EABS Newsletter

European Association for Brazing and Soldering

Issue 38 **Spring 2008**

A short note from the Chairman

Since circulation of the Autumn 2007 Newsletter we have:

1. Received a further set of interesting statistics from Blackfoot Hosting in regards to the 'hits' being made on the EABS Website. The details concerning the site activity provided to us by Blackfoot are given below.
2. Presented a technical training seminar in co-operation with Johnson Matthey Metal Joining. The seminar was held in Manchester on 26th February 2008, and discussed the brazing of Tungsten Carbide together with both pcd-tipped carbide, and the direct brazing of pcd. A Report on this event is to be found on Page 5 of this Newsletter
3. Details of the 8th Annual EABS-Solvay Aluminium Brazing Seminar in Hanover, Germany, scheduled for 2nd and 3rd September, have been circulated. Bookings for the event are being received at a level that point to it being 'over-subscribed. The details of the event will given in the Autumn 2008 Newsletter
4. The Autumn Technical Training Seminar in Maastricht scheduled for October 2007 had to be cancelled, and the date re-arranged for 6th to 8th May 2008. A full Report on the May event will appear in the Autumn 2008 Newsletter
5. We co-operated with Sapa Heat Transfer (Shanghai) Limited in the presentation of their first Joint International Aluminium Brazing seminar in Shanghai. Details concerning the event, and the relatively limited involvement of EABS with it, begins on page 2 of this Newsletter
6. The installation of a pdf creator on our computer has proved to be very useful. This has enabled us to ensure that a 'cut and paste' facility will no longer be available in relation to the data that we distribute on a CD to delegates at our seminars. Indeed, we have already implemented the exclusive use of pdf files on the CD's that we distributed at the Tungsten Carbide Seminar in February, and those that will be provided to the delegates at the Maastricht event in May will also be exclusively pdf files.

Website Statistics

The following Tables make interesting reading!

Period: 01.07.07 to 19.04.08

Month	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Visitors	386	374	413	453	695	339	449	462	500	305
No. of visits	520	540	494	602	534	416	524	575	611	386
Pages read	1225	1119	1051	1364	1331	993	1303	1545	1704	1091
Hits	2953	2868	2576	3534	3648	2520	3253	3738	3933	2722

Item	Review period figures	Same period last year	Change from last year	% Change
Visitors	4376	1988	+2388	+120.1
No. of visits	5202	2992	+2210	+73.9
Pages read	12726	7230	+5496	+76.0
Hits	31744	15827	+15917	+100.6

It seems clear from the above Tables that the traffic to our website in the past ten months has seen very significant growth. It is, of course, not easy to identify with any guarantee of certainty what has driven this much improved interest in our site, but in mid-October 2007, and just prior to our circulating information via our mailing lists, we posted details to the site of the Spring Training Seminar that is to be held in Maastricht, NL between 6th and 8th May. These actions have certainly brought forth a sufficient number of bookings to ensure that the event will be 'economically interesting' for us!

During early December we used the site to publicise the joint EABS-JMMJ Tungsten Carbide Brazing Seminar that was to be presented at the end of February. This was followed up in early January when Johnson Matthey Metal Joining used a combination of direct mail and e-mail contacts with potential attendees in their customer base. As mentioned later in this Newsletter, the Seminar was very popular, and well received by the delegates.

In the very recent past we have up-loaded details of the 8th Annual joint presentation of the Aluminium Brazing Seminar that Solvay Fluor and EABS present each September. Circulation of the Programme by e-mail some days later was also used to make direct contact with companies known to be interested in the brazing of aluminium. At the time of writing we already have more than 20 delegates coming from 9 countries. The number of places at the Seminar is limited, and from past experience it appears that we will again have requests for more places than the number that we have available.

Amongst the data that we can obtain from the Blackfoot Hosting statistics of the activities that relate to the visits to our site we are also able to determine the countries from which our 'visitors' come. The top 15 Countries, in descending order in the period under review, were:

1. U.S.A	**6. The Netherlands**	**11. Poland**
2. U.K	**7. France**	**12. Japan**
3. Germany	**8. India**	**13. Norway**
4. Australia	**9. Sweden**	**14. Italy**
5. Canada	**10. Singapore**	**15. Taiwan**

It is, perhaps, a pointer that the absence of such countries as the Czech Republic, Slovakia, Finland and Switzerland from the above list is an indication that their interest in brazing technology is not as far developed as some might wish to believe! However, broadly, the overall pattern of visits to the site can be seen as the evidence that supports the view that the world 'out there' thinks that EABS has something that is unique, and that we are doing things that are of interest to them!

SAPA Aluminium Brazing Seminar in Shanghai

On Friday October 12th 2007 Mr Torbjörn Sternsjö, Managing Director, Sapa Heat Transfer (Shanghai) Ltd., made the closing speech at the outstandingly successful International Aluminium Brazing Seminar that Sapa had been hosting in Jaiding, Shanghai. Consequently the day marked the culmination of some 18 months intensive planning and preparation by dozens of people in Sweden, China, The USA, Korea and the UK.

It is perhaps interesting to note that the idea of presenting a Seminar in China was being considered by Sapa Heat Transfer as far back as 2005, a time when EABS first approached Sapa, Sweden to ask if they would be interested having a 'tailored' seminar concerning the brazing of aluminium presented by EABS at their site. This approach to Sapa from EABS was triggered by the fact that by September 2005 it was seen that a total of 10 delegates from the Sapa sites in Sweden and China had already attended the joint EABS-Solvay Fluor GmbH aluminium brazing seminars over the past two years. One thing led to another, and while there was no plan to have an in-house seminar in Sweden, it was fortuitous that Sapa were already having internal discussions concerning the presentation of a seminar

The classical view of 'down-town' Shanghai at night!

close to their site in Shanghai in 2007, and that the person who would probably be organising such an event was Dr Doug Hawksworth. (Dr Hawksworth is an extremely talented brazing engineer that Philip Roberts had first met when visiting South Africa on Delphi Brazing Consultants business in late 1997). It was agreed that, even though EABS were not formally involved in any of the fine detail of the organisation of the event, our logo would appear both on the programme and at the Seminar Registration desk

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The Reception Desk for Seminar participants located in the foyer of The Blue Palace Hotel. Jiading, Shanghai

Following several exchanges of correspondence, Doug and Phil. met in the UK in October 2006 for a discussion on the format of the seminar that was proposed. This was followed up by a further exchange of correspondence between Phil. and Doug, and from this, together with discussions with his colleagues in Sweden and China, Doug formulated, and subsequently agreed, a detailed programme for the two-day event with the Sapa management team in Shanghai.

The event was scheduled to be held on 11th and 12th October at the Blue Palace Hotel, Jiading, Shanghai. This hotel is also the Conference and Activities Centre of the Shanghai Automobile Industry and so is superbly equipped for technical presentations. Sapa Heat Transfer (Shanghai) had invited a total of 46 delegates from 31 companies to attend. Naturally, the majority of the delegates came from China, but delegates from a further six countries, (Korea, India, Iran, Taiwan, Germany, and France), were also present, so making it a truly International event.

