TALAT Lecture 2203

Structural Materials Fabrication

42 pages, 26 figures

Basic Level

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Objectives:

– to give a brief introduction into the basic fabrication methods for structural aluminium alloy materials with respect to machining, forming, joining and surface treatments as a necessary background for the design process

– to describe the subject of welding structural aluminium alloys in order to understand the materials requirements which the designer has to take into acccount when designing load carrying welded aluminium structures

Prerequisites:

– general materials engineering background

Date of Issue: 1994

2203 Structural Materials Fabrication

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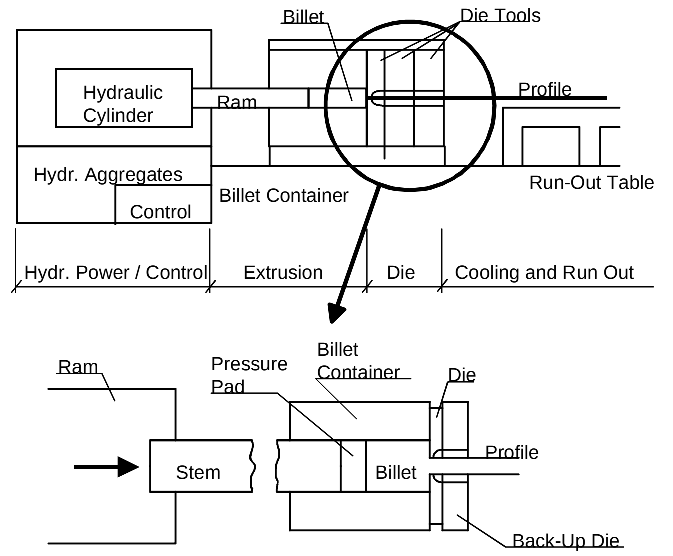
Process related methods

Although the preparation methods for the fabrication of aluminium semi-products in many ways are the same as for steel, aluminium has an outstanding advantage by the extrusion technique. By this process, profiles can be formed within the production limits into nearly every thinkable shape in section.



TALAT	General Layout of an Extrusion Press (Direct Extrusion Process)	2203.01.01

The Extrusion Process
(**Figure 2203.01.01**):

The extrusion press equipment is built up of five main units:

- the hydraulic power unit containing aggregates, a hydraulic cylinder and a pressure piston,.
- the extrusion tool unit containing a billet container and the extrusion die and tools,
- the control unit setting the pressure power, the speed etc.,
- the cooling unit using either air or water as cooling medium,.
- the run-out table.

The main operations are the following:

- The billet and the extrusion tools are pre-heated to a temperature of 480-520°C.

- The billet is placed into the container and the piston presses the billet metal through the extrusion die opening. The die opening is shaped to form the profile geometry.

- Immediately after leaving the tools, the profile is cooled and is run out on a long table unit.

- Still being on the table, the profile is straightened by stretching and, thereafter, cut into the wanted lengths.

The commonly used extrusion aluminium alloys are the 6000-series. These alloys are heat treatable and the last step in the process is usually age hardening.

