[c]	AG 9, AG 18	AG 7, 13[b]	All except AG 7, 13		
Ni and its alloys	AG 7, 13[b]	AG 7, 13[b]	AG 9, 18[c]	AG 9, 18[d]	AG 7, 13[b]			
Cast irons	AG 9, 18	AG 9, 18	AG 9, 18	AG 9, 18				
Stainless steels	All except[c] AG 5, 7, 13 18 and 19	All except AG 7, 13	All except AG 7, 13[c]					
Tool steels	All except AG 5, 9, 13 18, 19	All except AG 7, 13						
Cu and its alloys	All except AG 18, 19							
Precious metals	AG 1, 2, 14							

[a] With pretreatment to remove graphite, all alloys except AG 7, 13 and 19 can be used.
[b] Where stress cracking is not a hazard, all alloys except AG 19 can be used on cobalt, ferrous and nickel alloys. All alloys except AG 7, 13 and 19 can be used on copper and its alloys.
[c] Only AG 9 is suitable when the brazed joint is exposed to aqueous solutions during service.
[d] Preventative measures may be necessary to avoid stress cracking.

Group AG. Silver brazing filler metals find wide application in the low temperature brazing of materials given in **6.1** with the exception of aluminium, magnesium and refractory metals and their alloys. Special grades are available for vacuum applications. Suitable AG brazing filler metals for some combinations of parent materials are given in Table 5.

Group CP. These filler metals are usually restricted to joining copper and its alloys. They are self-fluxing on copper, but a flux or protective atmosphere is required on most copper alloys.

Group CU. These filler metals are generally used for high temperature brazing of ferrous and certain other high melting parent materials in a protective atmosphere or vacuum.

Group CZ. These filler metals are used for copper, cemented carbide and ferrous components.

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

Groups PD and AU. These high cost filler metals are used in protective atmospheres or vacuum to join metallized ceramics, copper, nickel and ferrous alloys. Suitable PD and AU brazing filler metals for some combinations of parent materials are given in Table 6.

Where there is a choice from the filler metal groups listed in Table 4, advice on the most appropriate should be sought.

6.3 Choice of brazing method for different brazing filler metal groups

Table 7 gives a guide to the suitability of various brazing filler metal groups for the commoner brazing methods. Of necessity, it has been drawn up in very general terms and there may be special circumstances in which a combination shown as unsuitable may well prove suitable and vice versa. In cases of doubt, specialist advice should always be sought.

6.4 Fluxes

6.4.1 *General.* Fluxes (see **3.6**) are an essential requirement when brazing in air, with the general exception of the self-fluxing copper-phosphorus filler metals. Fluxes are also an integral part of all flux bath and many dip bath processes.
In exceptional circumstances they are used in protective atmosphere brazing operations.

6.4.2 *Forms.* The most commonly available forms are powder and paste. Alternatives include gases and liquids, flux-coated or cored filler metals and flux/filler metal mixtures.

6.4.3 *Types.* Fluxes fall into three main categories.

a) *High temperature brazing fluxes (over* 750 °C). These are based on borax (sodium tetraborate), borates or similar boron salts and may also include additions of stable fluorides and other activating agents. In some instances volatile fluxes such as methyl borate may be employed.

b) *Low temperature "silver" brazing fluxes* (600 °C *to* 750 °C). These consist of low melting alkali metal borates with reactive fluorine compounds. Potassium fluoroborate fluxes of this type are the most widely used. Variations of these fluxes are used for special applications involving parent metals which form refractory oxides.

c) *Aluminium brazing fluxes.* These are mixtures of low melting alkali metal halides, principally chlorides and fluorides with additions of other chemically active salts.

Table 6 — Choice of PD and AU brazing filler metals for some combinations of parent materials

Parent materials	Brazing filler metal
Mo and W Metallized ceramic Fe-Ni Fe-Co Fe-Ni-Co Steels Ni-Cu Ni Cu-Ni Cu	PD 1 to PD 8 and AU 1 to AU 6 can be used almost universally on all the materials listed. Alloy selection is based largely on filler metal cost and brazing temperature restraints, due to sequential brazing operations. Exceptions to this rule are PD 7 and PD 8 and AU 4 which are not recommended for use on Cu and Cu alloys, due to excessive interalloying. PD 9 to PD 13 and AU 5 and AU 6 possess better elevated temperature strength and oxidation resistance than the other alloys in their respective groups and are used for brazing heat-resistant steels and Ni and Co alloys. PD 14 is recommended for brazing ferrous and Ni alloys and Mo, Ta and W, particularly when the brazed joint is subject to high service temperatures.

