

FLUX BATH BRAZING – AN ENGINEERING TECHNIQUE

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Reprinted from:

SHEET METAL INDUSTRIES (1964)

PARK THERMAL INT'L. (1996) CORP.

Introduction

While brazing is a method of joining which has been known for centuries, it is only in recent years that the method has been accepted as a production process. Joints made by this process are both strong and reproducible and assemblies of complex construction are regularly manufactured. However, there are still many designers and engineers who are unaware of the full potentialities of the technique, and one of the purposes of this paper is to indicate to them the scope of this joining method.

One field where brazing is being used to an increasing extent is in the assembly of aluminium-alloy components. As these become more complex, so problems associated with design and production are accentuated. A brazing method is now established which has overcome many of these problems, allowing the design of parts which had previously been considered impossible. This technique is flux (salt) bath brazing¹. Naturally there are limitations in its use but these are gradually being reduced with the development of new flux compositions and greater appreciation of the precautions to be followed in designing and producing brazed assemblies.

The principal objective of this paper is to underline the importance of joint configuration at the drawing-board stage, and to discuss the various operations, notably cleaning, essential to the production of well-brazed components.

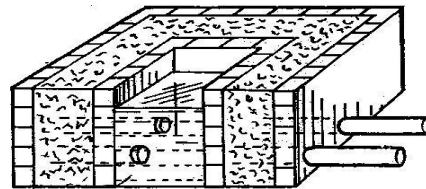
Heating Equipment

It is well known that the joining of aluminium and its alloys required a considerable amount of research. However, it is now possible to solder, torch braze, argon-arc, gas, resistance or ultrasonic weld a number of the alloys if well-defined conditions are observed, so that the tenacious oxide present on both parts to be joined and the filler or

brazing alloy is removed. In a number of applications, notably heat-exchanger parts, where long paths require to be joined, none of these methods is practical, and attention was turned initially to furnace brazing in an air oven with a flux additive, and subsequently after pre-treatment in a forced-air-circulation furnace, to flux-bath brazing using a proprietary salt. Of the two approaches examined. Most successful joints were obtained with the flux bath, and this technique was, therefore, adopted as a production process. Recently² vacuum brazing was examined but results were inferior to products obtained with the flux bath.

This paper would not be complete without a brief description of the flux bath which was used. This unit is one of the Efco-Upton products and is illustrated in Fig. 1. The bath (28 in. x 26 in. x 18 in.) has a refractory lining which contains the flux and is supported on insulating materials. The flux used is Efco-Park D which is essentially a mixture of sodium chloride and fluoride, and potassium and lithium chlorides, melting at 535° C., with a working range of 565° C. to 650° C. and having a density of approximately 100 lbs. per cu. ft. at 586°. The bath is heated by passing current through the molten flux using a low voltage alternating supply (60 kVA).

Fig. 1.—The flux bath



¹ 'Brazing Alcoa Aluminium', 1959. 135pp.

² Perry, E.R. Report to Institute of Metals, 1963, Spring Meeting, during discussion of paper by Wall, A.J. and Milner D.R. ('Wetting and Spreading Phenomena in a Vacuum' *J. Inst. Metals*, 90, June 1963, p. 394).

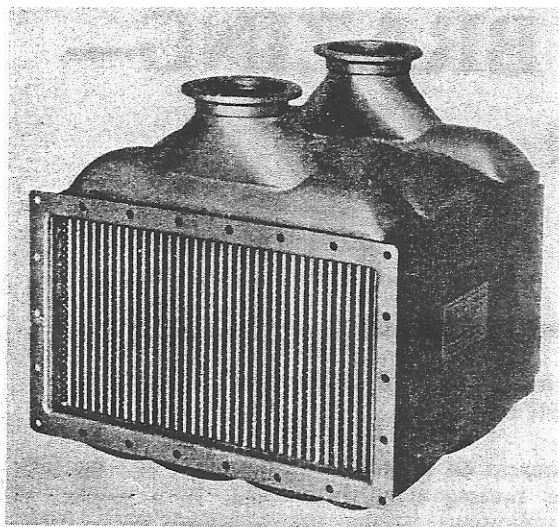


Fig. 2.—Secondary surface air-to-air heat exchanger. Brazing alloy applied in form of clad sheet

This method of heating, results in high heat transfer from the salt to the component undergoing treatment, with high uniformity of temperature throughout the bath. At the same time the salt has an excellent fluxing action on the oxides present on both parent metal and filler³. Accurate control of bath temperature is vital and it must be borne in mind that certain of the alloys which are to be brazed have a solidus which is within 5° C. of the brazing temperature.

Due to the closeness of the densities of aluminum alloys and the flux, there is only a slight tendency for the brazing alloy to flow downwards due to gravity effects, and capillary attraction is, therefore, the principal force involved in retaining molten brazing alloy in the joint. However, a further factor which may assist in placing alloy in the joint is the downward flow of brazing alloy due to flux-drag when components are removed from the bath.

Applications

The flux bath described has been in service for a number of years and experience with it has proved that joints which are inaccessible using other joining methods, can be made on a routine basis using certain aluminum alloys where sections have ranged in thickness from 0.006 in. to 2 in. However, while

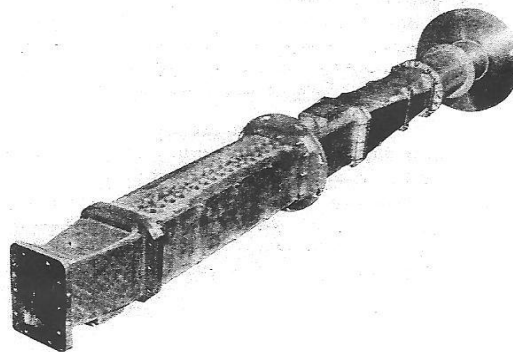
extremes of different thickness can be brazed, care must be taken to ensure that heating and cooling rates are not excessive, as the assembly will thus be subjected to thermal stresses which cause distortion and so affect brazing tolerances. This effect is increased in certain aluminium alloys, notably those hardened by additions of magnesium and silicon.

Typically components which have been successfully joined by flux-bath brazing are illustrated in Figs. 2 to 5. To consider Fig. 2 in more detail, those familiar with aluminium secondary surface heat exchangers will be aware of the difficulties of producing a metal-bonded corrugation sandwich capable of withstanding pressures in excess of 200 lbs. per sq. in. and having adequate thermal conductivity properties, this type of heat exchanger is built up of aluminium corrugations separated by sheets of aluminium – 1¼ per cent manganese alloy clad with aluminium 7½ per cent silicon brazing alloy. The use of clad sheet can make the most difficult assemblies possible. The cladding is preset as a percentage of the total thickness of the sheet, i.e. a 0.036-in. thick sheet, if clad on both sides with 10 per cent thickness of brazing alloy, had the following core thickness:

$$0.036 \text{ in.} - (2 \times 0.0036 \text{ in.}) = 0.0288 \text{ in.}$$

The coating of brazing alloy on clad sheet cannot readily be detected on the sheet as supplied, and experience has proved the advisability of using double-sided clad sheets as there is thus no chance of the piece parts being manufactured with the brazing alloy wrongly positioned, causing a scrapped assembly.