The seminar Chairman was Dr Hawksworth, supported by the following four speakers:

1. Dan Lauzon – Solvay Fluor GmbH, Korea
2. Ralph Woods – Brazing Consultant, USA
3. Torkel Stenqvist – Sapa Heat Transfer, Sweden
4. Philip Roberts – Delphi Brazing Consultants, UK

All of these gentlemen are generally recognised as Experts in the various areas of brazing technology that formed the subject matter of their individual presentations.

From the very beginning of the project it was clear that the ‘language problem’ could be a potential difficulty! Consequently it was decided that during the lectures there would be two screens in use, one to the left of the podium displaying each PowerPoint slide in the English language, the other to the right of the podium showing an identical ‘slide’, but with the text in Mandarin. This ‘dual language’ concept also extended to the Seminar folder that was given to each delegate on arrival. As a general principle each page of the folder carried two images. The upper image was in English, the lower in Mandarin. Naturally, the pages of the folder followed the slide presentation, but in order to explain some of the technical points it was found necessary to have perhaps five pages in the folder that in total linked, for example, to three consecutive PowerPoint slides.

All of the presentations were made in the English language and there was simultaneous translation into Mandarin by a team of bi-lingual translators. The system worked very well, and questions posed in Mandarin were translated into English with the responder replying in English, this being immediately translated into Mandarin!

A group picture of the Seminar Delegates and Presenters taken at the main entrance to The Blue Palace Hotel, Jiading, Shanghai

During the afternoon of the 12th October all the delegates and speakers were taken on a ten-minute coach-journey from the Conference Centre in order to visit the Production and laboratory area of the Sapa factory. This visit enabled all participants to not only appreciate the size and breadth of the Sapa Heat Transfer Limited operations in China, but also to recognise the innate expertise being displayed by the production teams working in each of the areas that were visited!

A short meeting of the team responsible for the planning and organisation of the seminar, together with the four speakers, was held shortly after the formal closure of the event in order to discuss our opinions and views of the outcome. It was unanimously agreed that the Seminar had been very successful and that it ought to be repeated at some future date.

EABS-JMMJ Tungsten Carbide Brazing Seminar

As with the Sapa Seminar mentioned above, discussions between EABS and Johnson Matthey Metal Joining concerning the possibility of our jointly presenting a seminar on brazing had been under discussion since late 2006. In the middle of 2007 the JMMJ Management decided that since 2008 was a land-mark year for them, (it marked 75 years of the involvement of the Johnson Matthey Group in the supply of Industrial Brazing Consumables) it would be very appropriate to present a technical training seminar early in the year concerned with a range of industrial products where brazing is a fundamental component in their manufacture. Perhaps the most obvious choice was a seminar that dealt with the brazing of tungsten carbide and pcd (**p**oly **c**rystalline **d**iamond); this is certainly a 'product-range area' that would not exist if brazing had never been 'discovered, (i.e no Rock-drills, no mining tools, no lathe-tools for metal working, etc).

It was decided that ease of access to the event was of paramount importance, and so the venue should be close to an airport, and one that was 'central' and that also had excellent rail and road connections. It took only a few minutes to decide that we should use a hotel close to Manchester Airport! We chose The Menzies-Pinewood, located about two miles from the Airport, the Motorway network, and the West Coast Mainline railway. It proved to be an excellent choice!

The lecture-room of the Menzies-Pinewood Hotel set-up for the EABS-JMMJ Seminar

As mentioned earlier in this Newsletter, while EABS had up-loaded full details of the event to our website it was JMMJ who undertook the task of making direct contact with the potential attendees. It had been decided previously that the maximum number of delegates that we could accommodate was 40, and this total was reached three weeks before the event was due to take place. Unfortunately, therefore, we had to disappoint five 'late-comers'. The delegates came mainly from the United Kingdom, but we did have 6 delegates from The Republic of Ireland and one from Germany.

The Seminar was a great success, with a substantial amount of inter-action between the speakers and the delegates on the wide range of subjects covered by the various presentations. Drawing comparisons is always a difficult task, but there is little doubt that it was one of the 'best' seminars that EABS has ever presented. It seems probable that something similar will be arranged for 2009 once the date and venue have been agreed between EABS and JMMJ.

The EABS Technical Article

From time-to-time we have used a Case Study in this area of the Newsletter to demonstrate where Process Analysis has been used to identify the cause a brazing problem and then go on to use the data obtained during the Analysis to develop a sensible technical solution to it. This is yet another case that looked straightforward at first sight, but proved to be quite complex, with many inter-related aspects playing an important part both in the original problem and its eventual resolution.

Case Study: The brazing of aluminium tube-to-fitting joints

The 'Holy Grail' of Production Engineers who employ brazing as their joining method is to have a process that is as close as possible to having an efficiency level of 100%. Unfortunately the reality is that in almost all cases the 'efficiency level' actually achieved is typically in the range 50 – 60%! This example shows how a combination of a Process efficiency analysis coupled to a detailed Process Analysis Procedure allows an engineer to readily develop a brazing procedure that is as close as possible to the goal of 100% efficiency.

1. Process efficiency analyses

As we know, brazing is a very versatile and forgiving joining process; all that one has to do to obtain a successful result is *to follow the rules*! This Case Study explains how these rules can be used to develop a 'best practice' solution to *any* brazing problem that has to be faced: the application of which can reasonably be described as a '*Process Analysis Procedure'.* However, and before we move on to discuss the methodology of the procedure, it is worth reminding ourselves that the most remarkable feature of the brazing process is the fact that there are just six fundamental, yet simple, rules that if followed will automatically provide the user with the desired result. These are:

1. The provision of a ***clean surface*** at the joint interface ***at brazing temperature***.
2. The need to ***heat*** the components of the joint ***evenly*** to brazing temperature.
3. The *selection of* ***the 'right' alloy*** for the job in question.
4. The selection of the most appropriate method of ***removing the oxide skin*** from the surfaces of the joint.
5. The use of an ***appropriately dimensioned gap.***
6. The application of the filler material to the ***appropriate part*** of the joint.

From the above it is reasonable to assume that the ultimate 'best practice' procedure will have an efficiency rating of 100%. If this is so, then it is also reasonable to say that each of the above six 'rules' can be given a rating of '10 points', this providing a maximum possible 'target' of 60. It then becomes possible to review systematically the particular brazing process being considered and apportion 'points' that are appropriate in regard to each of the six fundamental rules; the basis of the apportionment being shown in **Table 1**

Rating (based upon 'best practice')	Satisfactory	Acceptable	Poor to bad	Unacceptable
Points available	→ **10, 9, or 8**	→ **7, 6 or 5**	→ **4, 3, or 2**	→ **1 or 0**

Table 1: A rating scheme for the determination of percentage process efficiency for a particular brazed joint.