Table 7 — Suitability of brazing filler metal groups for the commoner brazing methods

Filler metal group	Brazing method								
	Flame	Induction	Resistance	Furnace			Immersion		
				Protective atmosphere	Vacuum	Open atmosphere	Flux bath	Dip bath	Salt bath
AL	S	S	U	U	S[a]	S	S	U	U
AG	S	S	S	S	U[b]	S	U	S	S[a]
CP	S	S	S	S	U	S	U	U	U
CU	U	S	U	S	S	U	U	U	U
CZ	S	S	U	S	U	S	U	S	S
HTN	U	S	U	S	S	U	U	U	U
PD	U	S	U	S	S[a]	U	U	U	U
AU	U	S	U	S	S	U	U	U	U

S = Suitable U = Unsuitable

[a] Not all the filler metals in the group are suitable.

[b] AG 7 is suitable for vacuum furnace brazing.

Table 8 — Protective atmospheres

Number	Source	Typical dew point of incoming gas	Approximate composition				Applications	
			H_2	N_2	CO	CO_2	Fillers	Parent materials
		°C	%	%	%	%		
1	Combusted fuel gas[d] (low hydrogen)	Up to + 30	1 to 5	87	1 to 5	11 to 12	AG[a], CP, CZ	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	CU, AG[a], CZ[a], CP	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	—	CU, AG[a], CZ[a], CP	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	—	CU, AG[a], CZ[a], CP	Cu and some Cu alloys, carbon steels, Ni-Cu alloy, Ni.
5	Dissociated ammonia[g] (cracked ammonia)	– 54	75	25	—	—	CU, AG CZ, CP HTN 6 HTN 7	Cu and some Cu alloys, carbon steels, Ni-Cu alloy, Ni and Ni alloys, alloys containing Cr[b].
6	Cylinder hydrogen	Up to – 30	97 to 99	—	—	—	CU, AG CZ, CP HTN 7	Cu and some Cu alloys, low and medium carbon steels, Ni, Ni-Cu alloy.
7	Deoxygenated and dried hydrogen[g]	– 55	100	—	—	—	CU, AG CZ, CP HTN	Cu and some Cu alloys, Ni-Cu alloy, Ni and Ni alloys, and alloys of Co, Cr, W and cemented carbides[b].
8	Inert gas[g]	below – 60	e.g. argon, nitrogen[c]	—	—	—	CU, CP HTN	Cu and some Cu alloys, carbon steels, Ni and Ni alloys[b], alloys containing Cr

[a] Flux required in addition to atmosphere when filler metals 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 metal contains boron or silicon.
[d] The combusted fuel gas (decarburizing) may be referred to as exothermic. It may also be available as synthetic gas.
[e] The combusted 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 metals in Tables 7 and 8 of BS 1845:1984 can be brazed in atmospheres number 5, 7 and 8.

6.4.4 *Flux removal*

6.4.4.1 *General.* Flux residues should be disposed of by an environmentally acceptable method. The difficulty with which they can be removed 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 minimum heating time. 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 metal has solidified.

Most flux residues are chemically active and their complete removal is essential if undesirable corrosion of the parent metals is to be avoided. This is especially important with nearly all the aluminium brazing fluxes and many of the low temperature types.

6.4.4.2 *High temperature fluxes.* The fused residues from borax and similar high temperature fluxes are hard, glassy and relatively insoluble in water. Removal by mechanical methods is therefore most efficient and grit or shot blasting or other abrasive techniques are preferable. Alternatively, prolonged immersion in boiling water or cold 5 % *V*/*V* sulphuric acid, with wire brushing, is necessary.

6.4.4.3 *Low temperature brazing fluxes.* 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. Cold 5 % *V*/*V* sulphuric acid, 10 % *m*/*V* sodium hydroxide or a 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.

6.4.4.4 *Aluminium brazing fluxes.* These fluxes are highly corrosive and require very careful post-braze cleaning. The flux residues are water soluble and can be washed away.

6.4.4.5 *Safety.* There is no British Standard on brazing fluxes and reference should be made to the manufacturer to ensure that the flux, filler metal and parent material are compatible.

Fluxes contain irritant or toxic chemicals and should therefore be treated with appropriate caution. Irritant fumes can also be emitted on heating; these fumes should not be inhaled.

