TALAT Lecture 4601

Introduction to Brazing of Aluminium Alloys

24 pages, 20 figures

Basic Level

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Objectives:

− to describe the characteristics of brazing aluminium and the process involved
− to understand the use potential and the limitations of brazing aluminium

Prerequisites:

− Basic knowledge of aluminium alloys designation system, surface treatment and corrosion behaviour

4601 Introduction to Brazing of Aluminium Alloys

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4601.01 Terms, Definitions and Brazeable Alloys

Brazing is a joining method which provides a permanent bond between the parts to be joined with the help of a *brazing filler metal*. The composition of the filler alloy is such that its melting point is slightly below the melting range of the parent metal of the parts.

Brazing is distinguished from welding by the fact that the parent metal does not melt during the process. It differs from soldering by the facts that

      a) the brazing filler metal is an aluminium-base alloy and
      b) the working temperatures for soldering are appreciably lower.

By accepted general definition of DVS (Deutscher Verband für Schweißtechnik, Düsseldorf) the working temperature for brazing is above 450 °C, whereas it is below 450 °C in the case of soldering (*Note: 800 °F, resp. 426 °C, by definition of the American Welding Society).*

At the brazing temperature the molten filler metal „wets" the surfaces of the joint and is distributed by capillary action. During "wetting" the filler and parent metals will come into tight contact (about 0,4 nm) and the inter-atomic attraction will bind them together in permanent metallic bond (brazing / soldering). Due to rapid diffusion kinetics at the high brazing temperatures the metallic bond is also characterised by an interchange of atoms between filler and parent metals.

Diffusion, preferably along the grain boundaries, will result in a solid solution or precipitation of intermetallic phases which are not desirable if the mechanical strength is not to be impaired. However, due to diffusion during brazing especially designed alloys ("long-life-alloys") for heat exchanger applications, will develop a surface layer with different electrochemical potential, thereby providing better corrosion properties by cathodic protection.

The oxide surface of aluminium, although very thin, prevents the tight contact of the metals. During brazing, therefore, the oxide has to be removed and, at the same time, the bare surface has to be protected against oxidation. It has to be remembered that oxide will immediately be formed on aluminium upon exposure to air and that the oxide melting point is very high (2038 °C). Aluminium oxide is neither molten nor reduced at the melting temperatures of the aluminium alloy itself.

Generally, brazing of the various aluminium alloys is restricted by the available filler alloys which are based on the binary system Al - Si.

Alloys of type 2XXX and 7XXX are, therefore, not brazeable as their solidus/liquidus temperature are too low for the filler metals.

Alloys with higher magnesium content (> 1 - 2 %) are difficult to braze due to increased oxide layer formation which cannot effectively be removed by fluxes. Alloys with higher Mg content (5XXX series) can be brazed by vacuum techniques. **Figure4601.01.01** lists the melting range and relative brazeability of common parent alloys.

Modern techniques of brazing aluminium have been established as an important mass production method over the past decades. Some of brazing's advantages are summarised below:

- − joining of components of very small thicknesses
- − joining of aluminium alloys to dissimilar metals
- − if welding temperatures required which are not permissible
- − if small distortion of components is required
- − if large scale joint areas
- − compact components containing many junctions per unit of area
- − less personnel training required
- − meniscus surface formed by the filler metal is ideally shaped for good fatigue properties
- − finishing costs are low.

Designation EN-AW	Approximate temperature (°C)				Relative Brazeability
	solidus	liquidus	recommended brazing range		
1050A	646	657	596	615	A
3003	643	654	593	615	A
3103	640	655	593	615	A
3004	629	654	582	604	B
5005A	630	650	582	604	B-C
5052	593	649	571	593	C
5056A	575	630	-	-	D
6061	593	652	565	585	B
6063	616	652	565	585	A
6951	616	654			A
2017A	512	650	-	-	E
7075	480	640	-	-	E

A alloys readily brazed by all techniques
B alloys that can be brazed by all techniques with some extra care experience
C alloys that require special care and effort
D alloys difficult to braze
E alloys not suitable to braze

TALAT Training in Aluminium Application Technologies	Melting Range and Relative Brazeability	4601.01.01

4601.02 Preparation for Brazing

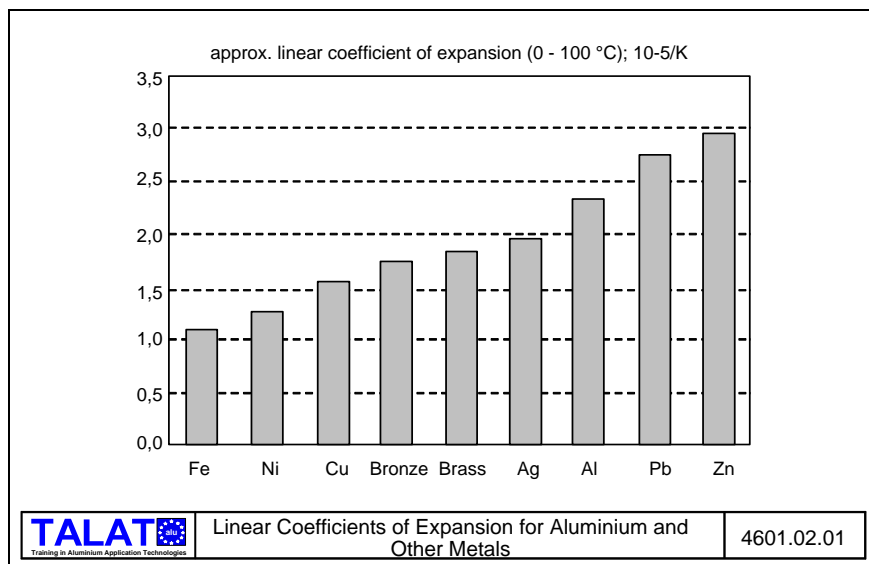- Joint and fixture design
- Pre-braze cleaning
- Oxide removal

Joint and Fixture Design

Strong and for many purposes entirely satisfactory brazed joints can be made by:

- lapping together clean, flux-covered pieces of aluminium
- placing brazing filler metal between or at the edges of the lap
- heating up to liquidus temperature of the filler metal
- cooling down to room temperature and removal of flux residues.

However, when high quality joints, tight tolerances and distortion free aluminium assemblies are required, specific design considerations are essential. Consequently the designer should bear in mind some basic aluminium brazing parameters:

1. The coefficient of expansion of aluminium is normally greater than those metals commonly used for fixtures (roughly three times greater, **Figure 4601.02.01**).
2. Aluminium softens significantly with increasing temperature and is barely self-supporting at brazing temperature.
3. Some distortion may be expected if complex assemblies have to be rapidly quenched from brazing temperatures.

approx. linear coefficient of expansion (0 - 100 °C); 10-5/K

Linear Coefficients of Expansion for Aluminium and Other Metals — 4601.02.01

Pre-Braze Cleaning

The normal oxide layer on mill-finish surfaces is generally not detrimental to satisfactory brazing. However, when high quality brazed joints are required, the importance of cleanliness cannot be overemphasised, i.e. both cleaning and oxide

removal (= thinning of the oxide layer) are necessary.