Fig. 3.—The feed unit of the aerial used in two-way trans-Atlantic telecommunications at Goonhilly Downs
(Courtesy, G.P.O. Engineering Department)



³ Jordan, M.F. and Milner D.R. 'The removal of Oxide from Aluminium by Brazing Fluxes' *J. Inst. Metals*, 1956-57, 85, pp. 33-40.

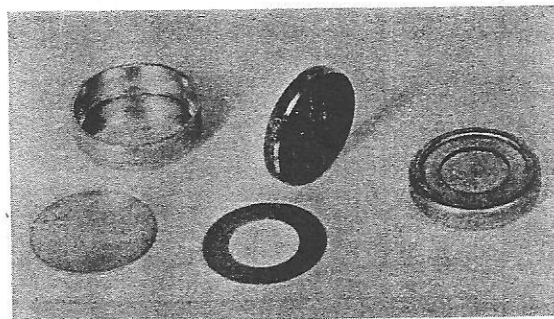
A further feature of using clad sheet is that while the cost of this is approximately twice that of the parent alloy plus brazing foil, there is a considerable saving in labour, as positioning of brazing alloy in a separate operation becomes unnecessary. It should be noted that during the brazing and later cleaning processes the clad sheet, due to attack by flux and cleaning acids, changes colour, becoming darker. At the same time it acquires a matte finish which will accept further treatment such as anodizing. Where a decorative finish is required, it should be remembered that most of the aluminium finishing treatments will result in a darkening of the brazed joint, and this may be unacceptable.

For larger heat exchangers it is possible to use a brazing alloy in the form of foil. However, when using very thin structural members, foils, which are not generally available below 0.0015 in. thick, would affect tolerances and result in alloy excess, i.e. consider brazing 0.006 in. thick aluminium with 0.002 in. brazing foil; in such a case the excess brazing alloy would tend to block the cooling passages of the matrix on solidification, thereby impairing heat exchange properties of the unit in service.

*Fig. 4.—Aluminium-alloy impellor: brazing alloy applied as foil between shroud and vanes
(Courtesy, Brown, Boveri and Co. Ltd.)*



As well as heat exchangers, complex pressurized boxes notably for containing airborne radar



*Fig. 5.—The encapsulation of cobalt discs for radioisotope applications, where the aluminium-silicon eutectic brazing filler is applied as a foil washer
(Courtesy U.K.A.E.A.)*

equipment are being manufactured by the flux-bath technique. Boxes have also been made using epoxy-resin-type bonds; however, the use of the flux bath has resulted in extremely high strength to weight ratios and for this reason, brazing is to be preferred. Corrugations for both boxes and heat exchangers lead to consistently strong structures, and they may also serve as the means by which a cooling medium is circulated (see Figs. 6a, 6b).

Although for heat exchangers and pressurized boxes there are advantages in using clad brazing alloys, there are many occasions when these are unsuitable and resort is then made to powders mixed to a paste with water or alcohol, foils or wires. The waveguide, turbine wheel and radioisotopes illustrated are examples of components which could not conveniently be made using clad materials alone.

The flux-bath technique is frequently used in the production of waveguides, where distortion must be a minimum and tolerances often require to be held to ± 0.001 in. Probably one of the largest aluminium-alloy waveguides is that installed at Goonhilly Downs for two-way television and the reception of telephony signals across the Atlantic Ocean, using the Telstar and Relay satellites; this waveguide is over 6ft. long (Fig.3).

Parts such as the impellor (Fig. 4) which operate at high speed under service conditions are fabricated from bar and sheet, and subsequently brazed. In producing these parts consideration is given to the grain flow present in heavily-worked aluminium alloys, so that the maximum strength is available in the component after joining piece-parts.

TABLE I—Brazable Aluminium Alloys
(a) Parent Metals

Alloy No.	Designation	Nominal composition	Melting range (°C.)	Condition	Mechanical properties		Brazability rating
					Tensile strength tons/sq. in.	Elongation per cent on 2 in./GL	
1	B.S. Series Nos.	99.99 per cent super purity Aluminium	660	O	4.0 max.	45 min.	Excellent
2	1470 to 1477: S 1	99.8 per cent purity Aluminium	645-657	O	5.0 max.	35 min.	Excellent
3	1470 to 1477: S 1A	99.5 per cent purity Aluminium	635-650	O	6.0 max.	30 min.	Excellent
4	1470 to 1477: S 1B	99.0 per cent purity Aluminium	630-655	O	6.5 max.	30 min.	Excellent
5	1470 to 1477: S 1C	Aluminium 14 per cent Manganese	643-655	O	7.5 max.	30 min.	Excellent
6	1470 to 1477: N S 3	Aluminium 1.7/2.8 per cent	595-650	O	11.0-14.0	18 min.	Can be brazed if magnesium <2 per cent and special cleaning takes place
7	1470 to 1477: H E 9	Magnesium 0.6 per cent Silicon					Very good
8	1470 to 1477: H E 19	Aluminium 0.4/0.9 per cent Magnesium 0.3/0.7 per cent Silicon	580-660	O	7.0 min.	15 min.	Very good
9	1470 to 1477: H E 20	Aluminium 0.4/1.5 per cent Magnesium 0.6/1.3 per cent Silicon	580-660	WP	12.0 min.	12 min.	Good
10	1470 to 1477: H S 3 0	Magnesium 0.2/0.8 per cent Silicon 0.15/0.35 per cent Chromium	580-660	WP	7.0 min.	15 min.	Very good
11	DTD 5008	Aluminium 0.4/1.5 per cent Magnesium 0.6/1.3 per cent Silicon 0.4/1.0 per cent Manganese	580-650	O	11.0 max.	18 min.	Good
		Aluminium 0.5/0.7 per cent Magnesium 0.25 per cent Silicon 4.8/5.7 per cent Zinc 0.4/0.6 per cent Chromium	600-660	WP	18.0 min.	8 min.	Very good

(b) *Clad sheet and strip*—These materials are covered by Aircraft Specification DTD 900K/4212.

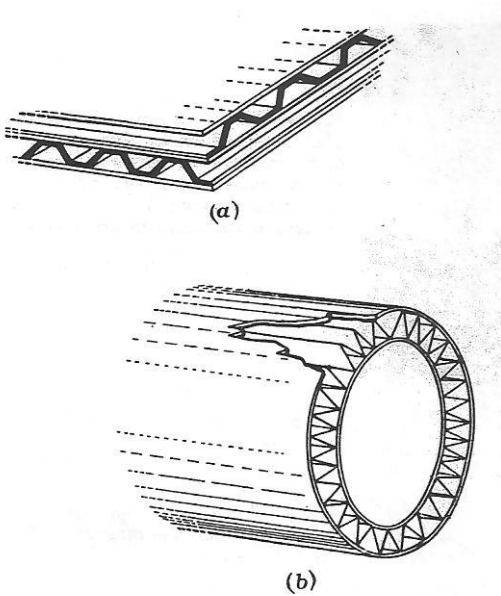
To ensure that there is sufficient brazing metal, strip which is 0.048 in., or less, requires a coating thickness of 10 per cent. For thicker sheets 5 per cent is necessary.