The Background

Several years ago EABS was invited by a leading European producer of brazed automotive aluminium pipe-work to examine and report on a problem that they were facing. The problem concerned the brazing of an AA 3003 tube into an AA 6063 alloy fitting, and ten different versions of the assembly were being produced The company concerned had made hundreds of thousands of parts in the preceding three years, and had experienced a reject rate from their customer that equated to 0.0016%, i.e 16 parts in a million. When the supply contract was renewed the design of the assembly remained unchanged, but the specification had been re-written to include a few extra words. These extra words were:

………………… *and the joint must be at least 60% filled with brazing material.*

The supplier was not concerned when he saw this very minor change of specification, particularly when he knew that his previous 'rejection rate history' was a mere 16 parts in a million. However one can imagine his amazement when the reject rate soared to the astronomical level of 87%; the reason for the rejections being entirely due to the failure of 'Production' to meet the customers' requirement of a joint that was ***at least 60% filled with brazing material!.***

Clearly, something was very seriously wrong, which was why EABS were approached to study the problem and then make suggestions to improve the situation.

What did EABS find when we examined the problem?

During the initial discussions EABS had with the client it was established that both the gas-tightness of the assemblies, and their ability to pass the relatively stringent physical tests demanded by their customer, were perfectly satisfactory. With that fact in mind it was hardly surprising that the management of the client company might have felt that it was 'unreasonable' for their customer to insist that joint filling had now become an important factor of their 'Goods Inwards' inspection procedures! Essentially, therefore, it was very clear that at the heart of the problem was the fact that nobody within the company that had asked EABS for assistance really ***understood*** **why** there was a problem…..*because nothing had changed!*

Clearly, whether a 60% joint fill was unreasonable, unnecessary, or unrealistic, was not a matter for discussion: the requirement appeared in the Specification. Further, the customer of the EABS client had made it clear that in order to continue as the supplier it was essential that *all* of the requirements set out in the Specification were satisfied, and that there was ***no prospect*** of the requirement of a 60% filled joint being removed from the Specification!

Fortunately, and following a detailed study of the overall production operation, it rapidly became clear what the main causes of the problem were, and that it would be relatively easy to resolve it within a reasonable time scale. However, it was explained to the client that there were ***no 'magic bullets'*** that could be fired at the job in order to resolve it in a time-scale of 'days'.

Certainly there were some short-term steps that might be taken that would have been of some assistance in regard to re-working and reject rates, but EABS considered that these were likely to have only a very marginal impact on the solution of the main problem of the '% joint fill'. This was because cause the problem was inextricably linked to the heat-patterns that were being developed during the brazing process in use. Unless the heating patterns could be changed we considered that it would be impossible to cure the problem.

There were also some clear-cut indications that this solution would, as a minimum, require substantial changes to be made to the existing machines and ***might*** even demand a complete change of equipment. The only way to determine the facts was to undertake a detailed Process Analysis: the remainder of the text in this document describes what EABS found, and the recommendations that were made to resolve the production problem.

To summarise, we identified 7 points that needed to be examined in detail: These were:

1. **The basic design of the assemblies**

These are shown in **Fig 1.** It is important to take note of the recessed **'well'** in the fitting into which both the 2.0mm wire diameter filler material ring and the flux were deposited before heating commenced

Not to scale!

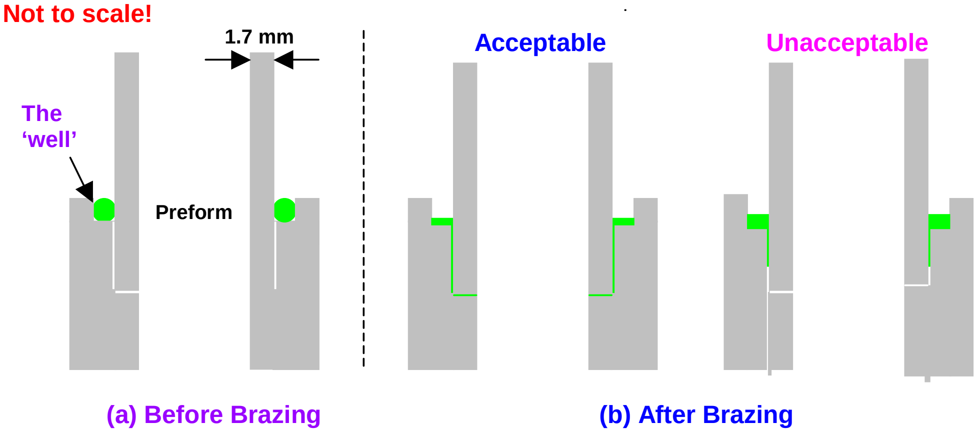


Fig 1: The basic form of the components to be brazed

2. A dispensable 'corrosive' aluminium brazing flux was being used but the ***amount of flux deposited via a manually operated gun was variable from assembly to assembly***.

3. All brazing was undertaken with AA4047 pre-formed rings made from 2.0 mm dia wire. These were located in the **'well'** as shown in **Fig 1(a)**

4. The radial joint clearance in the 'capillary portion' of the joint, (ie ***below*** the 'well') was in the range ***0.100 – 0.125mm***

5. ***The depth of penetration of the tube into the fitting varied from model to model*****,** and ranged from ***a minimum of 6.7mm to a maximum of 12.4 mm*** across the range of products (See **Table 3,** later)

6. Brazing was being undertaken on continuously rotating table machines using fixed-torch heating with Natural gas- compressed air flames, all of which being burning continuously and with ***a directionality*** that meant ***the majority of the heat was generated at the point where the tube entered the fitting***.

7. Traces of oil were found on some parts as they left the ‘cleaning area’ on their way to the brazing shop

Using the above data as the starting point of the Efficiency Analysis allows us to develop a Table that shows us the % Efficiency of the current process **(**See **Table 2)**

Rule Number	Comments on the proposed procedure	Points Score
1. Provision of a chemically clean surface	The corrosive dispensable flux being used for this job is acceptable, but not necessarily the best choice. Traces of oil were found on some parts and this can prevent wetting by a molten filler material during the brazing process	4
2. Even heating of the joint	The location of the filler material, together with the use of a continuous rotary machine, are all causes for concern in regard to the development of the heat pattern required to ensure acceptable % joint filling.	4
3. Filler metal selection	The choice of AA4047 as the filler material is good, however in view of the size of the joints to be filled the dimensions of preforms will need to be investigated further	5
4. Method of oxide removal	The corrosive flux being used for this job is acceptable, but there is an outstanding case to change from automated to manual application of flux	5
5. Size of Joint Gap	The radial gap size needs to be increased and the volume of flux deposited is insufficient to ensure that the entire joint will be wet by flux during the brazing process. This is a problem that is made worse by both the presence of the ‘well’ and the unsatisfactory heat-pattern that is currently being used. These facts explain why there is a lack full penetration of the filler material in many cases	3
6. Location point of the filler material	The current location point of the filler material is acceptable. However, as mentioned in Points 2, 3, 5 in this Table, there are a number of other problems that have to be considered in order to produce a product that meets the Customer Specification	4
Summary	Total number of points Efficiency of the current process	25 41.7%

Table 2: The % Efficiency Rating of the current process

Clearly, the fact that the current process is only about 42% efficient explains at least some of the reasons why a problem exists between the supplier and the end user…….no one can be content with a process that has such a poor level of efficiency! As we shall see as we proceed to move through the Stages of the Process Analysis, much can be done to improve the situation, but before we start to do this it will be helpful to spend a few moments considering the following question:

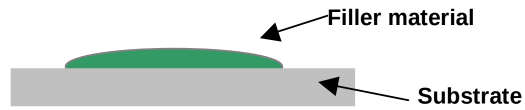
…………In brazing technology, what do mean by……*‘clean’*?