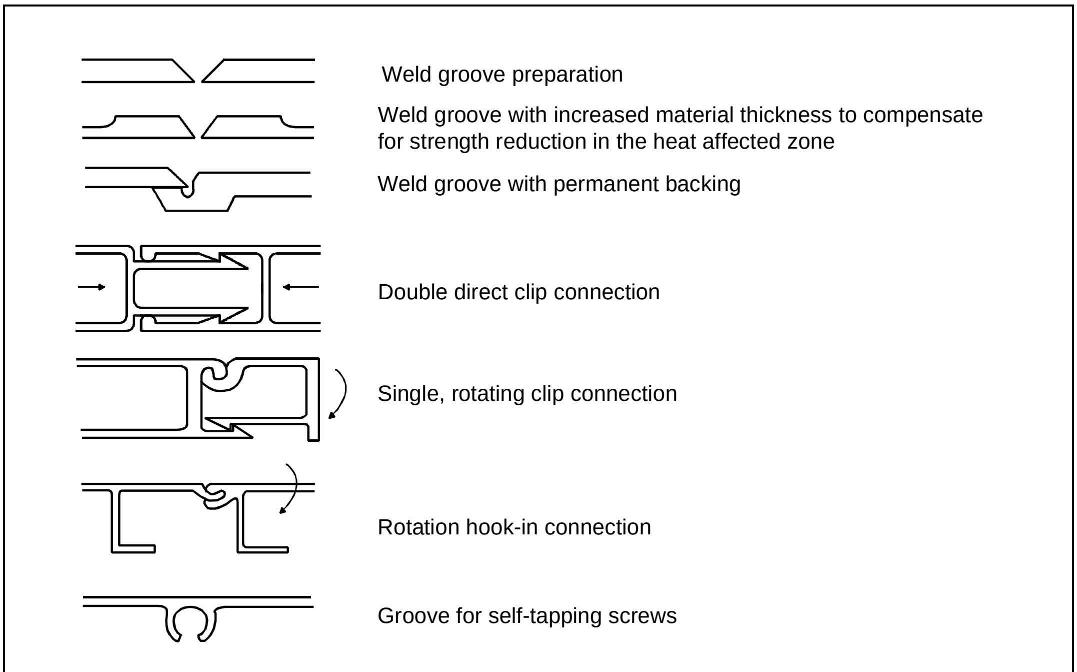
The extrusion process gives the designers and the users unique opportunities:

- Cross-sections of profiles can be designed with all kinds of special functions and, thereby, contribute to reduced fabrication and installation costs. Products can also be given a better design and function at relatively low costs.

- The extrusion die costs are usually relatively low for most types of profiles so that benefits can be expected already for small production series or even for singular product items.

There are numerous examples how extruded profiles can be formed or prepared to simplify or even exclude additional machining or forming operations which would have been necessary if only simple profile shapes or plate material had been available.

For example, functions can be ″designed into″ extruded profiles such as welding grooves, permanent backing for welds, positioning grooves for the drilling of holes, specially located ribs for easier installation or component mounting, or special surface protrusions to increase the strength of adhesive bonding. **Figure 2203.01.02** gives a few examples of such section designs.



TALAT Training in Aluminium Application Technologies | Special Profile Shapes: Example for Joints and Joint Preparation | 2203.01.02

Cutting

There are three methods in use:

Plasma gas cutting
Shearing (Scissors)
Sawing

Additionally, special types of cutting discs can be used for minor cutting operations. If weld grooves are cut, however, the remaining disc particles must be carefully removed. Otherwise they will be pressed into the surface and cause weld imperfections. Oxygen gas cutting can not be used on aluminium.

Plasma Gas Cutting

This method is highly effective, fast and versatile, particularly when cutting more intricate shapes. The cutting edge, however, may require further dressing to remove contaminations and dross. Plasma gas cutting is normally used on plate material and is not suitable to cut complex- or hollow-shaped extruded profiles.

Shearing (Scissors)

This method is also used on plate, sheet and flat bar profiles. It is fast and effective and gives an exact and clean cutting edge. The scissor equipment is usually stationary, and the workpiece has to be moved to the machine.

Sawing

Sawing is a rapid and versatile cutting method. The two main machine types are the band saw and the circular saw.

The circular saw is used for straight cutting. While a band saw usually has a high speed steel blade, the circular saw can be equipped with a high speed steel blade or a steel blade with tungsten carbide tips on the teeth. This latter type is preferred due to a longer lifetime and if a higher cutting speed is required.

All types of sawing blades for aluminium must have extra clearance between their teeth for chip release. The blade edge speed for a high speed steel blade should be up to 30 m/sec and for tungsten carbide tipped blades, the edge speed may be as high as 60 m/sec.

To obtain the highest possible cutting rates, to improve the cut quality and also to extend the lifetime of the blade, a cutting lubricant and/or coolant is recommended.

Machining

In general, the same machining operations as for steel can be used for aluminium alloys.
The usual methods are:

- Drilling
- Milling
- Thread cutting
- Punching

If the machining parameters and the forms of the tools are chosen right, most aluminium alloys can be machined with considerably higher speed than steel.