12	IMPALCO type PA/17/19	Aluminium 7/8 per cent Silicon cladding on NS 3 alloy	565-600	Properties are similar to NS 3 alloy in "O" condition.			
13	IMPALCO type PA/16/19	Aluminium 4.5/6 per cent Silicon cladding on NS 3 alloy	565-625				
14	ALCOA No. 22	Aluminium 7/8 per cent Silicon cladding on HS 30 type alloy	565-600	Properties as brazed, similar to HS 30 in "O" condition.			

Some of the radioisotopes produced by the U.K.A.E.A. consist of cobalt discs encased in flux-bath-brazed capsules (Fig. 5). These capsules must be leak-proof and after brazing and before irradiation, they are pressure tested using a vacuum technique. This is an application which could use torch brazing but where experience has shown that the flux bath is more economical, allied to the sure success of properly made joints.

Design of Joints

When considering the design of a component for flux-bath brazing, thought must be given to the mechanical properties of the parent metal and the brazing alloy. Also to be taken into account are the clearances to be adopted between adjacent parts which are to be joined, methods of maintaining clearance during the brazing cycle, i.e. jiggging, and ultimate strength of the joint. There are other considerations which are germane to the brazing process and which have been dealt with in detail elsewhere^{4/5}.



Brazeable Aluminium Alloys

Table I lists the aluminium alloys which are currently brazed on a production scale. The majority of the alloys referred to have equivalent specifications in the form of bar, sheet or extrusions, as appropriate. It should be

remembered that there may be a change in mechanical properties from the tabulated figures on going to a different type of the same chemical composition. Of the alloys shown, those numbered 1 to 6 are not heat-treatable. The properties given relate to the annealed ('0') condition, which is the state of the material after going through the brazing cycle.

TABLE II – *Brazeable Alloys – Constituent Limitations*

Copper	Not more than:	0.5 per cent
Magnesium	Not more than:	2.0 per cent
Manganese	Not more than:	3.0 per cent
Silicon	Not more than:	2.0 per cent
Zinc	Not more than:	6.0 per cent

Numbers 7 to 10 are heat-treatable alloys and in the case of these the tensile properties are given both as annealed and after solution and ageing heat treatment ('W.P.' condition). No. 11 is a heat-treatable casting alloy and Nos. 12 to 14 are clad alloys.

As new alloys are being developed (Fig. 7) and many of the European and American alloys do not conform to British Standards, the list of Table II indicates approximate compositional limits if the relevant aluminium alloy is to be flux-bath brazed. These limits have been arrived at in an empirical manner and are entirely based on experience. To give one example, NS 4 has magnesium content ranging from 1.7 to 2.8 per cent. Experience has shown that if the magnesium content is 2 per cent, or less, a satisfactory braze is consistently produced. However, if the magnesium is in excess of 2 per cent, porous joints may result and often the brazing alloy does not wet the parent metal. Recent attempts to braze the high magnesium content alloys have generally been impeded by the tenacious magnesia film which forms on the parent metal.

In certain cases (Fig. 8) it has been possible to braze aluminium alloys with greater percentages of constituents shown, although the strength of such joints may be weak or the structure of the alloy which is being brazed is affected – this can be particularly serious in the vicinity of the joint in the base of heat-treatable alloys.

⁴Haynes, K.R. and Perry, E.R. 'Design for Precision Brazing'. *Metalworking Production*, May 1963, pp. 51-54.

⁵BS.1723 : 1963. 'Specification for Brazing'.

Fig. 6 (above).—(a) Transverse corrugation structure suitable for pressure container and heat exchanger combined; (b) cylindrical structure

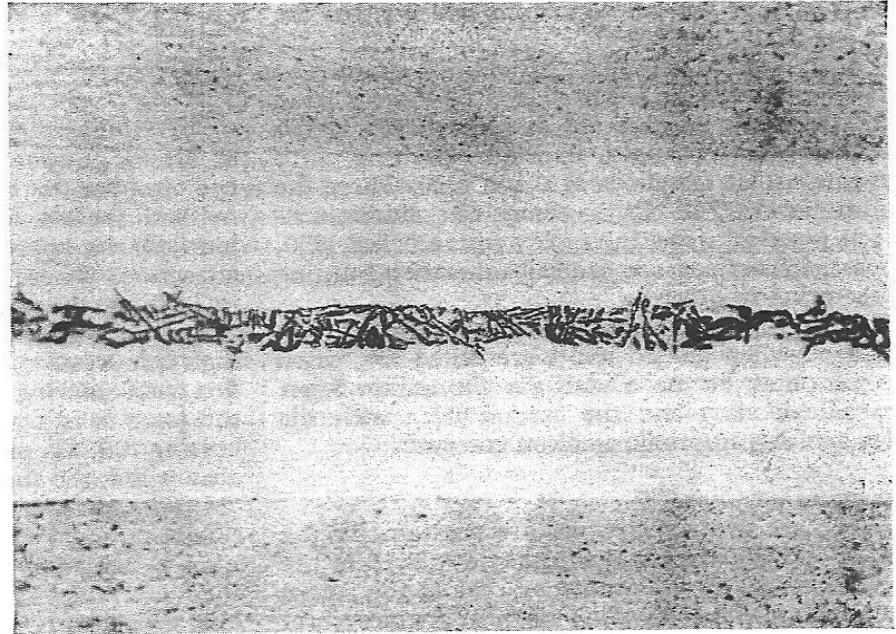


Fig. 7 (right).—S.A.P. alloy clad with pure aluminium and brazed with aluminium-silicon eutectic alloy. The brazing alloy failed to wet the S.A.P. and precoating with aluminium proved essential
(Courtesy, Swiss Aluminium Ltd.)

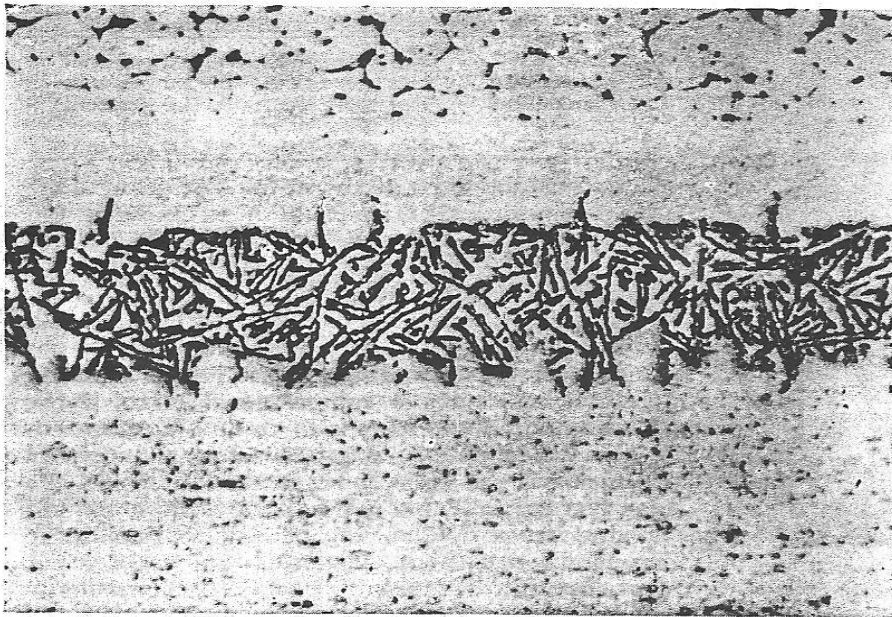


Fig. 8 (left).—Experimental cast aluminium-3.3 per cent manganese alloy brazed with the aluminium-silicon eutectic. The brazed joint has adequate strength but evidence of liquation is noted in areas near the joint
(Courtesy, High Duty Alloys Ltd.)