Pre-braze cleaning has two tasks:

1. removal of all grease, oil and dirt from parent and filler metal surfaces
   methods: vapour degreasing, ultrasonic degreasing, washing in hot detergents and water
2. prevention of re-contamination after cleaning
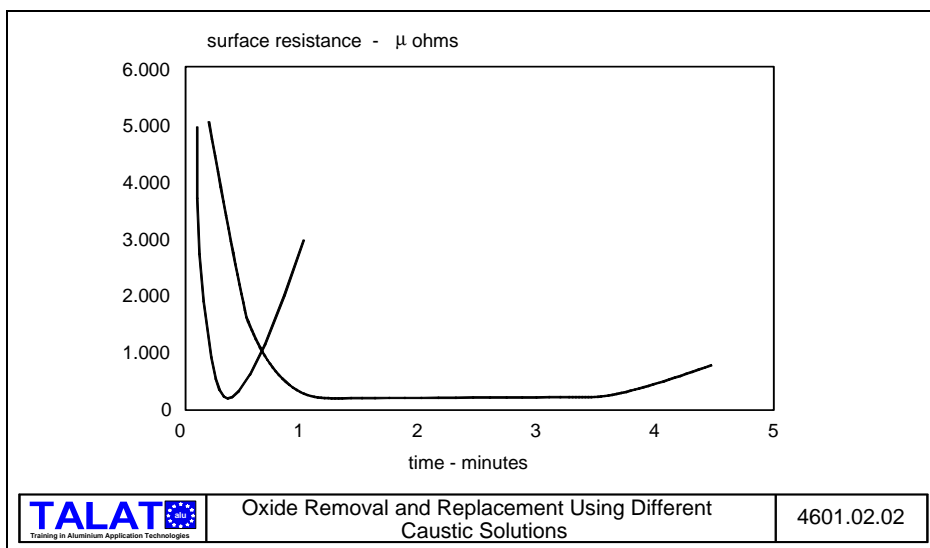   careful handling, avoid touching faying surfaces with bare hands.
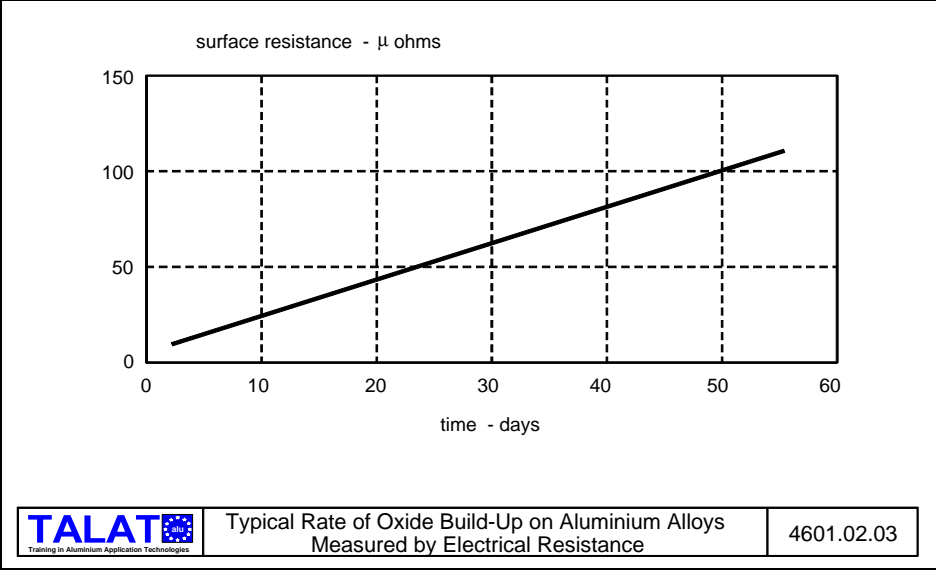
Oxide Removal

If the oxide layer is too thick it has to be removed by either mechanical or chemical means. Whether the oxide layer can be displaced by the flux or not may be determined empirically by a number of tests or the thickness of the layer may be measured electrically.

Mechanical methods are more practical for small areas or for repairs. Stainless steel wool or stainless steel brushes are preferred. Low pressure shall be applied to avoid folding the oxide into the surface of the component.

Chemicals, both caustics and acids, are used when large quantities of metals or complex components have to be cleaned.

Figure 4601.02.02 shows the actions of different caustic solutions (caustic "A" and "B"). It should be noted that caustic "B" reveals a fast oxide removal, however, quickly reverses its action and replaces the oxide. The oxide build-up after cleaning can be reduced by keeping the interim period between oxide removal and brazing as short as possible. The rate of oxide build-up as measured by surface electrical resistance is illustrated in **Figure 4601.02.03**.

| TALAT | Oxide Removal and Replacement Using Different Caustic Solutions | 4601.02.02 |

| TALAT | Typical Rate of Oxide Build-Up on Aluminium Alloys Measured by Electrical Resistance | 4601.02.03 |

4601.03 Brazing Process

- Brazing methods
  - Torch Brazing
  - Flux-dip Brazing
  - Furnace Brazing
  - Vacuum and Controlled Atmosphere
- Brazing Filler Metals
- Fluxes

Brazing Methods

Dependent on the source of heat the following methods may be distinguished:

- torch brazing
- flux-dip brazing
- furnace brazing
- vacuum and controlled atmosphere brazing

Figure 4601.03.01 illustrates schematically the different brazing methods.

Torch Brazing

Torch brazing is typically being used for repair work, small production runs and as an alternative to fusion welding. It is accomplished with the same type of torch and gases used for welding. Aluminium brazing merely requires a change in torch nozzles and goggle lenses. All commercial gases can be used to fuel the torch. The joint clearances and the pre-cleaning of the parts to be brazed have been described previously. The joint gaps are generally held between 0,1 and 0,65 mm. Aluminium at brazing temperatures is soft. As the assembly to be brazed will be subjected to the pressure of its own weight and to the pressure of the gases emerging from the torch, in particular long horizontal section must be supported, otherwise they will sag. Popular means of judging the brazing temperature are: the flux (will be transparent at brazing temperatures, the aluminium surfaces glows silvery), the brazing filler metal (softening and melting of filler's tip) or temperature indicating crayons.

Torch brazing is being applied either as an automatic or hand-held method. The processes are quite similar. In automatic torch brazing the assembly is moved automatically in relation to the torch, or vice versa.