There is no universally satisfactory answer to this question, but it is generally accepted that surfaces which are free from oxide layers, extraneous dirt and, of course, oil, can be brazed satisfactorily. It is, of course, relatively easy to ensure that the surface of a component is free from dirt and oil at the beginning of a brazing cycle. However, and as we have already seen, with the exception of silver, gold and the platinum-group metals, at room temperature an oxide film covers all other metals. If wetting and flow is to occur the surface this oxide film has to be removed so that a chemically clean surface is present at brazing temperature.

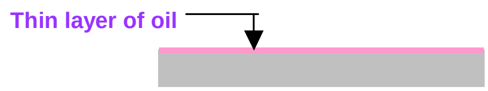
When heating is carried out *in air*, as the temperature of the parent metal increases there is an increasing tendency toward oxide formation. As a result, it is clear that some outside agency has to be used to remove the oxides in order that brazing can occur. This agency will be a fusible flux.

Washing is very often used to ensure the removal of extraneous dirt, or oil. However, if the washing process fails to remove the oil it will burn and leave a layer of carbon on the surface. Since carbon is a de-wetting agent its presence will mean that the subsequent wetting of the surface by molten brazing alloy might be *seriously impaired*, perhaps to the point of impossibility! **Fig 2.**

A. Satisfactory wetting



B. Substrate coated with a thin layer of oil



C. The result of attempting to wet a surface that has been contaminated with oil with a molten filler material.

The molten filler metal takes on a spherical shape and fails to wet the substrate

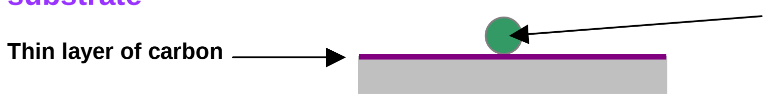


Fig 2: The effect on wetting when a surface is contaminated with oil

We will now move through the Nine Stages of a conventional Process Analysis, and note the situation that exists in each of them in regards to the job that we are discussing.

Stage 1. Service conditions and environment

As a general observation the cleanliness of the parts was reasonably good. However it was noticed that there was often some contamination by oil on the surface on some components that had been cleaned by the process in use in the factory. On looking at the washing system in close detail it was clear that there was the potential for the final rinse-tank to be contaminated with oil. In fact a thin layer was actually observed on the surface of the water in this tank during this inspection. Clearly, since the parts have to be passed 'through' the surface of the fluid in the tank, the presence of an oil-film can result in a very thin layer of it being present on the surface of the parts when they are removed from the final rinse-tank

As mentioned above, during brazing any oil that is on the surface of the components will 'burn' to produce a residue of carbon. This, in turn, will act as a de-wetting agent, making wetting and filler metal flow during the brazing process substantially more difficult to achieve.

The fact that oil was present in the final tank was worrying. It could be that the whole cleaning process is suspect, or perhaps it indicates a failure on the part of 'production control' to carry out routine cleaning of the plant!

Stage 2. Parent Materials
The parent materials are satisfactory and alternative materials do not need to be considered

Stage 3. Joint Design
Fig 1 shows that the AA6063 fitting has a machine recess at the point where the AA3003 tube enters it. This is large enough to take the filler material ring, and acts as a reservoir that can be used to contain the deposit of flux. However from the point of view of 'best practice' design

this reservoir is a device that *can* make a substantial contribution to the problem of incomplete joint filling!

As **Fig 1** shows, the 'well' is relatively large. While it is true that it is a very convenient place to locate the filler material and flux, as we shall see later there is absolutely no guarantee that first the flux, and then the filler material, will flow from the 'well' to make the joint. Indeed, as shown in **Fig 3,** we noted that a variable amount of filler material was retained within this well at the conclusion of the brazing operation, but we had no idea at all concerning the ***volume*** that was retained. For reasons that are associated with the heat pattern experienced by the assemblies during the brazing cycle it is probable that up to 30% of the available brazing filler material could be retained in this portion of the assembly. It is clear that a variable retention of filler material in the 'well' is a routine occurrence: some 13% of joints pass the customers test of 70% 'filling' while 87% do not. While this result can almost certainly be attributed mainly to the poor heat pattern that is currently being developed, it could also be partly due to there actually being insufficient alloy **and/or** flux available during the brazing process to ensure adequate filling of the capillary gap!

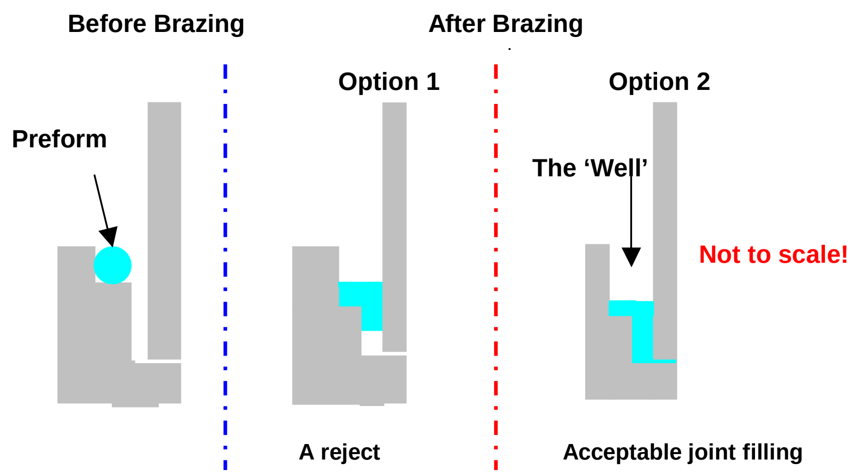


Fig 3: A schematic of the flow options that exist when a 'well' is provided for the brazing alloy preform. (Also see Fig 1)

We can now move on to examine some details of the 10 models that are being produced together with some data relating to the volume of brazing filler material and flux that is applied in each case. **(Table 3)**

Part No.	Joint overlap length mm	Volume of flux deposited mm^3	Total volume of joint'+ The 'Well' mm^3	Ideal volume of flux needed mm^3	Total volume of filler material applied mm^3	Maximum % Joint filling possible: Filler vol. / Joint vol.
TA4790 - g	10.2	109	193	**386**	**159**	**82.3**
TA4790 - k	9.5	105	170	**340**	**100**	**58.8**
TA4789 - g	12.4	112	276	**432**	**159**	**57.6**
TA4789 - k	8.6	112	153	**306**	**108**	**70.6**
TBA 594 -g	6.7	105	224	**448**	**159**	**71.0**
TBA 594 -k	9.0	105	106	**212**	**76**	**71.7**
TA4703	8.9	116	220	**440**	**177**	**80.4**
TA4709	7.7	114	214	**428**	**159**	**74.3**
TA4586	8.8	109	275	**550**	**76**	**27.6**
TA4588	6.8	105	201	**402**	**119**	**59.2**

Table 3: The relationship between joint volumes, flux and filler metal volumes applied, and the % joint filling that is therefore possible. (Note that in four cases it will *always* be impossible to produce a joint that is 60% filled)!