Fig. 9 (below).—Aluminium-silicon equilibrium diagram

Filler Alloys

The majority of brazing alloys are based on the aluminium-silicon system (Fig.9), where it is seen that a reduction in silicon content from 1.17 per cent is accompanied by an increase in the liquidus temperature. The properties of these alloys (Table III) are not markedly dissimilar from the alloys to be joined, and, for example, in the cast form Alloy 2 has a tensile strength of 10.5 tons per sq. in. (min.) and elongation of 5 per cent (min.). Alloys 2 to 4

have high resistance to corrosion but 1, because of its copper content, is less resistant. When heat-treatable alloys are to be joined, large overlapping must be allowed to ensure that after heat treatment the joint strength will not be less than the parent metal.

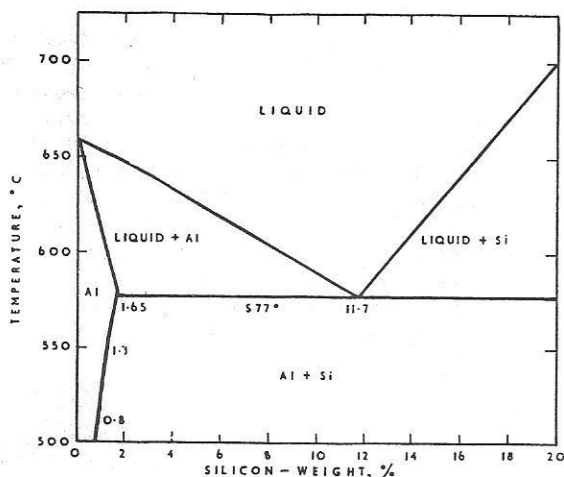
The first three alloys, mainly on the grounds of temperature latitude, are preferred by the company with which the authors are associated. While the

other alloy may be used, its higher melting point prevents its use for alloys H20 and H30, where the solidus is 580° C. Even using the aluminium-silicon eutectic as the filler alloy for H20 and H30, times of immersion are critical, otherwise burning or blistering may arise.

The higher-melting-point brazing alloy may be employed when graded joints are called for, when one joint may be made with the aluminium-5 per cent silicon alloy and the second joint with the lower melting aluminium-silicon eutectic.

Clearances

There are two ways of making the joint in the flux bath. In one method the alloy is placed in the joint by means of foil (shim) or clad sheet. In the other method the brazing alloy is in the form of wire or powder applied by camel-haired brush or eye dropper to the mouth of the joint; in this method molten brazing alloy is drawn into the joint, at the appropriate temperature, by capillary attraction. Where alloy is placed in the joint prior to brazing, the parts may have clearances ranging from zero to 0.006 in. The alloy should not be under high compression, as this could prevent the molten flux from entering the joint. Where foil is inserted in the joint it is advisable to use a slight excess of brazing foil. On melting this will feed the joint and ensure that the supply of filler alloy is adequate.



In the case of joints using wire or powder, a clearance must be selected which will allow the alloy to bridge and flow through the joint. Experience has shown that whereas the minimum of clearances can be tolerated in the case of clad alloys

and shim, if alloy is placed at the mouth of the joint, clearances should range from 0.002 in. to 0.006 in. If they are lower than 0.002 in., due to alloying with the parent metal and consequent increase in melting temperature, the alloy will not run completely through the joint unless this is very short. On the other hand, if the gap is greater than 0.006 in. it is possible that either there may be insufficient alloy to fill the joint, or due to gravitational effects, it will not be retained where it is wanted and may thus be porous.

There are many forms of joint used in flux-bath brazing, but they can usually be simplified into the three types shown in Table IV. Even here, though, the third is a modified form of the second type.

Assembly

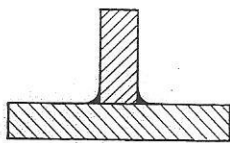

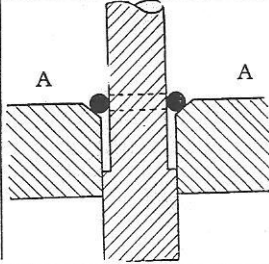
The care given to jigging is of extreme importance and the following precautions must be kept in mind when preparing a design which involves flux-bath brazing:

1. Wherever possible assemblies should be designed so that jigs are not required for holding piece-parts tightly in position. This can be achieved by making all the parts self-locating as in Fig. 10. The reason for this requirement is that external jigs frequently cause distortion of the aluminium assembly, since on heating this expands at roughly twice the rate of the jigging material – stainless steel or Inconel 600. Keeping jigging to a minimum additionally may have economic advantages.
2. When any form of screw or bolt jigging is used, the material should be Inconel or an 18/8 stainless steel, as it has been found for example that mild steels and free-cutting stainless steels quickly erode due to the combined effects of prolonged times, temperatures and nitric acid concentrations used for cleaning the parts after brazing. They also leave undesirable iron deposits in the bath. Where screws are used for joining the components these may be of a brazable aluminium alloy and left in position after brazing. If stainless-steel screws are used, these should subsequently be removed as galvanic corrosion could arise in the vicinity of these in certain atmospheric conditions.

TABLE III—Aluminium Filler Brazing Alloys

Type BS.1942	Alloy BS.1475	Nominal composition	Melting range (° C.)	Brazing range (° C.)
1	—	Aluminium 2.0/5.0 per cent Copper 10.0/13.0 per cent Silicon	550–570	580–640
2	N G 2	Aluminium 10.0/13.0 per cent Silicon	565–575	585–640
3	—	Aluminium 7.0/8.0 per cent Silicon	565–600	600–615
4	N G 21	Aluminium 4.5/6.5 per cent Silicon	565–625	620–640

TABLE IV—Joint Clearance

Type of joint	Illustration	Requirement	Clearance 1/1000 in.	Remarks
Butt		Low strength	0 to 5	Joints may not be completely filled in all areas. Thickness of vertical section should not exceed 0.400 in.
Butt		High strength	1.5 to 2.5	Thickness of vertical section should not exceed 0.25 in. or use shim in joint.
Butt		Vacuum	0 to 3	Not generally recommended.
Lap		Low strength	0 to 5	Overlap up to 1 in.
Lap		High strength	1.5 to 2.5	Overlap not to exceed 0.25 in. or use shim in joint.
Lap		Vacuum	2 to 4	Overlap not in excess of 0.400 in. or use shim.
Spigot		Low strength	0 to 15	Chamfer "A" to assist feeding joint. Important to have joint upright when dipping in flux if greatest clearance is used, as alloy may run away from joint. Difficult to maintain post in the centre unless a stepped post is used.
Spigot		High	1.5 to 2.5	"A" should not exceed 0.250 in.
Spigot		Vacuum	0 to 5	"A" should not exceed 0.400 in.

However, some difficulty may be experienced in the removal of screws as flux runs into threads 'cementing' them into position. The assembly should be left in boiling water which should soften the flux but if it still persists, penetrating oil will finally clear the threads of flux.