TALAT	Brazing Methods (Schematically)	4601.03.01
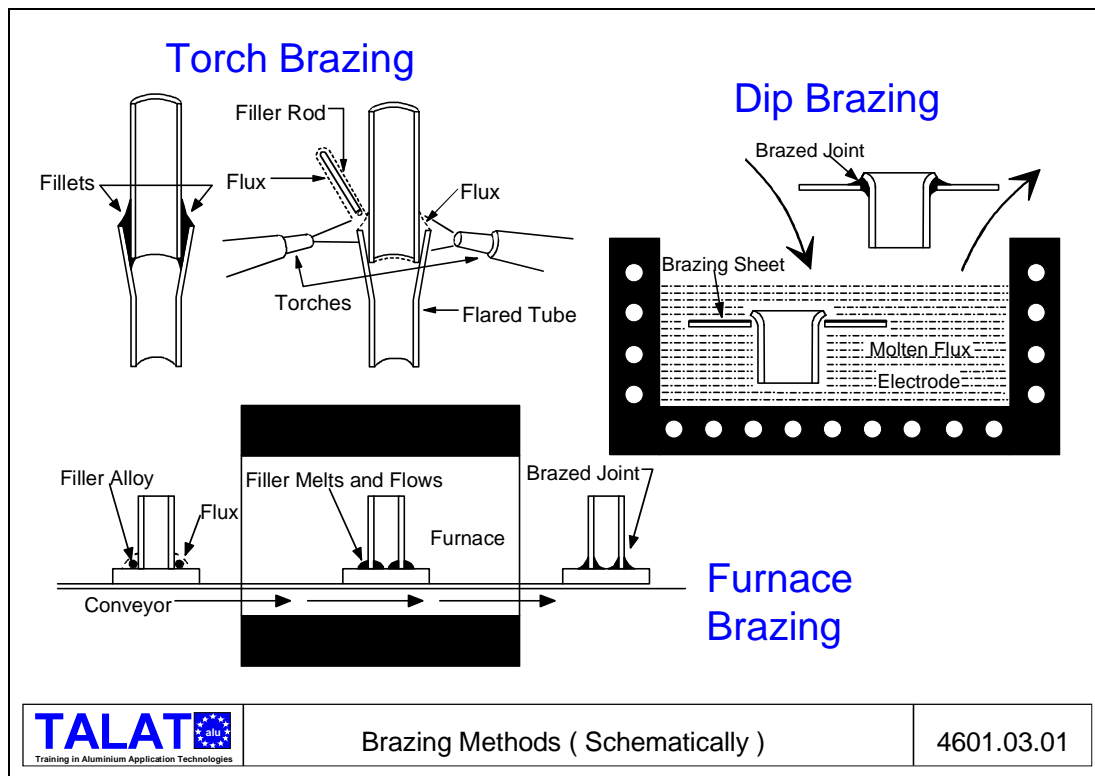
Flux-Dip Brazing

The parts to be brazed are cleaned, assembled and jigged together with the necessary filler metal. The assembly is pre-heated to approximately 540 °C, removed and immersed in molten flux (1 - 2 min.). Pre-heating avoids a temperature drop of the flux bath, or, respectively, an encrustation of flux at the surface of heavy components. In dip-brazing the temperature of the molten flux can be controlled within +/- 3 K which is better than can be routinely accomplished with other types of heating equipment. This will allow the use of filler metals with liquidus temperatures as close as 6 K to the solidus temperature of the base metal. Flux-dip brazing has a high flexibility with respect to the joining of components with significant variations of wall thicknesses and sizes or the design of the assembly. On the other hand, this methods has a relatively high consumption of brazing fluxes.

Furnace Brazing

Furnace brazing is second to dip brazing and the most popular method of brazing aluminium alloys. The parts to be brazed are cleaned as already discussed. The faying surfaces are fluxed, the filler metal positioned and the parts are assembled and jigged.

There are two types of furnaces used for brazing: the batch furnace and the continuous furnace. It is required to control the furnace temperature within +/- 3 K. The heat capacity of the furnace shall be large enough to allow fast heating rates to brazing temperatures in order to minimise silicon diffusion into the base metal. After brazing

the assembly shall be cooled or quenched if possible. If the assembly parts are considerably different in size and weight, difficulties may be encountered: slow and prolonged heating may result in liquation of the parent metal or, in significant diffusion, insufficient heating may cause lack of brazing.

6XXX alloys can be artificially or naturally aged after brazing provided that fast cooling rates can be achieved. However, the strengthening effect is less compared to usual heat treatment (as solution heat treatment by brazing thermal cycle and quenching is less effective).
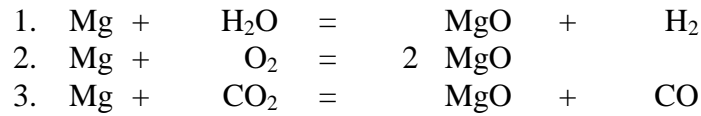

Vacuum and Controlled Atmosphere Brazing

Many of those techniques which have been developed to reduce or eliminate flux in brazing of aluminium are protected by patents. In one patented approach the furnace atmosphere is replaced by a non-oxidising gas in order to limit or remove oxygen from the surface. Optimum quality joints can be obtained with a minimum of flux. Another approach is the use of vacuum. Generally, vacuum brazing does not need any flux.

Controlled atmosphere means a dry, inert gas atmosphere. The dew point has to be kept below - 60 °C. Gases used are argon, helium, nitrogen or carbon dioxide. Parts to be brazed in controlled atmosphere have to be prepared as usual.

Vacuum brazing is attractive as it produces higher quality joints than any other known brazing technique, the process is non-polluting, the as-brazed-surface is free of any contaminants that are considered corrosive to aluminium and the processing costs are commercially attractive (no flux, post-cleaning). The preparation of the assemblies to be brazed are generally the same as discussed before. However, more emphasis has to be put on surface control and pre-cleaning (e.g. aqueous type chemical cleaning of clad vacuum brazing sheet must be avoided). In principle, the process works as follows: the thin oxide layer cracks during heating as the coefficient of thermal expansion of aluminium is three times greater than the coefficient of the oxide. Due to a vacuum of between 10^{-4} and 10^{-6} Torr the nascent aluminium surface will not oxidise again. The process is supported by magnesium containing filler metals, since magnesium vaporises and reacts with traces of oxygen ("getter effect").