When using chip releasing methods it is also very important to use a lubricant and/or cooling to ease the chip release effect and also to avoid too high temperatures near the tool cutting edges.

The aluminium punching tool is the same as for steel. The only difference is that the clearance between the piston and the tool die opening is somewhat larger for the aluminium tools.

Cold Forming

Cold forming of aluminium components is based on two different types of operations:

Bending
Cold forging (or impact extrusion)

Bending

The bending equipment and methods for aluminium are basically the same as for steel. However, when bending aluminium plate profiles, the alloy temper and elongation capacity should be considered carefully. Because of the fact that the surface hardness is generally lower than that of steel, the use of a lubricant is often necessary to avoid metal pick-up damages on the metal surfaces.

Cold Forging

This method is often used to form special components for machines, engines and other automotive parts. In addition to the exact forming of the components, the cold work process also increases the material strength.

Cold working is normally used to increase the mechanical properties, mainly of the non-heat-treatable alloys. The process is called strain or work hardening. **Figure 2203.01.03** (table) illustrates the effects of this process, both on the tensile properties and the elongation of a typical non-heat-treatable alloy.

The increasing degree of cold forming corresponds to a decrease of the elongation properties, and thereby also reduces the cold forming and bending abilities.

Alloy	Temper	Thickness (mm)	Tensile Strength (MPa)		Elongation (%)
			Ultimate	Yield	
5052	0	1.2 - 6.3	215	65	19
5052	H32	1.2 - 6.3	275	205	10
5052	H34	1.2 - 6.3	305	240	8

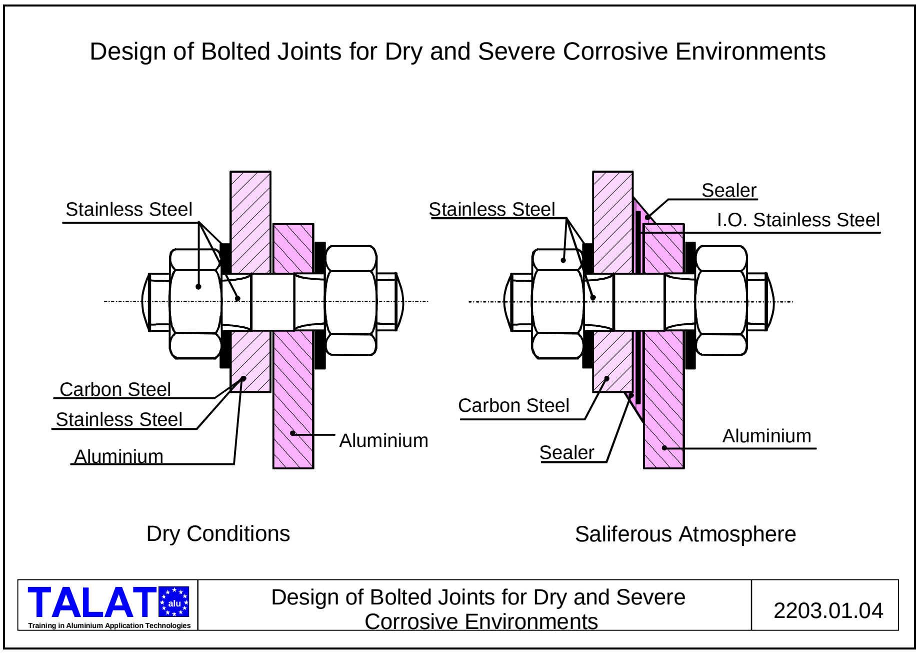
TALAT Training in Aluminium Application Technologies | Effect of Cold Working on Strength and Elongation. Example: 5052 Sheet Alloy | 2203.01.03

Bolting

In addition to welding, pervasive bolting is the commonly used joining method for aluminium structural components. The choice of joint design, bolt material and eventual corrosion protection is mainly dependent on the mechanical working conditions and the local environmental exposure.

When different metals are in contact and are located in an electrolyte, the electro-chemically least noble metal will become an anode and corrode. The degree of potential galvanic corrosion is highly dependent on the material, the type of electrolyte, the exposure time and the temperature conditions. If the environmental conditions are of corrosive nature, the electrical contact between the two parent materials should be broken by some kind of insulation.