3. As the complete assembly has to be dipped into a molten bath, any blind holes will fill with flux and may take considerable time to

clean after the salt has solidified on removal from the bath.

4. All potential air pockets should be vented otherwise flux will be prevented from entering and therefore, inhibiting, the brazing alloy from wetting surfaces in such regions.
5. An undercut on a shaft or behind a screw head may prevent capillary flow of brazing alloy because of a locally high clearance.

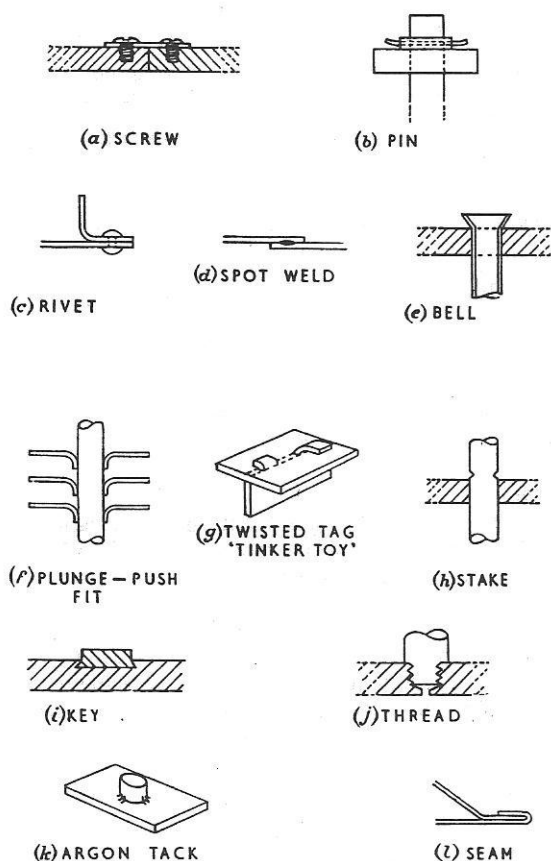


Fig. 10.—Jigging—methods of self location

6. There must not be any cavities inside the assembly. Such cavities could be hermetically sealed by the brazing alloy on solidification. If the part is reheated, as in solution heat treatment after brazing, it may blister, due to local high pressure in the area of the cavity, particularly if this has a thin-walled section.
7. In the case of Fig. 10(K) the argon tacks should be kept as small as possible, or excess welding material removed. If this action is not taken the tacks may keep the brazing wire away from the mouth of the joint, with the possible result that when it melts it will be too far away to flow into the joint.

Special Features of Joint Design

If the heat-treatable parent alloys are to be used, it must be realized that the brazing alloy itself is not heat-treatable. Therefore if optimum strength is required it is necessary to use lap joints where the overlap is three to four times the thickness of the

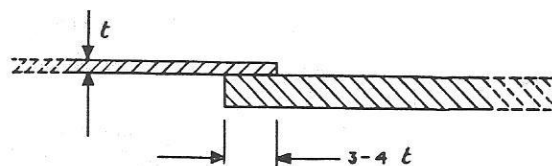


Fig. 11.—Lap joints for high strength

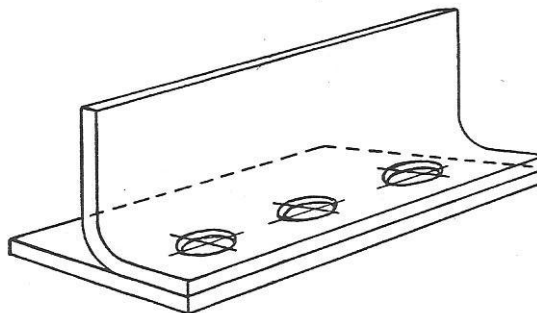
thinner member. Fig. 11 illustrates the overlap regarded as desirable. Such an overlap will give a joint which is stronger than the parent metal even after heat treatment. In the case of materials over 0.125 in. thick, this rule no longer applies as feeding problems will arise, as a result of the excessive distance between mouth and root of joint.

In these cases it is preferable to go to foil or clad sheet, using up to a 1 in. overlap with the thicker materials. The inclusion of flux which is more likely to be found in large overlaps can be reduced by having a row of small holes in one sheet along the centre-line of the joint to assist flux to leave the area (Fig. 12).

The solution heat treatment of HS30 alloy requires the assembly to be quenched in cold water from 530°C. This causes considerable distortion in most assemblies.

The amount of distortion arising on quenching depends on each type of assembly and will only be discovered by quenching trials with the part itself. It is, however, most pronounced when markedly different sections are joined together. Distortion can be offset to some degree by sizing subsequently, depending on the complexity of the assembly. If sizing is carried out it must follow solution heat treatment as quickly as possible and in any case within four hours to avoid cracking. Precipitation treatment takes place after the sizing operation for the purpose of developing optimum properties.

Fig. 12.—Flux entrapment prevented by venting



Units of simple shape can be quenched direct from the flux bath, thus dispensing with a further heating cycle to obtain the solution-treated condition.

Where very accurate machined parts are required, it is, however, more practical to leave excess material on the assembly and carry out final machining after brazing and heat treatment; this is of course, not always possible.

The hardness of HS20 and HS30 after heat treatment should be in the range 90 to 110 V.P.N. Occasions have been found when it is lower and this can inevitably be related to the rate of cooling. If the hardness is found to be low the cooling rate was insufficiently rapid and a further heat treatment, followed by water quenching is necessary. Usually this problem arises when large sections are brazed.

The designer should appreciate that the flux-bath brazing process allows the production of components to very close tolerances only if the material is in the correct condition for brazing. In this connexion material which is subjected to high temperatures as in brazing, will distort if there is any residual stress left in the component due to cold working, etc. In many cases, stress relieving before brazing is unnecessary, but in some assemblies, notably complex waveguides, internal stress may cause considerable embarrassment unless precautions are taken.

Care is needed when designing parts which are to be subjected to fatigue stresses during service. In one simple waveguide where a large end plate was rigidly retained and the opposite end was subjected to vibration in service, the waveguide fractured through parent metal and there was no sign of rupture at the brazed joint. Generally a brazed joint which is uniform distributes stresses evenly and there are no stress concentrations due to the fillet where flange and waveguide are joined together.

TABLE V – *Effects of Surface Condition on Brazeability*

Method of cleaning	Contacts angle (deg.)
Untreated.....	22
Trichloroethylene.....	13
Trichloroethylene + Nitric Acid.....	9
Nitric Acid.....	10
Propyl Alcohol.....	22
Propyl Alcohol + Nitric Acid.....	10

The Process

Once the part has been designed and the piece-parts produced, the assembly is ready for processing. This is, therefore, regarded as an appropriate time to consider details of the process and to highlight features calling for special attention.

Cleaning

For joints to have optimum properties, the cleanliness of piece-parts prior to brazing is of the utmost importance, and is emphasized by the following tests which were carried out to ascertain the effect of surface contamination on the efficiency of flux-bath-brazed aluminium components.