The most pre-dominant reactions are:

$$1. \quad Mg + H_2O = MgO + H_2$$
$$2. \quad Mg + O_2 = 2\ MgO$$
$$3. \quad Mg + CO_2 = MgO + CO$$

Reaction (1) above is assumed to be the prevailing getter" reaction.

	vacuum	air furnace	controlled atmosphere
heating	radiation	forced convection	radiation/convection
use of flux	no	yes	yes
quantity of flux	-	30 to 50 g/m³	< 5 g/m³
washing	no	yes	no
aqueous rejections	yes (if chromating)	yes	no
atmospheric rejection	no	(yes)	no
core materials (groups)	1000 / 3000 / 6000	1000 / 3000 / 6000	1000 / 3000
brazing alloys	4004 / 4104	4045 / 4047 / 4343	4045 / 4047 / 4343
corrosion resistance[1][2]	1	3	2
sensitivity of process[2]	1	2	3
continuous process	no	yes	yes

[1] process only
[2] rating: 1 high, 2 medium, 3 low

TALAT	Comparison of the Three Main Brazing Processes for Heat Exchanger Production	4601.03.02

Training in Aluminium Application Technologies

Brazing Filler Metals

The standard commercial filler metals are based on the aluminium-silicon-system containing 7 to 14 % silicon. Increasing silicon content decreases the liquidus temperature, solidus is equivalent to the eutectic temperature. Additions of copper and zinc act to lower both solidus and liquidus temperatures still further, these elements, however, increase the corrosion susceptibility of the brazed joints. Furthermore, sometimes elements like magnesium, zinc or bismuth are added to improve the brazeability. The elements added and their concentration are dependent on the individual brazing process. **Figure 4601.03.03** and **Figure 4601.03.04** summarise the compositions and melting range of brazing filler metals.

designation		weight (%) of alloying elements							approximate temperature (°C)		
AA	AWS-ASTM	Si	Cu	Fe	Zn	Mg	Mn	Cr	solidus	liquidus	brazing range
4044	-	7.8 -9.2	max. 0.25	max. 0.8	max. 0.20	-	max. 0.10	-	577	602	593-613
4343	BAISi-2	6.8 -8.2	max. 0.25	max. 0.8	max. 0.20	max. 0.10	-	-	577	591	593-621
4045	BAISi-5	9.0 -11.0	max. 0.30	max. 0.8	max. 0.10	max. 0.05	max. 0.05	-	577	591	587-604
4145	BAISi-3	9.3 -10.7	3.3- 4.7	max. 0.8	max. 0.20	max. 0.15	max. 0.15	max. 0.15	521	585	571-604
4047	BAISi-4	11.0 -13.0	max. 0.30	max. 0.8	max. 0.20	max. 0.10	max. 0.15	-	577	582	582-694
4245	-	9.3 -10.7	3.3- 4.7	max. 0.8	9.3 -10.7	max. 0.07	max. 0.07	max. 0.07	516	560	549-571

TALAT Training in Aluminium Application Technologies | Composition and Melting Ranges of Flux Brazing Filler Alloys | 4601.03.03

designation		weight (%) of alloying elements							approximate temperature (°C)		
AA	AWS-ASTM	Si	Cu	Fe	Zn	Mg	Mn	Bi	solidus	liquidus	brazing range
4004	BAISi-7	9.0 -10.5	max. 0.25	max. 0.8	max. 0.20	1.0- 2.0	max. 0.10	-	554	569	588-604
X4104	-	9.0 -10.5	max. 0.25	max. 0.8	max. 0.20	1.0- 2.0	max. 0.10	0.02- 0.20	554	569	588-604
-	BAISi-8	11.0 -13.0	max. 0.25	max. 0.8	max. 0.20	1.0- 2.0	max. 0.10	-	559	579	582-604

TALAT Training in Aluminium Application Technologies | Composition and Melting Ranges of Vacuum Brazing Filler Alloys | 4601.03.04

Fluxes

The flux performs a number of important functions simultaneously during the brazing process:

  – displacement of the oxide layer from the surface
  – protection of the bare metal surface from contact with the air
  – lowering the surface tension of the filler metal
  – promotion of base metal wetting characteristics and filler fluidity.

Aluminium brazing fluxes contain primarily alkali and alkaline chlorides and fluorides, occasionally aluminium fluoride or cryolite. Sometimes chlorides of heavy metals are added individually or in combinations.

The purpose of the different mixtures is to provide a flux that

  (1)   melts at temperatures slightly below the filler metal,
  (2)   accomplishes the tasks listed above,
  (3)   the evolution of gas will be kept at a minimum,
  (4)   there is none or only slight attack of the parent metal,
  (5)   can be easily removed, and that
  (6)   is inexpensive.

The fluxes are often highly hygroscopic and contain fluoride which is poisoning. Flux must therefore be handled with caution at all times. Many of the fluxes are protected by patents and are specified by their trade names. Due to their composition fluxes will attack aluminium after brazing if the residues become moist. Thus the assembly has to be cleaned carefully. Chloride-free, non-corrosive fluxes are under development. Residues of these fluxes can be left on the surface of the brazed component.

4601.04　　Properties of Brazed Joints

- Mechanical properties
- Microstructure
- Corrosion

Mechanical Properties

The thermal cycle of the brazing process will change the mechanical properties of both types of alloys, non-heat-treatable and heat-treatable. The effect depends on the alloy and its original temper. Provided a fast cooling after brazing can be accomplished heat-treatable alloys can be naturally or artificially aged. Typical mechanical properties of various parent alloys in the post-brazed condition are shown in **Figure 4601.04.01**.