6.5 Atmospheres

6.5.1 *Protective.* The types of protective atmosphere available are listed in Table 8.

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 material and filler metal so that the latter can flow freely during brazing. They are an effective alternative to the use of flux usually above 900 °C.

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

6.5.2 *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 rapidly evacuate 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[5)] is easily achieved, but a low leak rate is equally important in order to control the residual atmosphere. 10^{-3} mbar is equivalent to a gas impurity content of approximately 1.1 parts per million by volume.

7 Methods of brazing

7.1 Flame brazing

7.1.1 *Hand torch brazing*

7.1.1.1 *The process.* In this method the heat is generally applied using a single torch (blowpipe) held in the operator's hand, but may also apply to two or more operators heating a large workpiece using hand held equipment.

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.

[5)] 1 mbar = 10^2 N/m^2 = 100 Pa.

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

Oxy-acetylene

Oxy-methyl acetylene mixtures (proprietary)

Oxy-hydrogen

Oxy-propane

Oxy-butane

Oxy-natural gas (methane)

Compressed air-acetylene

Compressed air-methylacetylene mixtures (proprietary)

Compressed air-hydrogen

Compressed air-propane

Compressed air-butane

Compressed air-natural gas (methane)

Aspirated air-acetylene, propane, and butane

(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.

7.1.1.2 *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 metal occurs.

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

7.1.1.3 *Advantages/disadvantages.* 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 cost;

e) minimum maintenance.

Disadvantages of the process are:

1) high labour content (cost);

2) training is required to achieve consistent results;

3) relatively low production rate;

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

7.1.1.4 *Size limitation.* 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).

7.1.1.5 *Safety.* 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 expert and trained personnel, to whom all cases of repeated backfiring have to be referred.

All hoses should be regularly checked for signs of chafing and cracking and replaced as necessary.

It is essential that non-return valves and flashback arrestors are not under any circumstance modified or removed to increase gas flow.

7.1.2 ***Mechanized flame brazing***

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

Burners with various profiles are available. They enable heat patterns to be designed to suit 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

7.1.2.2 *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 metals to copper, can be applied manually by brushing or dipping, or automatically using specialized equipment.

Brazing filler metals 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 metals generally used are specified in Tables 2, 3 and 5 of BS 1845:1984.

7.1.2.3 *Advantages/disadvantages.* The main advantages of the process are:

a) moderate equipment cost;

b) simple maintenance;

c) high output;

d) flexibility regarding component shape and size;

e) suitable for continuous or indexing machines.

Disadvantages 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 for high temperature brazing, i.e. 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.

7.1.2.4 *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).

7.1.2.5 *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.

7.2 Induction brazing

7.2.1 *The process.* When alternating current is passed though 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.

7.2.2 *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 metal 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.

7.2.3 *Advantages/disadvantages.* The main advantages of the process are:

a) rapid heating;

b) closely controlled reproducible heat pattern for simple shapes;

c) economical running costs;

d) the heat is concentrated in the joint area.

Disadvantages of the process are:

1) high capital cost;

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

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

7.2.4 *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.

7.2.5 *Safety.* It is essential that care is taken when high frequency current is passing through the coil, as close proximity of metal objects, including rings, will cause a severe burn (not electric shock). Skin contact with the coil will also cause a r.f. burn. The manufacturer's instructions should be carefully observed when using equipment of this type and it should be maintained, according to the manufacturer's instructions, by authorized personnel.

7.3 Resistance brazing

7.3.1 *The process.* The parts to be joined are raised to the appropriate 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.

7.3.2 *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 about 800 °C, because of excessive burning and wastage of the graphite electrode, whereas 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 an explosion. In consequence, self-fluxing brazing filler metals are preferred or, less commonly, a localized protective atmosphere. Where the use of a flux cannot be avoided, a small quantity of thin paste or liquid flux is employed.

7.3.3 *Advantages/disadvantages.* The main advantages of the process are:

a) extremely rapid localized heating;

b) low running costs;

c) lower capital costs than induction heating;

d) closely controlled reproducible heat pattern.

Disadvantages of the process are:

1) higher capital costs than hand torch brazing;

2) severe limitations on shape and size;

3) high wear of graphite electrodes may be a problem;

4) potentially poor repeatability if flux is used;

5) not suitable for high temperature parent materials.