Test panels, 3 in. square by 0.048 in. thick NS3 alloy were vapor degreased and exposed to the normal factory atmosphere for three days. The panels were divided into sets of three and the various sets were subjected to different procedures, as follows:

- Set 1. Control test – no further cleaning was carried out.
- Set 2. Vapor degreased with trichloroethylene.
- Set 3. Vapor degreased followed by treatment in 5% nitric acid at 60°C.
- Set 4. 5% of nitric acid pickled at 60°C.
- Set 5. Degreased in propyl alcohol.
- Set 6. Propyl alcohol degreased followed by 5% nitric acid pickled at 60°C.

Quantities of brazing alloy were carefully weighed and applied to the panels which were then flux-bath brazed according to a prescribed procedure. Brazing alloy was applied to each panel in two forms – wire and paste, however, no difference was noted which could be related to the type of application. After brazing, the panels were examined, followed by metallographic sectioning and evaluation of the contact angle using the technique described by British Non Ferrous Metals Research Association workers⁶. Table V lists the methods of cleaning and the contact angle which resulted after passing the individual tests through the brazing cycle. Results confirmed that it is important to braze the assembly as soon as possible after cleaning.

⁶ Cibula, A. 'The Soundness of High-Temperature Brazed Joints in Heat-Resisting Alloys. The Influence of Composition and Brazing Conditions on the Spread of Molten Brazing Alloys'. *Brit. Welding Journal*, 58, May, 5(s), pp. 185-201.

It was shown that if cleaning is ignored, leaving the parts contaminated with a thin film of oil, grease and dirt from the atmosphere, then the molten brazing alloy is less satisfactory in wetting the parent metal, i.e. it will 'ball up' or run away from the joint. As a result of these experiments, the following method was adopted:

Brazing Procedure

- (i) All piece-parts are chemically cleaned. Cleaning is carried out in two stages, in the first, parts are cleaned in a trichloroethylene vapour degreaser for 15 minutes; they are then immersed in 5 per cent nitric acid solution for 10 minutes at 60°C.
- (ii) Parts and brazing alloy are assembled in a clean area and by operators wearing Terylene or cotton gloves.

Stop-off materials such as magnesia, graphite or anodizing, can be used when it is necessary to keep regions of the parent metal free from exposure to brazing alloy. For example, waveguide designers often require a slot in the vicinity of joints and where these exist, there is a tendency for brazing alloy to enter due to normal capillary attraction. If for any reason the joint has to be rebrazed, it is necessary to apply a further coat of 'stop-off' material to the slot as the post-brazing cleaning operation will have removed the material applied initially.

- (iii) The assembly is placed on a brazing jig which, bearing in mind the advisability of keeping parts self-jigging, should be of a support type rather than using a conventional jig to retain parts in position.

TABLE VI—*Causes of Defects*

Cause	DEFECTS						
	Alloy flows away from joint	Weak joints, leaks	Parent metal melts	Porosity, flux inclusions	Joint opens up	Distortion	Staining
Design		X		X		X	
Precleaning	X	X		X			X
Positioning of filler	X	X		X	X	X	
Clearance	X	X		X			
Jigs					X	X	X
Flux	X	X	X	X			X
Parent material	X		X			X	
Filler material	X	X	X	X			
Temperature		X	X	X		X	
Time		X	X	X		X	
Quench		X			X	X	
Post cleaning							X

- (iv) The jigged assembly is heated for a pre-determined time in a forced air circulation furnace until a uniform temperature is achieved which is within 40°C. of the brazing temperature, obviating distortion when the assembly is transferred to the flux bath.
- (v) The component is transferred from the heat furnace and carefully dipped in the flux bath, immersion times being critical, particularly with the more highly-alloyed materials. The temperature of the bath must be below the solidus of the parent alloy but above the liquidus of the filler alloy, and depending on filler alloy and parent material combinations, will be controlled between 580°C. and 630°C.

- (vi) After cooling in still air the residue of the flux is removed by immersion in water which is between 80°C. and 100°C. and preferably agitated. The duration of immersion is governed by the time taken for removal of all visible signs of flux residues. At the conclusion of this operation the brazed assembly is removed from the jig.
- (vii) The assembly is placed in a 5 per cent nitric acid solution to remove the last traces of flux and to eliminate water staining from the preceding treatment. The concentration of nitric acid and times and temperatures of immersion are all critical features, as certain of the alloys will dissolve if any of these conditions are excessive.

- (viii) The assembly is rinsed in running water and oven dried.
- (ix) Chemical checking. This is necessary in the case of complex structures to ensure that all traces of the flux are removed. Complete removal of the flux must be assured as residues are highly corrosive. The technique used is to immerse the component in a 0.01 per cent nitric acid solution. An aliquot portion is titrated against silver nitrate solution and if any halide (chloride) is reported at all, the assembly is re-cleaned, followed by a second chemical check. As a small amount of halide is present in distilled water, it is necessary to run a blank to check that interference does not result from water sources.
It is also proved necessary to check chemically the flux bath itself periodically, to ensure that the concentration of copper and iron is kept at a minimum, as these elements may have a harmful effect on the corrosion resistance of aluminium alloys which are being brazed.
- (x) The last process to be carried out on an assembly which has been brazed is that of inspection. With complex assemblies it is difficult to examine every joint as these may be hidden inside the unit; even with an introscope, visual examination of a joint does not necessarily show that this is sound. Whereas a continuous fillet may be evident, it is also possible that there are large voids inside the joint which are due to faulty design, faulty assembly or inadequate cleaning, and the only type of visual examination that may be regarded as reliable is that which shows a fillet at both sides of a joint, when the filler material was applied to one side only.

In the case of fillets showing signs of porosity, this can often be related to the time of dip in the flux bath. If too short, flux is trapped in the brazing alloy on solidification. Porosity of this nature can be overcome by re-dipping the unit for a longer period.

If joints brazed by placing alloy at the mouth fail to show a 'witness' of alloy throughout the joint, this may be due to: (1) insufficient brazing alloy; (2) excessive joint clearances; (3) joints too long for capillary flow to be effective, usually associated with small clearances; (4) dipping time in the flux bath too short; (5) inadequately cleaned surfaces inside the joint. A guide to defects and their causes is given in Table VI.

With some assemblies, the quality of the braze can be established by carrying out a pressure test, as in the case with heat-exchanger and pressurized boxes. This may be an air underwater test, or resort may be made to a spectrometer when high vacuum soundness is a mandatory requirement.

In the case of simple type joints, radiography can often be employed, but this technique becomes difficult with complex joints.

In general, dye penetrants are not favoured for it has been found on occasions that cracks in the braze tend to retain the dye and this is difficult to remove; hence re-dipping for repair of a unit showing cracks in this test will not result in a sound joint.

Ultrasonic testing has been used on occasion, but again if complex joint configurations are present, it is often difficult to determine where sealing is unsound, and in the case of really complex assemblies, often metallographic sectioning of a complete assembly is necessary to establish the method for the particular item.

Treatment after Machining

Despite the greatest care, a flux-bath-brazed joint may have hidden small pockets which retain flux. Machining can lead to exposure of such flux pockets to the atmosphere, with consequent corrosion – usually this takes place within 24 hours of machining. This corrosion is manifest as a white cotton wool like growth in the joint area. It has therefore proved advisable to re-clean after machining, following the method outlined in

Paragraphs (vi), (vii) and (viii). If the amount of flux is small it will probably be of little consequence; however, it is a sensible precaution to ensure that it is completely removed by cleaning in this way. Flux growth is often confused with a blotchy and somewhat similar growth which can appear all over an assembly, and not be confined solely to joint areas. In the latter case, the growth is relatively harmless and results from residues in tap water. This type of growth will not arise if parts are properly dried after cleaning.