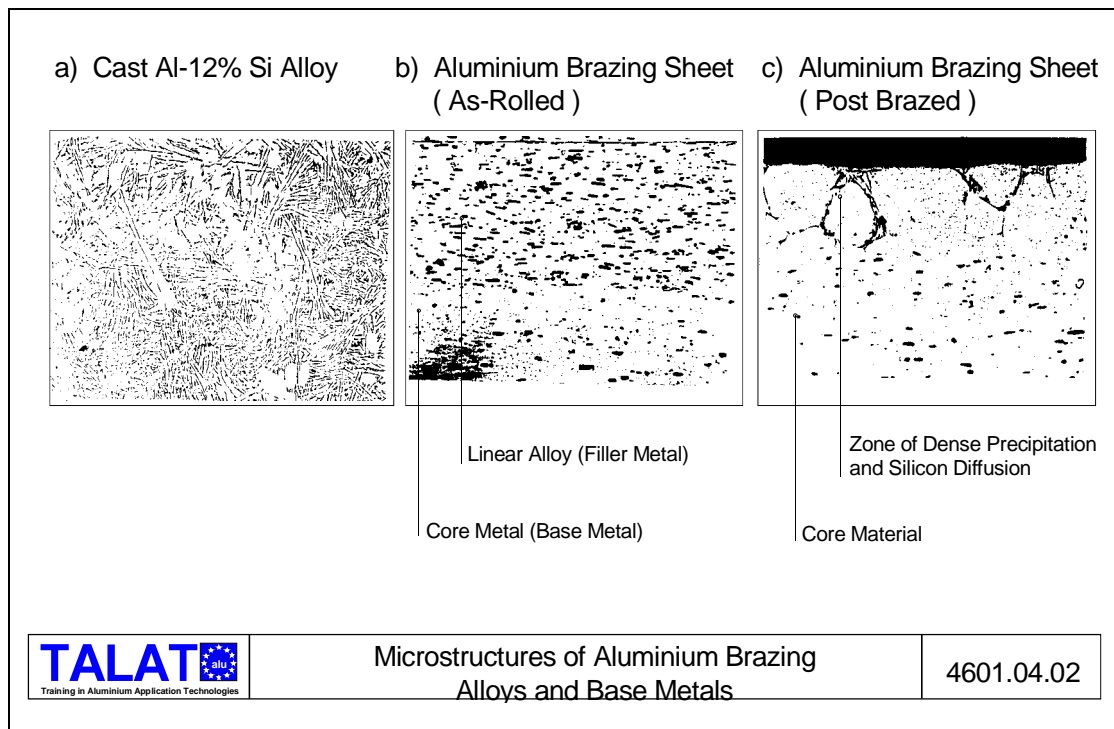| AA designation	Rp0.2 N / mm²	Rm N / mm²	A50 %	remarks
3003	35	95	28	
3103	35	95	28	
3005	50	120	14	
5005	35	105	16	
3190 [1]	55	130	18	"long life alloy"
3532 [2]	50	120	18	"long life alloy"
6063	65	130	13	naturally aged [3]
	160	200	10	artificially aged [4]
6951	65	130	13	naturally aged [3]
	160	200	10	artificially aged [4]

[1]　Hoogovens designation of modified 3005

[2]　Hoogovens designation of modified 3005

[3]　after brazing accelerated cooling rates required - naturally aged at room temperature

[4]　after brazing accelerated cooling rates required - artificially aged at 185° C for 4,5 h

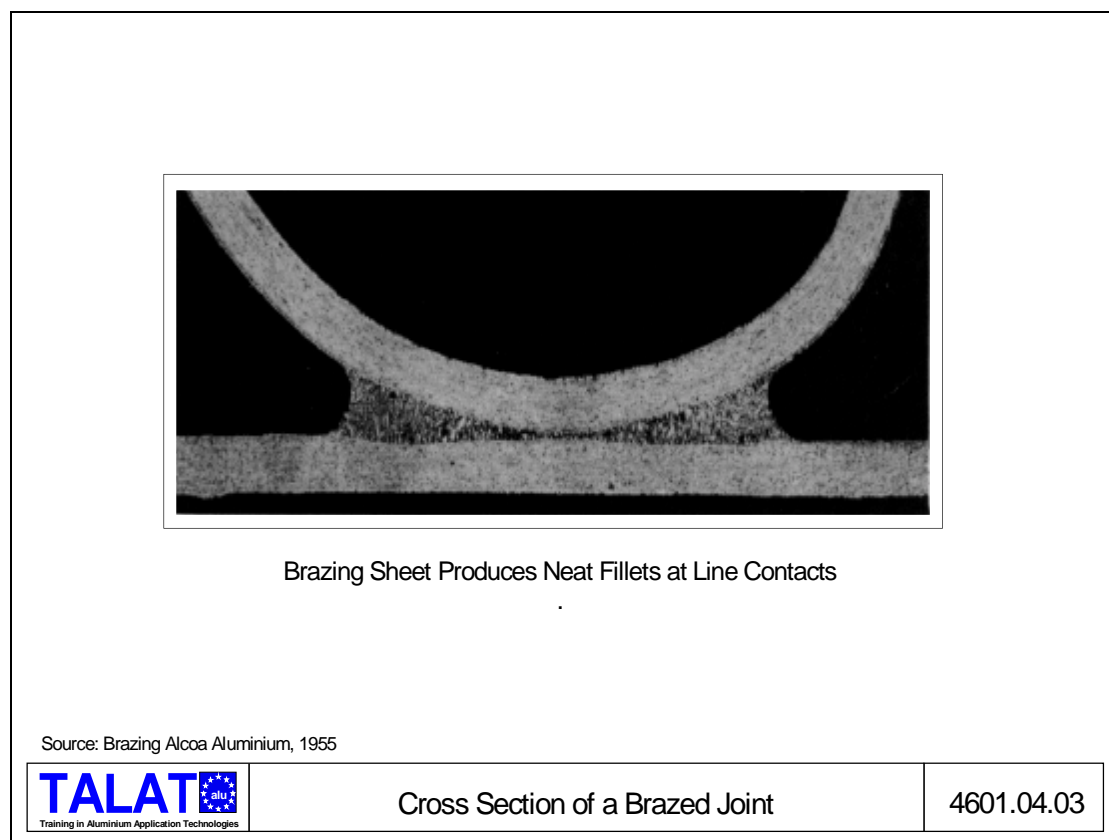| TALAT Training in Aluminium Application Technologies	Typical Mechanical Properties of Aluminium Brazing Sheets in the Post-Brazed Condition	4601.04.01

Microstructure

The changes of the mechanical properties are due to alterations of the sub-microstructure (recovery, recrystallisation, dissolution and re-precipitation of phases). Furthermore in particular the base metal in contact with the liquid filler metal will change its microstructure. This and the formation of a fillet will give some indications about the quality of the brazed joints. **Figure 4601.04.02 a** reveals the microstructure of a cast Al-12%Si alloy. Layers of such cast Al-Si alloys are rolled on to aluminium base alloys (**Figure 4601.03.03**) in order to produce aluminium brazing sheets (roll-bonding process) e.g. used to manufacture heat exchangers. **Figure 4601.04.02 b** shows the

microstructure of a aluminium brazing sheet. During the brazing process silicon diffusion from the filler metal to the base metal occurs accompanied by grain growth (**Figure 4601.04.02 c**).

a) Cast Al-12% Si Alloy b) Aluminium Brazing Sheet (As-Rolled) c) Aluminium Brazing Sheet (Post Brazed)

Linear Alloy (Filler Metal)

Zone of Dense Precipitation and Silicon Diffusion

Core Metal (Base Metal)

Core Material

| TALAT | Microstructures of Aluminium Brazing Alloys and Base Metals | 4601.04.02 |

A typical cross section of a brazed joint is shown in **Figure 4601.04.03**.

Brazing Sheet Produces Neat Fillets at Line Contacts
.

Source: Brazing Alcoa Aluminium, 1955

| TALAT | Cross Section of a Brazed Joint | 4601.04.03 |

Corrosion

The corrosion potential of the various alloys (**Figures 4601.03.03 and 4601.03.04**) differs due to their chemical composition. The corrosion potentials (mV versus S.C.E. acc. ASTM G 69) are listed in (**Figure 4601.04.04**).