7.3.4 *Size limitations.* Energy requirements increase rapidly with increasing size of joint, so restricting the use of the process for large joint areas.

7.3.5 *Safety.* Health hazards are limited to a spatter risk caused by dirty or high resistance parts, flux films or insufficient holding pressure. Since the time cycles are short and the volume of fume producing material small, local extraction is adequate.

7.4 Furnace brazing

7.4.1 *Process variants.* There are three variants of the process, protective atmosphere, vacuum and open furnace brazing. The second of these can generally only be batch operated. The others can be continuous or batch operated.

These variants are individually discussed in greater detail in **7.4.2** to **7.4.4**, but certain aspects are common to all of them and are therefore considered here. Many small components or one large one may occupy the available furnace space but, irrespective of the size, it is essential to realize 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 metal and (where relevant) flux. The joint should be designed to ensure correct positioning of the brazing filler metal 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 parent material(s). Some advantages and disadvantages 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.

Disadvantages of the processes are:

1) through heating of components is inevitable, which may not be tolerable in some applications;

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

7.4.2 *Protective atmosphere brazing*

7.4.2.1 *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, and is reducing. Cracked ammonia, hydrogen and nitrogen mixtures and endothermic atmospheres are also used. The highest purity atmospheres are most commonly used in batch furnaces only which can be used for temperatures up to 1 250 °C.

7.4.2.2 *Continuous furnace brazing*

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

7.4.2.2.2 *Application.* Although applied to many materials, the major application of continuous furnace brazing is for the furnace brazing of mild steel with copper.

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.

7.4.2.2.3 *Advantages/disadvantages.* 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 metals.

Disadvantages of the process are:

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

2) not practical to switch on and off.

7.4.2.2.4 *Size limitations.* The maximum size of component is limited only by furnace cross-sectional area.

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

7.4.2.3 *Batch furnace brazing*

7.4.2.3.1 *The 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.

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

7.4.2.3.3 *Advantages/disadvantages.* The main advantages of the process are:

a) usually fluxless with no post-cleaning requirements;

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

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

Disadvantages of the process are:

1) long cycle time;

2) limited retort life at higher temperatures;

3) energy inefficient.

7.4.2.3.4 *Size limitations.* Large components can be processed.

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

7.4.3 ***Vacuum brazing***

7.4.3.1 *The process.* The furnace generally comprises a water cooled chamber, with 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 metal flow in the absence of flux.

Accurate means of regulating temperature, heating and cooling rates is normally available. To speed cooling after brazing, provision is made to circulate cooled protective gas through the furnace.

7.4.3.2 *Application.* Although in principle widely applicable, vacuum brazing is normally used for the high temperature brazing of the corrosion and heat resisting types of alloy.

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

7.4.3.3 *Advantages/disadvantages.* 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.

Disadvantages of the process are:

1) very high capital cost;

2) 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).

7.4.3.4 *Size limitations.* Production furnaces with ruling dimensions of 300 mm to 1 000 mm are common, but 2 m is large.

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

7.4.4 *Open furnace brazing*

7.4.4.1 *The process.* Components are loaded into a muffle furnace which may be either gas or electrically heated. Loading may be carried out with the furnace at room or elevated temperature, depending on factors such as the nature of the components, the size of the furnace, etc. After brazing, the components are allowed to cool below the solidus of the brazing filler metal before removal from the furnace.

7.4.4.2 *Application.* The process is mainly applied to low temperature brazing of suitable parts in small-scale production.

7.4.4.3 *Advantages/disadvantages.* The main advantages of the process are:

a) simple equipment of relatively low capital cost;

b) very large components can be brazed.

Disadvantages of the process are:

1) extended cycle time may lead to premature flux exhaustion;

2) except where protected by flux, components will be oxidized;

3) if the heating elements of an electric furnace are exposed to flux or the fumes from flux, they will be damaged.

7.4.4.4 *Size limitations.* Although normally used for small components, the size is only limited by the size and weight capacity of the furnace.

7.4.4.5 *Safety.* The only hazards are those associated with flux and the normal operation of furnaces.

7.5 Immersion brazing

7.5.1 *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.

7.5.2 *Flux bath brazing*

7.5.2.1 *The 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 metal preforms are placed adjacent to the joint areas prior to immersion.

7.5.2.2 *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.

7.5.2.3 *Advantages/disadvantages.* The main advantages of the process are:

a) provides precise and even heating of complex assemblies;

b) simultaneous heat treatment can be carried out in some instances.