DISCUSSION

Mr. M. H. Sloboda (Johnson Matthey and Co. Ltd.) said that the scope of the paper was limited to the brazing of aluminium, and as far as he knew not many people were using salt-bath brazing for joining other metals. He thought that Mr. Perry, who had vast experience in using this process, would be best qualified to say why this process was not used more widely for brazing steel, copper and other things. Mr. Sloboda also wondered if the main reason for salt-bath brazing aluminium alloys was that it was difficult to braze these by other methods.

Mr. G. W. Eldridge (Aluminium Federation) said that the paper was of a very great use to him because he was always being asked questions about flux-bath brazing, and he was very grateful indeed to the authors for producing such a document.

Powders as Filler Metal

With regard to the reference to the use of powders as a filler metal, he asked what were the circumstances which justified what he would have thought to be a rather difficult technique.

With regard to Table I, HE19 was shown as having a 'very good' brazeability rating and HS30 as 'good'. Was there really so much difference between these two, and if so, why was it in that order and not in the reverse order? He thought this was splitting hairs and preferred to call them all 'very good' or 'good', and he did not think there was any real justification for separating the two in this way.

With regard to casting alloys, he did not know whether the authors had explained properly why things were pretty thin when it came to casting alloys for this process. It was because the casting alloys had generally lower solidus levels and so were

more likely to melt in the brazing process. They were being a bit too restrictive in putting one alloy only as suitable for the process. DTD5008 was not the easiest of alloys to make. It has some limitations in its foundry aspects, and that might make things difficult if it was the only casting alloy suitable for this process. Once upon a time quite a number of castings in another alloy were dip brazed, albeit perhaps less successfully than this, but at least moderately successful. He thought it was 23. It was normally called LM7, B.S.1490.

Before leaving DTD5008 entirely, perhaps there was an error in the description of the condition 'WP'. This alloy was normally not solution-treated but was naturally aged from the casting. Did Mr. Perry find it necessary to solution-treat after brazing prior to precipitation treatment?

Constituent Limitations

Turning to Table II, these were constituent limitations, and it was true that there must be some level of value as to where one drew a line, and he would not argue at all on the authors' remarks about magnesium content; so much so that he would prefer to say that NS4 was not suitable for brazing rather than that a special NS4 was suitable. He thought it best to say that it was not suitable and leave it at that. The one he took exception to in Table II was the manganese level, where a maximum of 3 per cent was shown. It did not normally worry them in this country but there was an alloy used on the Continent, and to some extent in this country, as a casting alloy, which contained roughly 3 ¼ to 3 ½ per cent manganese. He did not remember seeing anything on the equilibrium diagram which suggested that a higher manganese content was a bad thing, so he wondered why there was a limit here of 3 per cent which would appear to exclude this particular casting alloy which was used on the Continent and to some extent here for special applications.

On Table III, it struck him as peculiar that there was a melting range and a brazing range which did not always have the same relationships. He was particularly concerned with No.3, in which it said that the present range was 600 to 615°C. It struck him as rather tight and he could not see really that it was necessarily tight when compared with types 2 and 4, basically the same system, in which a much

wider range was accepted. He was not sure of the position of anodizing when it came to stopping-off. Did not nitric acid really affect anodizing afterwards? He was referring to what was said on page 146 under 'brazing procedure', where the passage read, "if for any reason the joint has to be re-brazed, it is necessary to apply a further coat of 'stop-off'", whereas previously it was said that the stop-off entailed mainly magnesia, graphite or anodizing. In the case of anodizing, every time this was removed there were changes in dimension. He would have thought these could be embarrassing.

Mr. Perry (in reply) thanked Mr. Sloboda and Mr. Eldridge for their comments. With regard to the question, 'Why only aluminium?', the simple answer was that it was not only aluminium. Steels had been salt-bath-brazed on many occasions. In the case of his own company, salt-bath brazing was not used. Furnace techniques are preferred and, using vacuum as an 'atmosphere' distortion during treatment was kept to a minimum and there was no need to apply flux to the work beforehand. Finally expensive and messy cleaning treatments were not necessary for flux residues removal after brazing with this type of controlled atmosphere. Why was aluminium salt-bath-brazed rather than furnace-brazed? The answer was that simple aluminium-alloy joints were regularly torch brazed and more complicated shapes in pure aluminium were furnace-brazed. The refrigerator people had been furnace-brazing tubes on to aluminium base plates for years in the United States, but for general work one did not get high quality consistently produced that would be obtained with the flux-bath technique. Further, experience has proved that it is much more difficult to produce good joints if alloys other than commercially pure aluminium are used.

Turning to Mr. Eldridge's first point, they did use powdered brazing alloy, and it was used in many places. For example, there were times when brazing alloy failed completely to fill joints on the first attempt. Such areas could have paste applied locally before re-brazing. This was one application. There were other cases, such as where one might want to put tubes in a collector plate and for some reason or other had not the clad sheet available. The powder could be mixed with water to a slurry, and applied using an eye-dropper technique. A lot of powder was used in aluminium salt-bath brazing and they

were currently working on designs where there were all four methods of applying brazing alloy, namely, clad sheet, foil, wire and powder.

Referring to Table I, HE19 versus HE30, the short answer here was that a vast number of differently shaped components in alloy had been brazed to yield extremely good results. On the other hand only a few HE19 parts had been brazed to date by his company. These gave excellent results, and it was really a question of quality of available data which resulted in these particular assessments being given. Otherwise he was inclined to agree with Mr. Eldridge that there was not a great deal in it.

Casting Alloys

With regard to casting alloys, he was rather sorry that Mr. Eldridge picked on the 3 ¼ per cent manganese alloy, because if he looked on page 142 he would find in Fig. 8 a microsection of this very alloy, and at the top of the illustration there was some evidence of liquation. For this reason it was felt that it was marginal to quote as a permissible limit 3 to 3 ¼ per cent. On the other hand, as could be seen, the joint appeared to be perfectly well made.

With regard to DTD5008 WP, the conclusion had been reached that it did not need the rapid quench after solution heat treatment that so many of the other aluminium alloys need, and in fact solution treatment is accomplished simply by air cooling. The figures given were after age hardening and by this definition it was considered that WP was the correct designation.

There were mixed feeling with regard to NS4. A lot of NS4-type alloy was being brazed in the United States, and they has also brazed a little of it themselves. This meant going to specialized cleaning techniques, and treatment in a proprietary cleanser was necessary immediately before pre-heating and brazing.

With regard to Table III, the question was asked why the brazing range was higher than the melting range. It had been shown that the brazing temperature did not necessarily coincide with the melting temperature, and that very often it was necessary to go to a super-heat temperature to obtain optimum fluidity, hence the difference between brazing and

melting temperatures. In the case of aluminium – 7 to 8 per cent silicon alloy, experience with this in the form of clad sheet showed there had no need to go outside the temperature ranges quoted. It might well be that it was possible to go to a higher temperature, but Fig. 9 suggests that there might be an excessive amount of molten filler alloy if highest temperatures are used. Thus if vertical structures were brazed at a higher temperature it would be found that there was an excessive amount of alloy at lower regions. Another complication is that due to their tendency to alloy with the parent metal pronounced erosion can take place; this is particularly dangerous in the case of thin sections.