Such electrochemical measurements have established the influence of alloying elements on the corrosion potential of aluminium. The results outline that additions of Cu, Ti or Mn raise the potential, whereas Ga, In, Sn, Bi, Zn or Cd lower the potential.

alloy	potential mV versus SCE
2024 [1]	-610
3532	-685
3190	-690
4343	-720
3003	-725
5005	-740
1100	-750
6063	-755
4045	-760
7072 [2]	-880

[1] for comparison only, T3 temper
[2] liner alloy for anodic protection

TALAT — Training in Aluminium Application Technologies	Corrosion Potentials	4601.04.04

Figure 4601.04.05 shows results of salt water exposure tests. The greater depth of attack of the core alloys are caused by less noble corrosion potential compared to the filler metal. However, it should be emphasised that the galvanic series can only give a clue of what <u>could</u> happen, since the microstructure and the corrosion potential will change due to diffusion processes and microstructural changes occurring during brazing. This has been utilised by designing so-called "long-life" alloys which have a less noble surface area in the post-brazed condition which provides cathodic protection. This microstructural change results in an improved resistance against corrosion compared to conventional aluminium base alloys.

core alloy	liner alloy	attack of core alloy depth, mm			attack of fillet depth, mm		
		type	maximum	average	type	maximum	average
3003	4145	P	0.25	0.06	P	0.04	0.03
5052	4145	P	0.46	0.11	P	0.11	0.04
6063	4145	P + I	0.32	0.07	P	0.03	0.02
6061	4145	P + S I	0.32	0.08	P	0.11	0.04

Furnace-brazed aluminium joints were exposed for two years to intermittent sprays of 3,5% sodium chloride.

Specimens were small inverted T-joints of 1,63 mm sheet.

Depth of attack have been determined by metallographic examanination.

SI = slight intergranular attack

I = intergranular attack

P = pitting attack

TALAT Training in Aluminium Application Technologies	Salt Water Exposure Test Results	4601.04.05

4601.05 Quality Control

- Non-destructive testing
- Assembly tests and destructive testing

Non-Destructive Testing

Visual examination is most commonly used and allows a rapid assessment of the joint quality. More sophistic conventional methods like radiography, ultrasonic inspection and dye penetrant tests may also be applied. The brazing quality of special components, e.g. brazed honeycomb structures, can be verified by thermal-transfer-tests.

Visual examination allows a fast assessment of the brazed joint quality. The inspection is preferably made before the assembly has been cleaned as cleaning may remove significant failure indications. Some typical brazing failures, their characteristic appearance and causes are listed below (**Figure 4601.05.01**).

Failure Appearance	Possible Cause
broken, uneven fillet surface	heat may not have been applied evenly, the parts may have moved in relation to one another
flumpy fillet surface	brazing temperature too low, time at temperature too short
rough fillet surface	filler metal liquated, temperature was too low and applied too long
pock-marked fillet surface (tiny circular depressions)	formation of gas due to hydrogen trapped within the filler metal, substances beneath the filler evolving/ turning to gas during brazing
joint is marked by skips	faying surfaces out of alignment, metal flow has been stopped by burrs on the edges of the joint
long skips	absence of flux or insufficient flux, surface contamination (oil, dirt, excessive oxide)
filler does not arch smoothly	insufficient heat, improper cleaning, ineffective flux
fillets are undersized	insufficient filler metal, insufficient temperature or time at temperature, vibration, lack of flux, improper cleaning, brazing sheets: low temperatures or long brazing periods tend to reduce fillet size
joint is cracked / open	quenching too fast, lack of compliance in the supporting jiig or fixture locking the parts in place, uneven heating or uneven cooling, uneven expansion / contraction due to excessive mass differences between the parts
fillets below normal height	vibration, uneven heat, dirt or lack of flux on the vertical member

TALAT alu Training in Aluminium Application Technologies	Characteristic Appearances and Causes of Typical Brazing Failures	4601.05.01

Assembly Tests and Destructive Testing

Brazed aluminium joints or completed assemblies may be tested for leaks (a porous joint may still be leak tight), proof tested (by subjecting the joint/assembly to loads depending on service loads expected) or tested for corrosion resistance.
Peeling the joint by locking one portion of the joint while the side is rolled back (peeled) is a quick and simple way of both testing the joint and to visually inspecting its interior ("peel" test). Unbonded surfaces may be dull and the visual aspects of the pores exposed

by peeling may be an indication of their causes, i.e. voids produced by flux would be filled with flux or voids caused by hydrogen would be empty. The force necessary to peel a joint cannot be taken as a direct measurement of the joint's strength. The evaluation has to be carried out on a statistical basis or by comparison with peeling forces of similar joints pre-tested by other means.

Metallographic methods are utilised to evaluate the filler metal flow, wetting characteristics, porosity, metal diffusion, changes of the microstructure (grain size), or final joint clearance.
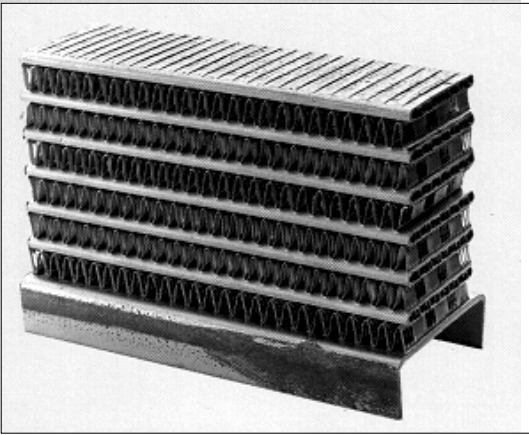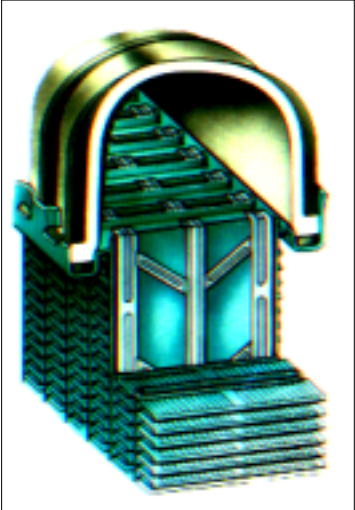
4601.06   Application Examples: Automotive Heat Exchangers [4]

In recent years, brazed aluminium heat exchangers have been increasingly introduced in radiators, oil coolers, heating and air conditioning equipment for all types of vehicles. For large-scale production, new material combinations of aluminium core and cladding alloys had to be developed by the aluminium industry in co-operation with the manufacturers.