Disadvantages 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.

7.5.2.4 *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 flux bath size but may be of the order of 1 m.

7.5.2.5 *Safety.* Safety hazards include a significant explosion risk if pre-heating is not carried out efficiently. Irritant fumes are emitted by the molten flux and require adequate extraction, but metal oxide fume is minimal. Splashing by molten flux is an ever present risk.

7.5.3 *Dip bath brazing*

7.5.3.1 *The process.* Dip bath brazing involves immersion of the immediate joint area of the assembly in a molten filler metal 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.

7.5.3.2 *Application.* Filler metals 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.

7.5.3.3 *Advantages/disadvantages.* The main advantages of the process are:

a) process is tolerant and wide joint brazing gaps can be accommodated;

b) good standard of joint;

c) rapid heat transfer.

Disadvantages of the process are:

1) compositional drift of the bath;

2) need for frequent flux replenishment;

3) need to preheat components;

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

7.5.3.4 *Size limitations.* Components joined 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.

7.5.3.5 *Safety.* Health hazards include the risk of an explosion with damp assemblies, splashing of molten metal and flux and the evolution of toxic metal oxide and flux fume from the bath surface. Cadmium-bearing AG series filler metals and their associated fluxes are the most hazardous combination in this latter respect.

7.5.4 ***Salt bath brazing***

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

7.5.4.2 *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 BS 1845, AG and CZ filler metals with melting temperatures in excess of 750 °C will be suitable.

7.5.4.3 *Advantages/disadvantages.* 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.

Disadvantages of the process are:

1) need for 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.

7.5.4.4 *Size limitations.* It is not a practicable process for small parts of low mass. Maximum dimensions are limited only by the size of salt bath available.

7.5.4.5 *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.

7.6 Special methods

7.6.1 ***Infra-red brazing***

7.6.1.1 *The process.* This heating system is used to braze assemblies using infra-red or near infra-red quartz lamps as the heating source. The heat is transmitted by radiation. The array of lamps is mounted in a reflective insulated holder, the shape of which usually conforms to the shape of the component. The process is usually fluxless and so components are shrouded by an inert gas or in some cases the assembly is evacuated. The process is used for temperatures up to 1 100 °C. The brazing filler metal is always pre-placed, and by careful design an even temperature can be achieved over large areas.

7.6.1.2 *Application.* Use of the process is currently restricted to aircraft wings and in situ brazing of critical joints, e.g. pipe joints.

7.6.1.3 *Advantages/disadvantages.* The main advantages of the process are:

a) can be used in situ;

b) heat can be focused;

c) large areas can be brazed;

d) heating rates are quicker than with furnace brazing but slower than with induction brazing;

e) temperature control and measurement are simple.

Disadvantages of the process are:

1) normally custom built for specific applications;

2) need for a controlled atmosphere to be incorporated into the design;

3) lamp terminals require water or forced draft cooling;

4) delicate equipment.

7.6.1.4 *Size limitations.* The process is used to heat quite large areas and large diameter tubular components. It is applied to small components with difficulty.

7.6.1.5 *Safety.* It is necessary to provide eye protection because of the high temperatures of the filaments in the lamps.

7.6.2 ***Electron beam brazing***

7.6.2.1 *The process.* The spot produced by the beam is of extremely high energy even when defocused. This enables a joint to be made with minimum heating of the parent materials, whilst at the same time fusion of the joint area and filler metal enables a leak-free joint to be made.

7.6.2.2 *Application.* The process is particularly suitable for the manufacture of ceramic to metal seals where a mixture of ceramic, metal and filler metal combine to locally seal the joint.

7.6.2.3 *Advantages/disadvantages.* The main advantages of the process are:

a) localized heat source;

b) can reach locations impossible to reach by other processes;

c) ceramic to metal joints can be made with minimum residual stress.

Disadvantages of the process are:

1) high capital and running costs (higher than vacuum brazing);

2) not always reproducible;

3) components need to be in vacuum;

4) complex manipulators are necessary to hold/rotate components.

7.6.2.4 *Size limitations.* Very small components can be processed, as in the micro-electronics industry, but size is limited by the capacity of the manipulator and vacuum chamber.

7.6.2.5 *Safety.* Electron beam brazing presents considerable problems involving specialist knowledge of radiation and high energy beam containment and should only be used by competent personnel under the guidance of qualified engineering personnel.