All measurements given in **Table 3** relate to the actual situation that existed in the workshop. The volumes of the joint and the ring were derived from the measurements of parts taken from the shop floor, while the volume of flux being used was calculated from in-house records of the ***weight*** being deposited. It is also a general rule that ***the amount of flux*** that needs to be present on a joint ***is double the volume of the joint that has to be brazed***. As can be seen in **Table 3** the ***ideal volume*** of flux is, indeed, double that of the whole joint. This means that there should be more than enough to flow into the joint during the brazing process. However, and as we shall see later, it is a lack of flux that accounts for at least some of the problems of % joint filling!.

It was known that the flux has a notional density of 1.1g/cc, and so the transposition of the weight value to a volume value was readily achieved. It is a well-established fact that dispensable fluxes have a density that changes with viscosity. It is also known that the temperature of the environment in which the flux is stored and employed has a marked effect upon its viscosity. Put simply, a dispensable flux that might be used where the ambient temperature is, say, 25º C will have a higher viscosity, and hence higher density, ***when manufactured*** than one that is to be used in an ambient temperature of 20ºC. In order to bring some semblance of realism to the situation we used a density value at the lower end of the possible range. At this level the volume calculations provide values that are the maximum that are likely to be achieved in practice anywhere within the factory. Fluxes of higher 'manufacturing viscosity' will have lower volumes when deposited. This whole matter is yet another reason why dispensable fluxes might not be appropriate for use in the case that we are considering!

From **Table 3** it is possible to draw the following conclusions**:**

1. The volume of the ring is always less than the total volume of the joint + well
2. The maximum volume of flux dispensed is always substantially less than the volume that 'theory' says is required to produce a satisfactory joint
3. Joints made in different parts that have identical tube diameters have different joint volumes. This is the result of their being no common length of overlap between the tubes and the fitting; as can be seen in Table these tend to vary from Part No. to Part No.

These three observations certainly point to the ***potential*** for the current process to produce joints that have no prospect of filling almost irrespective of what steps are taken by Production!

Joint overlap lengths.
When brazing Aluminium it is a well-established feature of joint design that for a sleeve joint, (a tube into a fitting for example), the maximum joint strength will be obtained when the overlap length, **(L),** lies in the range of 1.5 to 2.5 times to thickness of the thinnest member of that assembly, **(t)** (**Fig 4)**

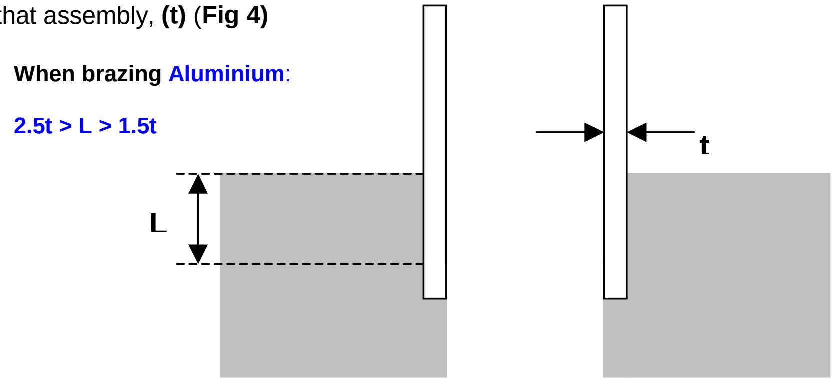


Fig 4: The determination of joint overlap length for brazing sleeve-joints

When brazing aluminium particularly when, for example, a tube is required to be vertical in its joint as shown in **Fig 1(a)**, it is not always best practice to limit the overlap length to the maximum overlap length that theory recommends! However excessive overlap lengths, say greater than about 8mm, even where the radial joint gap lies in the range 0.125 – 0.175mm, ought to be avoided. This is because the composition of the parent materials and the brazing filler alloy are very similar. As mentioned earlier in these notes, in such circumstances when brazing aluminium, there is always a tendency for the molten brazing material to dissolve relatively large amounts of the material over which it is flowing with a consequent ***increase*** in the *liquidus temperature* of the filler material. This will almost certainly result in the flow characteristics of the filler changing in an unfavourable way, ie it will tend to become more sluggish and hence result in it having difficulty in flowing throughout the joint!.

Consequently, there is always a case to examine the metallurgy of the situation to determine precisely what the effect will be. As can be imagined, it would be very annoying for the air-conditioning system in the car to breakdown during a journey simply because a joint had failed due to an insufficient flow of filler material during a brazing process!

As a result, and in the case we are considering, there is an outstanding case for compromise. We have seen that a joint overlap length of only 2.5 times the tube wall thickness will impart adequate mechanical strength to the joint. However in this particular case there is a very good reason to make the overlap length of ***all*** tube-into-fitting joints to, say, 7mm. This move, coupled to a small increase in the size of the radial joint gap, (see **Stage 4**), will greatly reduce the risk of premature 'freezing' of the molten filler material as it flows through the joint. Clearly, these steps this will lead to design and manufacturing process changes, and two other benefits arising from them would be that they will permit elimination of the 'well' *and* move the position of the ring to the inside of the joint. Such changes will:

1. Make it much easier to develop a more appropriate heat pattern than the one that currently exists.
2. Reduce the quantity of filler material needed to completely fill the joint
3. Enable easy modifications to be made to the existing continuous rotary brazing machines, so eliminating the need to replace them with new equipment.

The concept of the design changes mentioned above, and a diagrammatic representation of the heat-pattern that could be developed, is illustrated in the Section headed **'Recommendations concerning the way forward'** later in this document.

Stage 4. Joint gap dimensions

The current situation is that joint gap has a *radial clearance in the range 0.1 to 0.125mm*. These dimensions represent the *lower end* of the joint-gap size range that is recommended when aluminium-base alloys are to be brazed. The use of such a small gap might lead to premature freezing of the filler material during the brazing operation. Consequently, in order to avoid this problem, 'best practice' suggests that it would be sensible to increase the radial gap size to a range of *0.125 to 0.175mm*. This increase in the size of the radial gap, together with a reduction in the joint overlap length, will almost certainly mean that the diameter of the filler material wire used to make the pre-formed ring will have to be changed.

This is a potential 'knock-on' effect that we will need to examine further in **Stage 5!**

The coefficient of linear expansion of each of the parent materials that are being brazed are almost identical. This means that there will not be any significant changes in the size of the radial joint gap due to the effects of differential expansion between the components during the heating and cooling stages of the brazing cycle.