World-wide, approximately 150.000 to 200.000 tons aluminium brazing sheets have been produced in 1992, equivalent to 60 millions heat exchangers of all types. The thicknesses of brazing sheet or coil vary between 0,15 and 15 mm, the width between 30 and 1250 mm. Depending on the thickness of the semi-finished products and their application, the liner can represent 2 to 20 % of the total thickness of the sheet. A brazed heat exchanger is a typical component with a large number of rather inaccessible joints per unit area, i.e. about 175.000 joints per radiator for a passenger car. A plate-fin aluminium heat exchanger is schematically shown in **Figure 4601.06.01**. The separator sheets are clad on both sides with aluminium brazing alloys. Typical core material for separator sheets, extruded sections and fins is AA 3003.

The Separator Sheets are Clad on Both Sides with Aluminium Brazing Alloys.
Typical Core Material for Separator Sheet, Extruded Sections and Finsis AA 3003.

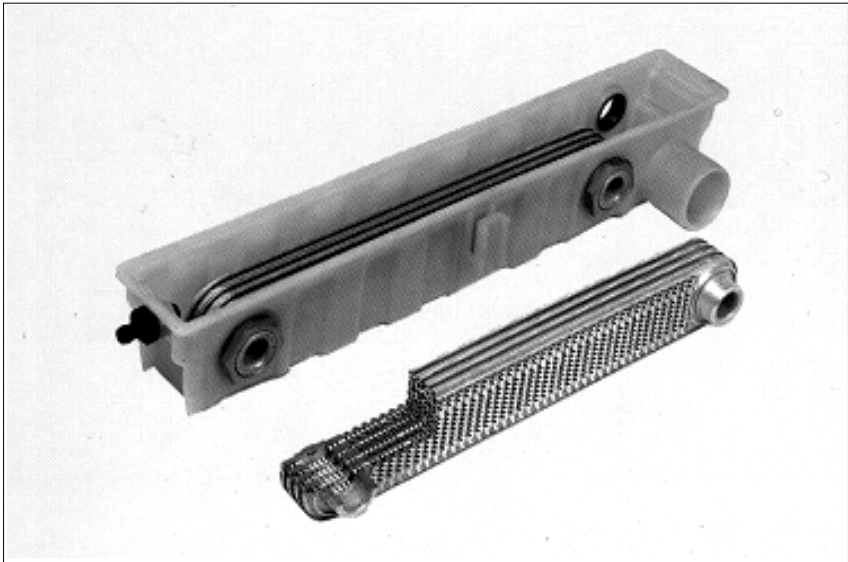| TALAT | Schematic Plate-Fin Type Aluminium Heat Exchanger | 4601.06.01 |
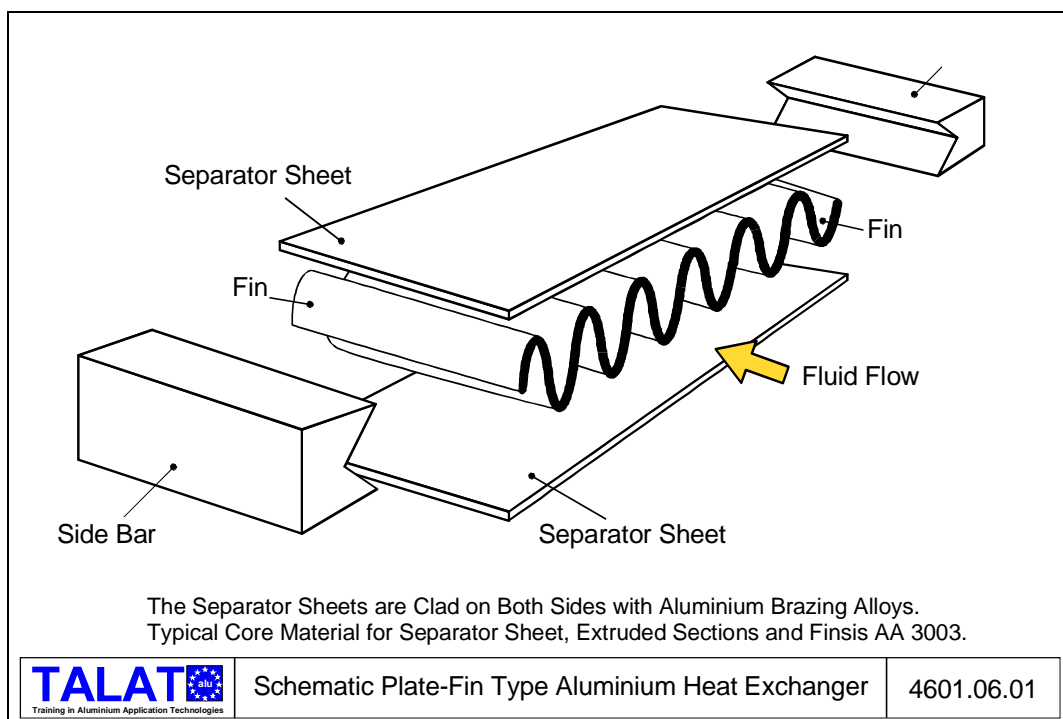
Figure 4601.06.02 illustrates a typical flat-tube-fin type construction. A shell-and-fin type heat exchanger for oil cooling is shown in **Figure 4601.06.03**. **Figure 4601.06.04** shows an assembled combination of brazed aluminium oil and water coolers for automobiles.
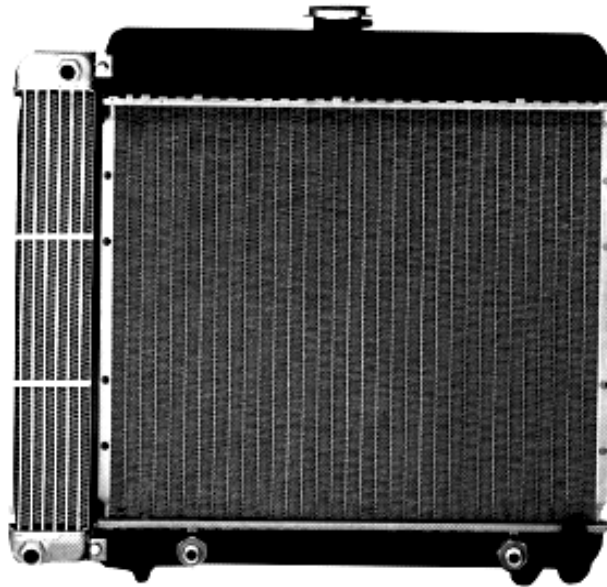

Source: BEHR, Engine cooling for motor vehicles

TALAT Training in Aluminium Application Technologies	Flat-tube Oil / Air Coolers	4601.06.02

Source: BEHR, Engine cooling for motor vehicles

| TALAT Training in Aluminium Application Technologies	Shell- and Fin Type Heat Exchanger	4601.06.03