Anodizing as a Stop-off

With regard to the question of anodizing as a stop-off agent, it had in fact been widely used in this connexion. On the few occasions when it was necessary to re-process parts they had to go to another type of stop-off, as cleaning in nitric acid removed the anodized layer and this had to be done before treatment.

Mr. B. T. Wilkes (Marston Excelsior Ltd.) said that, as Mr. Perry stated, in presenting the paper there were very few of these salt baths in Europe. The meeting might like to hear of his own company's use of salt bath, as it was rather different in scale from the one so far described. They were operating a bath of about 14ft. long and 4ft. wide and 6ft. deep, and processing something like 100 tons of aluminium a year. It was possible in this bath to braze an assembly which weighed a ton and to produce at that time something like 200,000 ft. of joint all in about quarter of an hour, so that it could be seen that this technique was capable of considerable expansion. The question might be asked, "Why such a large salt bath?", and as in the early days of salt-bath brazing, the impetus to produce baths was given by the aircraft industry, who wanted high performance but light heat exchangers, the impetus now had been given by the requirement of air-separation plants and oxygen plants which require light-alloy heat exchangers, and this was why such a large bath had been used. However, it was known that in Japan and in fact, in this country, motorcar radiators were being made by this method. There was a production line in Japan which produced automobile radiators for the normal mass-production car. In this country perhaps only the high-performance and racing cars

had gone to such exotic or comparatively exotic radiators, but there was no reason why this should not extend and in fact be part of production lines in the future.

He was rather surprised, on reading the paper, to find that on using foil as thin as 0.002 in. they got blocking of the passages, because he knew of assemblies using up to 0.006-in. thick foil in which this did not occur. It might be that using a brazing alloy with a higher liquidus would overcome the problem.

Sodium Fluoride in Flux

He was interested to know as well that the flux used contained sodium fluoride. What were the authors' comments on the difference in nature of this flux and the other fluxes which used aluminium fluoride? Was it used because of the lesser sludge formation? This was a problem with operating baths, and in a bath of the size his company operated there, was a considerable problem in removing the sludge every week.

Finally, he congratulated the authors on giving a very clear exposition of the problems of salt-bath brazing and of the present position. Any extension of this was up to the industry. There was great scope here. People must think of salt-bath brazing as something that was probably going to help them to make things which were not made before. He could only reinforce his remarks by saying that if people wanted to use this technique they must start at the design stage. This did not only apply to this but to everything they tried to do.

Mr. Perry (in reply) said that it was interesting to have Mr. Wilkes' comments on the 0.002-in. shim, and he was probably right when he said that using the higher-melting-point brazing alloy they had greater latitude in this connexion. The authors were using the eutectic composition where all the brazing alloy was molten at the same time and was perhaps more likely to fill up small passages.

The flux used by his company was a proprietary American salt marketed by Park Chemical Co., who claimed that one of the advantages it had over the aluminium fluoride-type flux was that a minimum of sludge formed. Certainly any sludge rose to the top of the bath from where it could be readily removed,

whereas in other types of bath sludge formed on the bottom where it could not be seen. There had thus in these other types to be a daily practice of cleaning out the bath to prevent excessive sludge build-up.

Mr. N. H. Jones (Joseph Lucas Ltd.) said that he would like to enter into this discussion as to the relative merits of flux brazing and salt-bath brazing as compared with other forms for other metals, but he would refrain from doing so as this was not the subject of the paper. Mr. Perry was probably a little more fortunate than most of the lecturers during this conference – although he might not fully appreciate this – in so far as for the process he was describing and for the metals he recommended for the process, there was no real alternative. Experts agreed that flux-bath brazing of aluminium, particularly with the designs he had illustrated, was certainly the right way of doing it.

On the question as to how far the process could be applied to aluminium alloys, this was of interest but was not vitally important. If comments were restricted to the use of the process for pure aluminium it would certainly serve a useful purpose in the industry, as there was no other way of joining the components that he demonstrated.

Distortion

He would, however, question the one statement he made about the relative distortions of a component with furnace brazing and flux-bath brazing. It was often said that furnace brazing resulted in distortion, but in his own experience this was not necessarily so. The fact that the component was heating up slowly and that in this instance they were dealing with a material with a very high degree of thermal conductivity did mean that there were few temperature gradients through it during the heating up process, and there was no reason why it should distort from thermal stressing. If it were suddenly exposed to shock, heating distortion was more likely. Would the authors qualify that point?

The radar unit showed on one slide as being used on Goonhilly Downs illustrated one point which has been brought out strongly enough so far: that was the question of design not only for function but to facilitate the removal of the very obnoxious fluxes which were necessarily part of this operation. Design was not only for operation or for assembly

but should also be for cleaning, washing and removal of these things afterwards. The authors' comments on the design from this aspect would be of interest.

Preparation of Parts Prior to Brazing

Mr. Dudley (in reply) dealing first of all with distortion, flux bath versus furnace, agreed with Mr. Jones that the most important feature in connexion with distortion was the preparation of the parts prior to putting them into either a furnace or a salt bath with the right amount of heating given to those parts and the necessary stress relieving which must take place on parts on which very tight tolerances were to be held. He did not want to over-stress tight tolerances because quite a number of assemblies had been shown which were of a specialized nature – aluminium secondary surface heat exchangers, which were by no means a mass-produced item, aluminium waveguide, which again had applications in the aircraft field, the missile field and fields of this sort. Here designers were looking for close tolerances and trying to hold them to as little as ± 0.001 in. on a joint assembly. Before brazing the utmost caution must be used in making sure that such parts were fully stress-relieved.

When parts were put into a salt bath or furnace, if (and as often happened) there was a great deal of differential thickness of material (he could quote instances of 2 in. thick block aluminium being brazed to tubes which had a wall thickness of no more than 0.006 in. to 0.008 in.), obviously the thin-walled tube would heat far quicker than the 2 in. thick block, so care must be taken in heating the assembly reasonably slowly to make sure that distortion was kept to a minimum, particularly when the thinner members could be held apart by a heavy member.

Coming on to flux removal, there was one further point to be emphasized: that this flux was highly corrosive and very precaution should be taken to make sure it was removed after brazing.

The authors agreed that the designer should consider cleaning difficulties after brazing and further advised (it would be found in the paper) that a chemical check should take place on parts which were of a very complex nature and could not be very readily inspected visually. Waveguides after the inclusion

of flux very quickly grew what he would loosely term “whiskers”, which would completely throw out the performance of a waveguide and would attack the aluminium. A chemical check was obviously advocated for such parts. Similarly after brazing, some parts require machining in order to get certain conditions. If a brazed joint had to be machined it was imperative that the unit should be cleaned as per the simple cleaning specification given in the paper, because although flux bath brazing would give the soundest joint, it would still yield very small pockets or inclusions of flux, which were trapped inside the joint. On machining, some of these small pockets, often the size of a pin head, would be exposed, and in certain environmental conditions corrosion would arise in that area, hence after machining a further cleaning operation was advisable.