Stage 5. Filler metal (and flux) selection

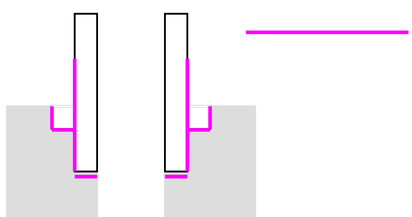
The brazing alloy selected for the process, **AA4047**, is ideally suited to the brazing operation that has to be undertaken. Whether the filler material rings being used are ideally sized is another matter, and this matter is commented upon later in this section**.** There is, however, concern in regard to the *corrosive* *dispensable* flux that is being used.

While *dispensable fluxes* have certain attractions they are really only suited for use in those situations where the heat-pattern can be developed such that the flux will flow under the combined influence of the temperature gradient and capillary force from its 'deposit' position to the point in the joint where it is required to perform its function.

It is important to understand that the function of a flux is to remove the surface oxides that are on the workpieces when they are assembled and to remove any that form during the heating cycle. In addition, they must be capable of maintaining these surfaces in an 'oxide-free' condition during the time that the brazing alloy is flowing to fill the joint.

Under ideal conditions the flux should be present on the mating surfaces of the joint ***before heating is commenced***. By arranging for this to occur it is certain that the flux will begin its work of oxide dissolution from the moment that it attains its working temperature. This ensures a more efficient fluxing action than if the molten flux has to 'move' from its deposit position and flow into and throughout the joint. Since the flux will, when molten, dissolve oxide, it follows that any advancing front of flux will become increasingly 'contaminated' with the oxides that it dissolves as it moves over the surface of the material. This inevitably results in this 'front' becoming increasingly less able to dissolve oxides, and increasingly viscous due to the presence of the oxides that it has already dissolved. Added to this is the fact that the oxide films on aluminium are both difficult to dissolve and re-form very readily. This means that if the heat pattern is other than exactly correct there is always a very **high risk** in such cases that ***incomplete fluxing of the joint faces*** will result. Since parent materials that are covered with a layer of oxides cannot be wet in the absence of flux, a poor fluxing action was almost certainly a contributory factor to the filling problem that is being experienced by the EABS client!

As mentioned earlier, the **quantity** of flux that should be applied to a component is **double** that of the volume of the gap to be filled. This provides sufficient flux to both 'clean' the capillary gap, and provide sufficient excess to ensure adequate fluxing of the area around the joint line. This 'extra' flux will also assist in the formation of an adequate fillet at the joint edges.



Areas to be fluxed *during assembly*

Fig 5: The recommended areas where flux needs to be applied

When dispensable fluxes are employed there is no prospect of the flux being present on all of the surfaces indicated in **Fig 5** when the heating cycle begins. Since it is vital that flux is present in the areas indicated it is clear that ***manual fluxing of the components*** needs to replace the current method of automatic deposition of flux by manually operated pistol-grip applicators

Finally, the matter of the composition of the flux that was being used needed to be examined for the following reasons

There are many different flux formulations that have been developed for use with aluminium. Each of these has different properties and physical characteristics. This means that it is inevitable that a product that is ideal in some applications may be less so in others. A further objective of this Process Analysis was to look at the incidence of pinholes in the fillet of alloy at the mouth of the joint after brazing. This presence of this problem required about 40% of product to be re-brazed, 99.5% of which being satisfactorily accomplished. It is clear that a considerable improvement in productivity would result if the incidence of pinholes during the initial brazing operation could be reduced.

This problem was subsequently investigated in the laboratory, and a change to an alternative 'corrosive' flux paste that was formulated to be applied manually was subsequently recommended.

The other matter that needs to be investigated is whether the preform ring that is being used is correctly sized for the joints that it is required to make.

The formula **$D = 1.27\sqrt{(L \times G)}$** enables an engineer to calculate the most appropriate wire diameter for a preform ring that will contain enough material to both completely fill the joint and have a modest excess to provide an external fillet at the mouth of the joint. In this formula:

L = joint length
G = radial joint gap
D = diameter of filler metal wire from which the ring should be made

In the cases under review it has been recommended that the overlap length for all the joints should be 'standardized' to **7mm.** Thus **'L'** in the equation has a value of **7**.

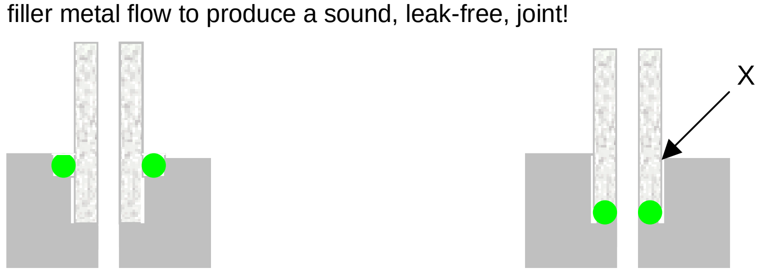
As we know from **Stage 4**, in both cases the suggested value of **G** = **0.175mm** (The *maximum gap-size possible* ***must*** be used for the formula!) The application of the formula to the situation produces the following result:

The wire diameter needed for an assembly with **a 7mm overlap** is: **1.40mm**

A wise engineer would make a small allowance for variations in the tolerance of the parts and select a standard wire diameter of 1.5mm from which to make a ring.

However, the a above calculation assumes that the 'well' has been eliminated from the design and that the total length of the capillary gap extends from the upper surface of the AA6063 fitting to the shoulder in the fitting upon which the AA3003 tube locates.

While we are discussing the matter of the filler material it is also necessary for us to consider its point of location at the joint. As a general rule, and particularly where it is necessary to know that filler metal flow throughout the joint has occurred, it is always 'good practice' to locate the filler material at the last part of the joint to attain brazing temperature. By this means it is reasonable to expect that when the filler metal melts it will be drawn by a combination of the temperature gradient and capillary attraction towards the point of application of the heat. In the case in point this means that it will be best to locate the brazing filler material ring *inside* the joint as illustrated in **Fig 6(b).** Clearly, when the components are assembled the filler material ring will be inside the joint, and so out of sight. Once the assembly has been heated to brazing temperature and allowed to cool, it is almost certain that a small concave fillet of filler material will be visible around the mouth of the joint at **'x'.** When such a fillet is seen one can at least be sure that there has been the required amount of filler metal flow to produce a sound, leak-free, joint!



(a) Initial design **(b) Suggested design**

Fig 6: The design change that will provide 'satisfactory' filler material flow

Naturally, one ***could*** argue that by careful development of the heat-pattern it would be possible to draw molten filler from the external location shown on **Fig 6(a**) *down* into the joint.