Source: BEHR, Company Documents

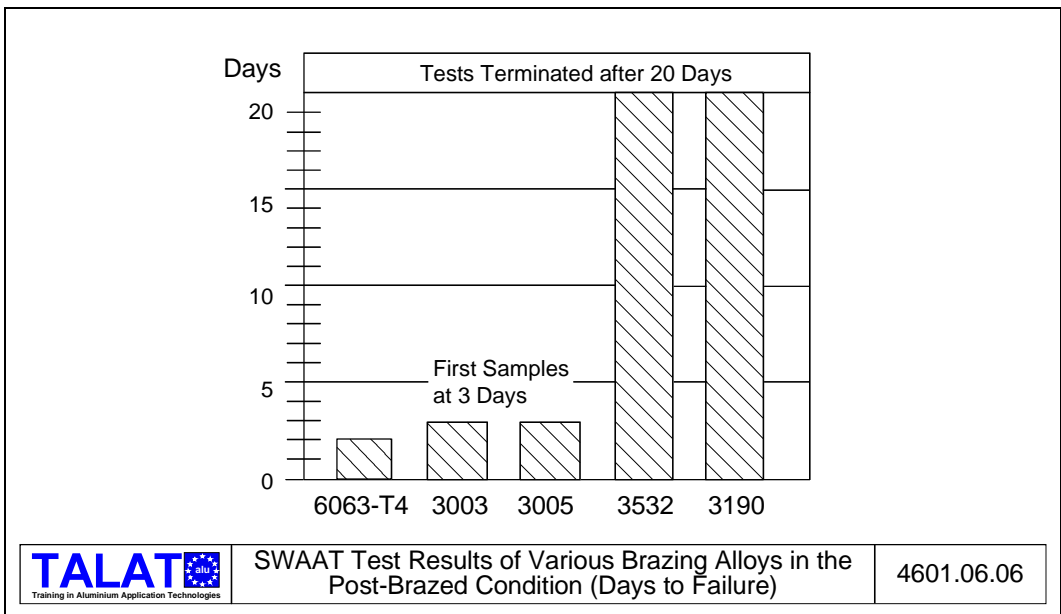| TALAT | Brazed Automotive Oil and Water Heat Exchanger | 4601.06.04 |

Depending on the size of the unit and the number being produced the following brazing methods are currently in use:

- flux-dip brazing
- furnace brazing with fluxes
- vacuum and controlled atmosphere brazing without fluxes.

Manufacture of clad aluminium brazing sheet is done by a hot-roll-bond process in order to clad the liner (brazing) alloy to the core (parent) material. The cladding may either be on one or on both sides. Aluminium brazing sheets may also be clad with alloys acting as cathodic protection (cladding alloys: AA 1145; AA 7072; AA 3005). **Figure 4601.06.05** reveals schematically a brazed tube section of a heat exchanger utilising a 3005 cladding for corrosion protection of the coolant side and the 3190 long life alloy that provides a less noble diffusion zone after brazing(compared to the core material) acting as cathodic protection.

TALAT	Schematic of Brazed Tube Section of a Heat Exchanger	4601.06.05
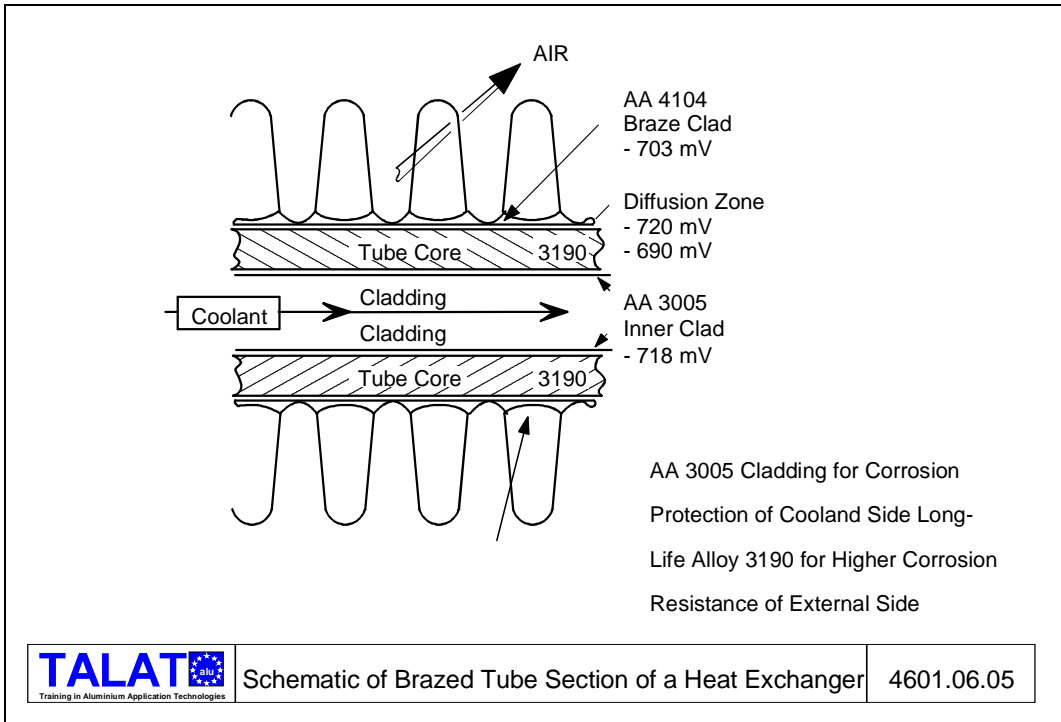
Today the resistance to corrosion is mainly tested by the so-called SWAAT test (Seawater Acetic Acid Test - ASTM G 85), i.e. radiator testing to outside corrosive attack as well as corrosion test for aluminium brazing sheet. In comparison to other corrosion test method the SWAAT revealed the best coincidence to the field behaviour of brazed aluminium radiators. The so-called long-life alloys reveal excellent performance in the SWAAT test (**Figure 4601.06.06**).

TALAT	SWAAT Test Results of Various Brazing Alloys in the Post-Brazed Condition (Days to Failure)	4601.06.06

4601.07   References

1.   "Aluminum brazing handbook" ; Aluminum Association 1974

2.   "Löten von Aluminium" (Aluminium Merkblatt V 4); Aluminium Zentrale 1987

3.   "Aluminum fluxless vacuum brazing"; Aluminum Association

4.   F.J. Reker "Roll bonded aluminium sheet for brazing of automotive heat exchangers"; Hoogovens Aluminium 1992

5.   Klock & Schoer "Schweißen und Löten von Aluminiumwerkstoffen"; DVS-Fachbuchreihe Bd. 70; 1977

6.   Brazing Alcoa Aluminium , 1959

7.   A. Paquet , SAE paper 931093

8. Julius Behr GmbH & Co., Stuttgart, several product information brochures

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