7.6.3 *Laser brazing*

7.6.3.1 *The process.* A pulsed or continuous wave laser beam is used as the heat source. With a defocused beam it is possible to heat the pre-placed brazing filler metal to its melting temperature as well as heating the joint surfaces of the components to a temperature sufficiently high for localized filler metal wetting and flow to occur. The laser beam is absorbed in the top surface of the joint only, and the temperature profiles generated as the heat is absorbed from this surface region into the joint will be controlled by the incident laser power and processing speed.

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

7.6.3.3 *Advantages/disadvantages.* 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.

Disadvantages of the process are:

1) high capital cost (but lower than electron beam brazing);

2) cannot be used for extensive capillary flow.

7.6.3.4 *Size limitations.* Only small joints can be processed.

7.6.3.5 *Safety.* Laser beam brazing presents considerable problems involving specialist knowledge of radiation and high energy beam containment and should only be used by competent personnel under the guidance of qualified engineering personnel.

8 Economics of brazing methods

The choice of heating method for brazing is seldom made on financial grounds alone, since it is constrained by the required properties of the joint, and by the availability of equipment and labour. The two primary factors likely to influence the decision are the mass and geometry of the parts to be joined and the melting temperature of the chosen brazing filler metal.

The factors which may affect the jointing cost of a brazed assembly include the following:

brazing quality category

labour (skilled and semi-skilled)

capital investment

cost of jigs and fixtures

filler material and consumption

total fuel cost

atmosphere cost and usage

component preparation

flux and flux removal cost

pre- and post-braze cleaning cost

quality assurance cost

maintenance cost

space cost

health and safety costs

training costs

rectification costs.

The higher the technology of the process, the higher is the likely capital investment. The additional characteristics of heat transfer efficiency and freedom from oxidation of the more expensive processes should be offset against capital and running costs, so careful total costing is required for each and every circumstance.

9 Quality assurance

Joints brazed in accordance with this guide will be such that their brazing quality can be identified and evaluated to the satisfaction of both the purchaser and supplier. (See clause **4**.)

In this respect, it is important to record aspects which will be of value to all interested parties and to allow quality levels to be achieved dependent on the application. Specific requirements on quality important to the purchaser and supplier should be agreed before any work is carried out, so that errors and misunderstandings can be avoided.

A list of relevant items is given below from which the purchaser/supplier can select to achieve the appropriate quality:

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 metal 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 joined 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 metal;

k) repair of defective joints;

l) equipment controls and maintenance requirements;

m) recording of test results.