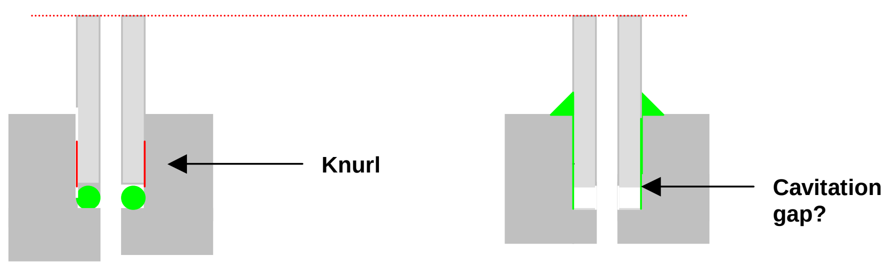
This is certainly true, but without undertaking a destructive test one can *never* be certain whether the joint penetration achieved was 1mm or some other amount up to and including 7mm. **For this reason internal location of the filler metal preform is to be preferred!**

Stage 6: Oxide skin removal

The existing flux is 'corrosive'; this means that its residues must be removed at the completion of the brazing cycle in order to ensure that they do not hydrolyze and so promote corrosion of the parent materials. Consequently, the current practice of using a post-braze cleaning operation to remove all traces of the flux residues can continue. **Thus the use of a corrosive flux is entirely satisfactory for this job**. An added advantage of the use of a 'corrosive' flux is that the active range of such fluxes typically lies in the range 500 - 660℃, so satisfying one of the criteria for flux selection, namely that the flux should become active some 50℃ below the solidus if the filler material that is to be used, and still be active at a temperature that is 50℃ above the liquidus of that filler material.

Stage 7: Fixture design

Since the AA6063 fittings have a flat base the primary requirements for the fixture is that it will hold the tube so that it is vertical. *This* ***might*** *be achieved by knurling the tube ends so that the 'high-points' of the knurl make an interference fit when they are entered into the hole in the fitting.* However, this method of fixturing will mean that the tube will be held in place by the 'high-points' of the knurl, and once the brazing operation has been completed there will be a radial cavity at the base of the tube in the block. **Fig 7**



(a) Assembled for brazing **(b) The brazed assembly**

Fig 7: The effect of the use of a knurl to fix the tube into the fitting

Such gaps are very often undesirable since they can be the sites of cavitation problems, and so a better solution will be to arrange matters so that the tubes are held in position by its presence in the hole in the fitting. When the filler material melts, and due to the combined effects of gravity and the capillary force arising due to surface tension effects, the tube will move down into the fitting so that it 'bottoms' onto the 'shoulder' at the base of the hole. This concept is illustrated in **Fig 8.** The movement that results will also have the additional advantage of assisting in the destruction of any flux-pockets present within the joint.

(a) Assembled for brazing **(b)The brazed assembly**

Fig 8: The design change that will provide 'satisfactory' filler material flow

Special attention must be paid to the fittings. It is important that the fixture is designed so that irrespective of their height the upper surface the fitting is always in a common plane. This concept is illustrated in **Fig 9.** The purpose of this fixture design feature is to ensure that the heat-pattern developed during the brazing operation will be suitable for either assembly.

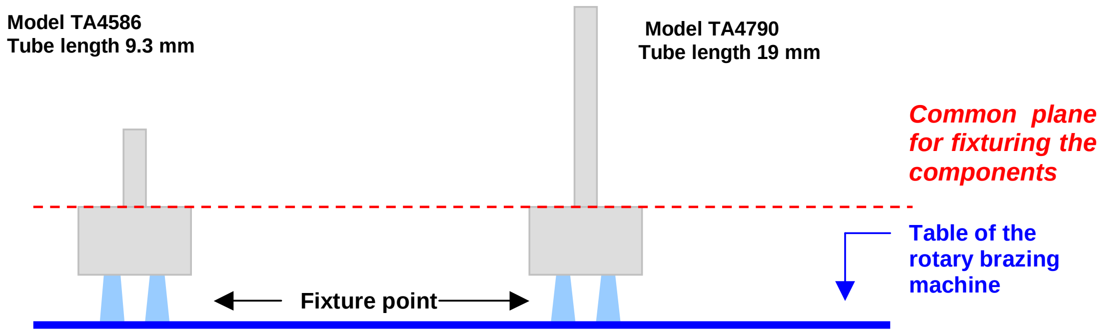


Fig 9: The fixturing concept to ensure that the joint lines of both model-types are in a common plane during brazing.

Stage 8. Heating method selection.

As mentioned earlier, the brazing machines in use at the factory were of the continuous-rotary type. Because of their design such machines can, in certain circumstances, be arranged to provide differential heating rates in various parts of an assembly. This allows the development of a controlled heat-pattern in the assembly being brazed. Unfortunately this was not being achieved in this case. The *fixed-torch* burner array *on the machines produced a directionality of the flames that meant that the* ***majority of the heat was concentrated*** *at the point where the tube* **entered** *the fitting**.*** This meant that the heat-pattern being developed was far from ideal for the components that were being brazed. Unfortunately, and again because of the design of these particular machines, there was considerable doubt in the minds of the EABS consultants concerning whether any of the equipment that was available in the factory could be 'fine-tuned' so that something near to the 'required' heat-pattern could be developed. However, if changes to the joint design and location point of the filler material in line with the recommendations given earlier in this document, coupled to some modifications to the positioning and control of the burner arrays were implemented, it ***would*** be possible to produce the required heat pattern. If the recommendations that were made were not accepted it was clear that the required heat-pattern could not be developed. In this situation there would be no possibility that the existing equipment could be used to solve the problem of 'partial filling' of the joint with brazing alloy.

The matter of heat-pattern development together with filler metal and flux flow is dealt with at length below

Heat-pattern development

When taken with the other points mentioned above, the heat pattern that is generated in the assembly is the only remaining problem that has not yet been fully addressed!

As we saw earlier in these notes, one of the fundamental rules associated with brazing is:

A molten filler material will **always** tend to flow to the hottest part of a joint, ***even if this means that it has to flow against the force of gravity.***

This concept is illustrated in the simple sketches shown in **Fig 10.**

It is vital to the success of all brazing operations that the due care and attention is paid to the development of the required heat pattern. **Experience dictates that even if the parts are clean, the joint design is correct, the joint gap ideal, the fixturing adequate, and the correct brazing alloy and flux have been selected *if the heat pattern is incorrect* it is inevitable that there will *be problems with alloy flow through the joint!.***

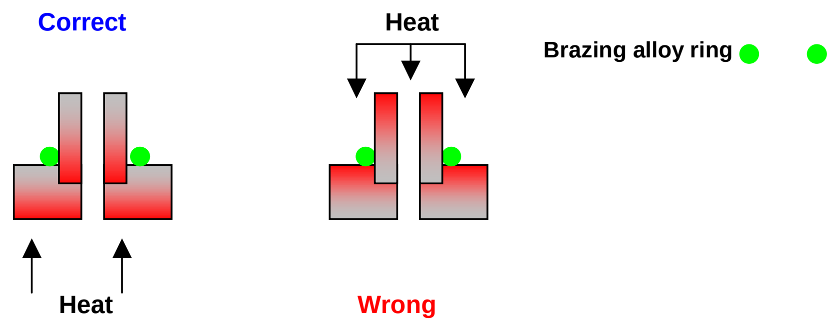


Fig 10: The two extreme possibilities that exist when brazing a tube into a fitting

The brazing that was carried out by the client was done exclusively on continuous rotary equipment. These machines are arranged such they transport the components through a band of flame, this being the heating source for the brazing process. As a general observation it is clear that the heat pattern that is developed during this procedure is broadly in line with that shown in **Fig 11**

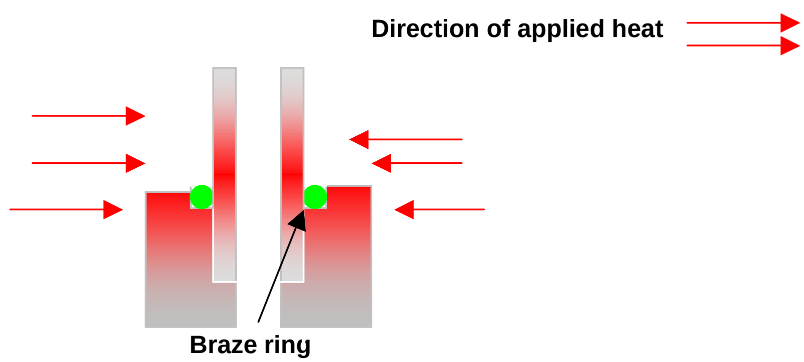


Fig 11: The heat-pattern currently developed in the parts at the Client Company.