Appendix A Defects in brazed joints

Figure 5 to Figure 11 illustrate defects in brazed joints

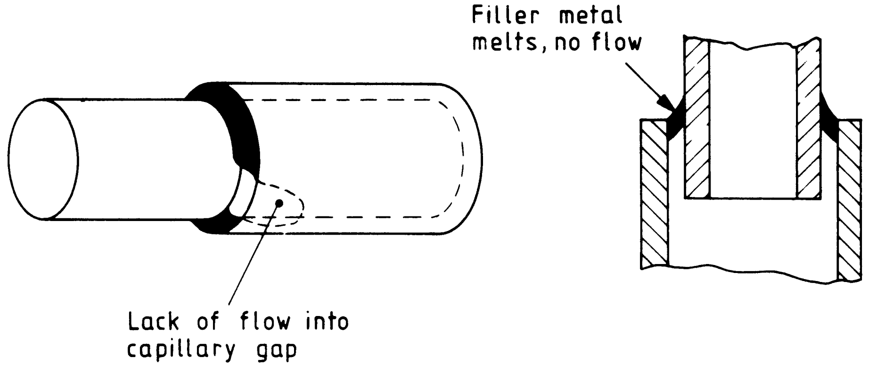


Figure 5 — Incomplete flow at fillet and in capillary

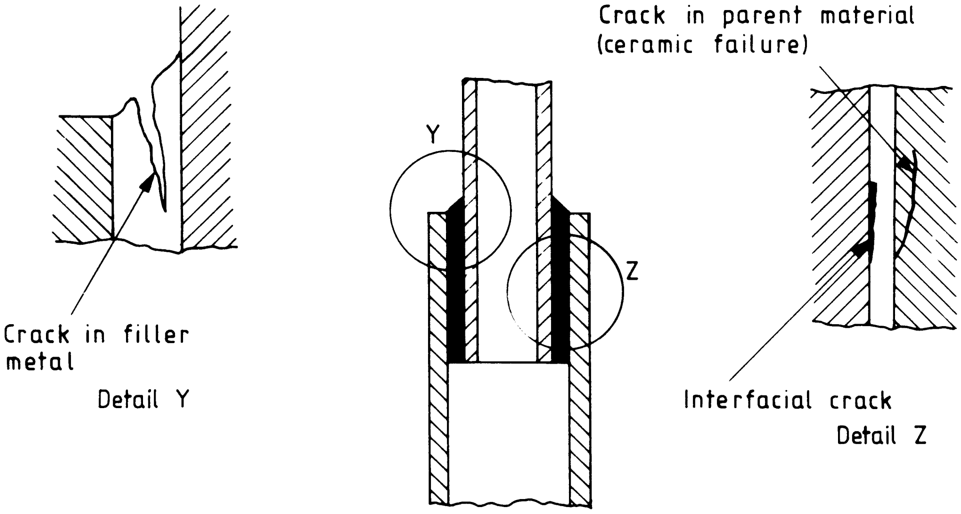


Figure 6 — Longitudinal cracks

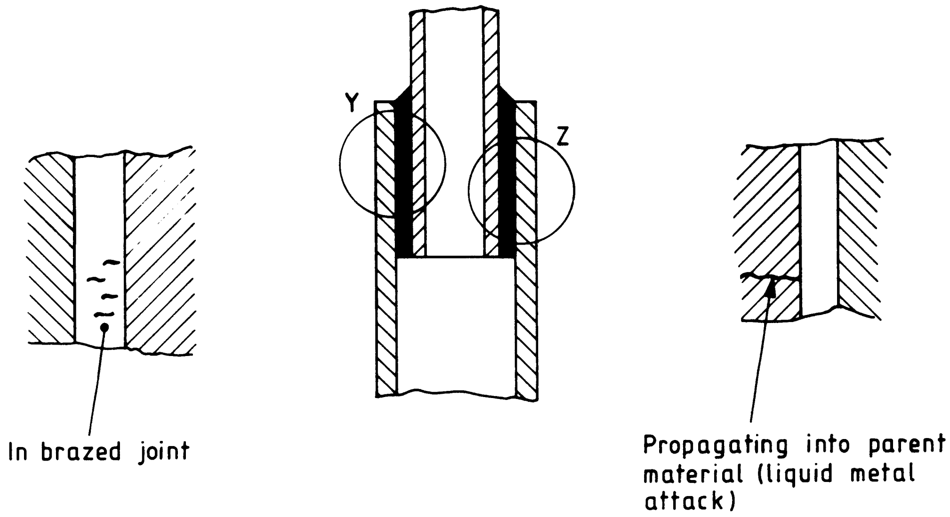


Figure 7 — Transverse cracks

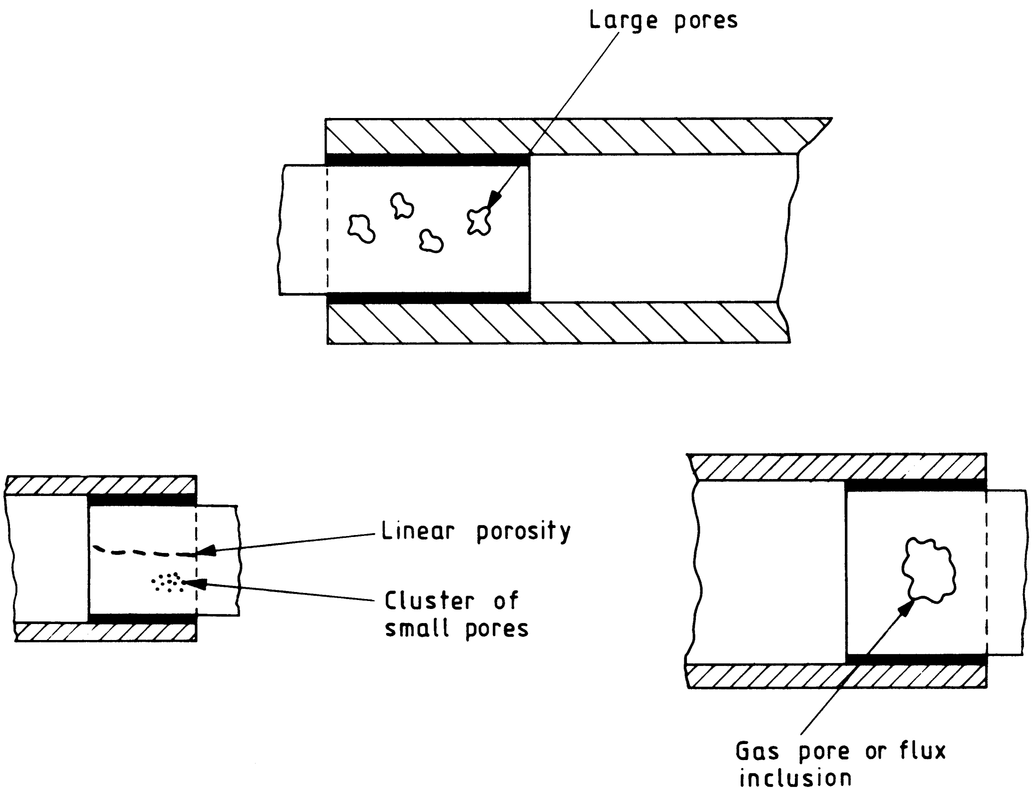


Figure 8 — Porosity and inclusions

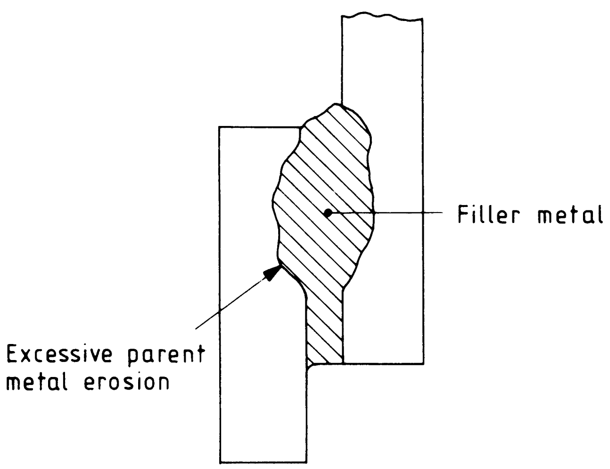


Figure 9 — Erosion

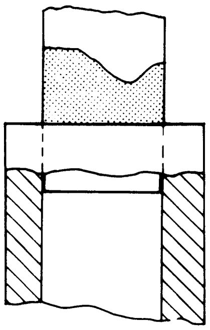


Figure 10 — Excessive filler metal flow

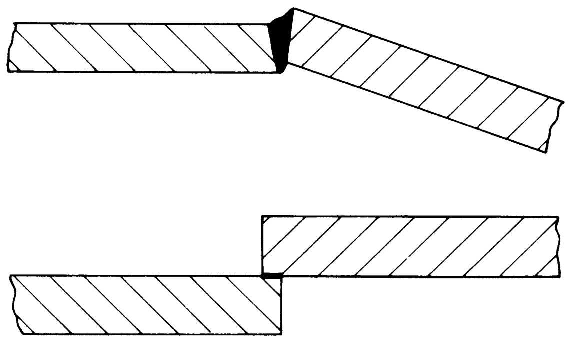


Figure 11 — Incorrect component assembly

Appendix B References to health and safety publications

The following publications about health and safety are available:

Health and Safety Executive Guidance Note EH15 “Threshold Limit Values”.

Health and Safety Executive Guidance Note EH22 “Ventilation of buildings; fresh air requirements”.

Recommendation for the Safety Use of Cadmium-containing Filler Metals for Brazing. The British Association for Brazing and Soldering 1978.

Health and Safety at Work November 1981. pp 25-30. “Fumes produced during brazing” L A Heathcote.

BS 679 Filters for use during welding and similar industrial operations

DD 54 Methods for the sampling and analysis of fume from welding and allied processes

DD 54-1 Particulate matter

DD 54-2 Gases

Appendix C Sources of technical information on brazing

Some sources of technical information on brazing are:

British Association for Brazing and Soldering

The Welding Institute

American Welding Society Brazing Manual

Brazing filler metal manufacturers

Publications referred to

See also Appendix B.

BS 499, *Welding terms and symbols.*

BS 499-1, *Welding brazing and thermal cutting glossary.*

BS 1723, *Brazing.*

BS 1723-1, *Specification for brazing.*

BS 1723-3, *Destructive testing and non-destructive evaluation*[6].

BS 1723-4, *Procedure and operator approval*[6].

BS 1845, *Specification for filler metals for brazing.*

[6] In preparation.

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