Clearly, this heat pattern is largely similar to that shown as being **'Wrong'** in **Fig 10!**

Brazing theory says that the fundamental requirement is to arrange matters so that the when the filler material melts it will be drawn through the joint under the influence of capillary force and the temperature gradient. This means that during assembly of the item the ideal place for the filler material is at that point in the joint that is the **last part** of it to reach brazing temperature!

The heat pattern being developed in this case is the exact opposite of the theoretical requirement. Here the filler metal is placed at almost the **first part** of the joint to reach brazing temperature! Consequently, it can be ***never be guaranteed*** that the molten filler material will move from its point of application ***down*** towards to the base of the joint!. In addition, it is clear that the flux is also required to travel from its deposit position ***down*** through the joint as an essential part of the brazing operation. These two features, coupled with the requirement to fill excessively long joints, provide all the necessary ingredients for a joint that will only be partially filled!

Reference to **Table 2** earlier in this Session shows the % Process Efficiency of the current procedure. Clearly, some changes to the brazing procedure are required if the efficiency is to be moved closer to the ultimate target of 100%.

Recommendations concerning the way forward

The fact that currently some joints were adequately filled was more by luck than by attention to the requirements of 'best practice' brazing! Clearly, none of this work would have been necessary had it not been that the revised Specification issued by the client's customer called for the joints that possess a 60% degree of filling. As mentioned earlier, whether this stated requirements in regard to percentage filling is necessary is a matter that is not worth the debate: **the customer wanted a 60% joint fill!** The situation remains, therefore that since this requirement exists, and because the components are brazed, and the machines used do not produce the required heat pattern to provide the necessary flow of filler material, there is no option other than to make changes to the production process if the % filling requirement is to be satisfied. The recommended changes that are needed are as follows:

1. Redesign the joint so that the 'well' at the point of entry of the tube into the fitting is eliminated. See **Fig 6.**

2. Arrange for the joint overlap length to be 'common' for all models at **7mm**

3. Make the radial gap size for all models to be in the range **0.125 – 0.175mm**

4. Replace automatic flux deposition using pistol-grip guns with manual fluxi application to the part as indicated in **Fig 5.**

5. Change the dimensions of the pre-formed ring from 10 .2 mm **i.d** x 2.0mm dia wire to 10mm **o.d.** x 1.5mm dia wire

6. Locate the ring on the shoulder at the base of the hole in the fitting. See **Fig 8 (a)**

7. Make modifications to the control system of the brazing machine such that the burner groups on the machine are capable of being regulated individually so as to produce the heat-pattern illustrated in **Fig 12**

8. Adjust the position of the burners on the brazing machine such that the heat-pattern developed in the parts will ensure that the molten filler material and flow ***upwards*** from the bottom of the hole in the fitting. See **Fig 8 (b)**

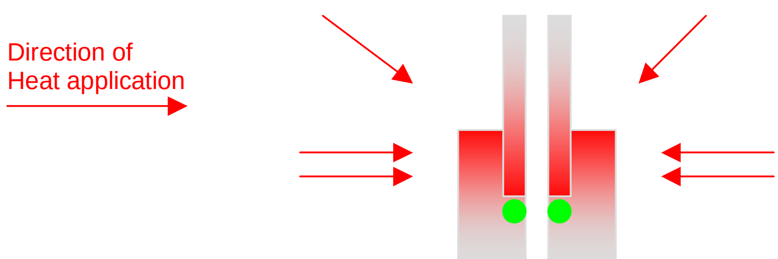


Fig 12: The heat pattern that will results in the required direction of flow of the filler material

The eight points set out above are a summary of the conclusions drawn from and evaluation of the situations that exist in each of the Stages of the Process Analysis. It is clear that if these recommendations are acted upon the overall efficiency of the brazing process being used will improve. However, in order to determine what the overall improvement will be requires that the we now cross-refer the benefits that will be accrue to the brazing process when the eight points are considered in relation to the six fundamental rules of brazing mentioned at the beginning of this Session. This assessment is detailed in **Table 4** below:

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Rule Number	Comments on the proposed procedure	Points Score
1. Provision of a chemically clean surface	The manual application of a corrosive flux paste will improve the overall effectiveness of the brazing process. However we have to take account of the fact that the manual fluxing requires the operator to pay strict attention to the job he doing. Consequently the fluxing process can ***never*** be guaranteed to be 100% effective. The pre-cleaning of the parts has to be checked on a regular basis to ensure that all components are free from processing oils ***before*** brazing commences.	7
2. Even heating of the joint	The change of location of the filler material, together with the modifications suggested for the heating system on the rotary machine, will provide a major step forward in regard to the development of the heat pattern required to ensure acceptable % joint filling. However, we are relying on the filler material moving against the force of gravity. Thus the flow ***might*** be less satisfactory than would be the case if it were gravity assisted !	7
3. Filler metal selection	The choice of AA4047 as the filler material is good. The change in the radial clearance range of the capillary joint, coupled to manual fluxing, the use of a ring known to have a volume of material that will completely fill joint, and an improved heat pattern, will lead to substantially improved % joint filling	10
4. Method of oxide removal	The manual application of corrosive flux is a major improvement to the overall process.	8
5. Size of Joint Gap	The increase in both radial gap size and the volume of flux deposited is sufficient to ensure that the entire joint will be wet by flux during the brazing process. The elimination of the 'well' and the change of location of the filler material will mean that there is every prospect of the 'now satisfactory' heat-pattern providing a properly filled joint.	8
6. Location point of the filler material	The current location point of the filler material is much improved, but the molten filler material still has to flow against the force of gravity.	8
Summary	Total number of points Efficiency of the current process	48 80.0%

Table 4: The % Efficiency Rating of the process when the eight modifications suggested are incorporated into the brazing procedure.

As can be clearly seen from **Table 4** the changes suggested in this case will move the overall efficiency of the process from 41.7% to 80% and will also deal with the problem of % joint filling. Clearly, the above example demonstrates how a combination of a properly conducted Process Efficiency Analysis linked to a detailed Process Analysis does allow an engineer who is facing a production-brazing problem to develop a much-improved procedure.

End of Spring 2008 Newsletter