Figure 2203.01.04 illustrates alternative joint designs, based on different environmental conditions.



Riveting

During the last 10 - 20 years, this joining method has gradually been reduced in connection with aluminium structural components. Welding or bolting have become the commonly used methods. The main reason for this is that the aluminium alloy rivets have considerable lower shear and tensile capacities than steel bolts.

The overlap joint type is also exposed to potential crevice corrosion, and by riveting, the joint surfaces can not be examined or maintained without destroying the rivets. However, the air- and spacecraft industry, and occasionally also the automotive industry are still using combined riveted and adhesive bonded joints on thin sheet materials. The main reason is that they often use aluminium alloys not recommended for welding.

Special riveting systems, such as the POP-rivets and similar types are also widely used on all kinds of products, mostly on non-structural types, such as window frames, doors, panels etc. These types of rivets can be made of aluminium alloy, steel or other materials.

Adhesive Bonding

The main development of structural metal bonding came with the aircraft industry and its search for lightweight panel assemblies required in high performance aircrafts. The development of successful processes for structural bonding of metal assemblies has thereby been made possible by comparatively recent advantages in polymer chemistry. The new and improved adhesive technique and equipment has spread these techniques from the production of supersonic airframe components to products as windows, boats, furniture, automobiles etc. and aluminium has figured prominently in this rapid advance of metal bonding technology.

The main advantages of adhesive bonding of aluminium are:

- increased fatigue strength
- no metal weakening by bolt or rivet holes or by weld heat input.

Other general advantages:

- Possibility of simplified production
- Easy assambly of different materials
- Smooth joint surfaces with no bolt heads or other distortions
- Normally good corrosion resistance in joint areas

The main disadvantages are:

- Relatively comprehensive demands for environmental and fabrication process precautions
- Non-destructive control of joint quality is difficult, and impossible by the use of the normal techniques and equipment

Figure 2203.01.05 (table) is a general adhesive selection guide for aluminium/aluminium joints based on different service conditions.

The different types of adhesives might also be very different to handle and different in price. It is, therefore, recommended to do a forehand evaluation of needs and possibilities.

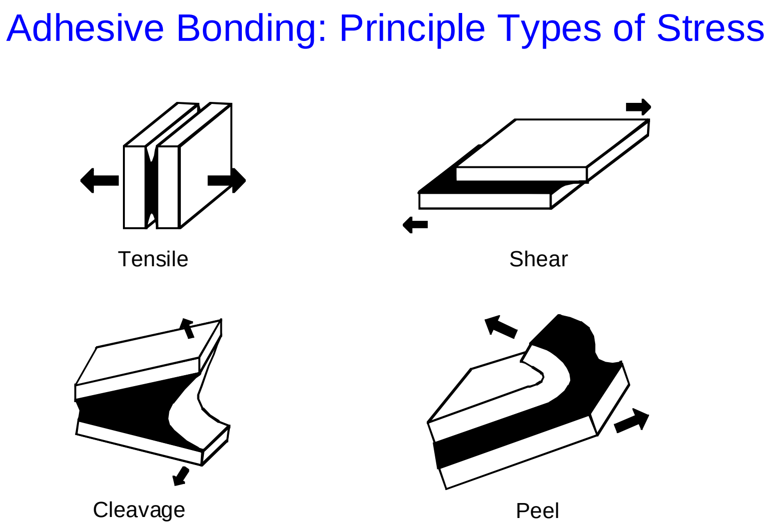
Selection of Adhesives for Al/ Al Joints

Service Conditions		Adhesives
High Stress	High Temperature	Expoxy Phenolic
	Moderate Temperature	Nitrile Phenolic/ Vinyl Phenolic
	Room Temperature	
Medium Stress	Moderate Temperature	Epoxy/ Epo.PVC/ Epo. Polysuphide
Low Stress		Neopr./ Nitrile/ Polysulphide

TALAT Training in Aluminium Application Technologies | Selection of Adhesives for Al/ Al Joints | 2203.01.05

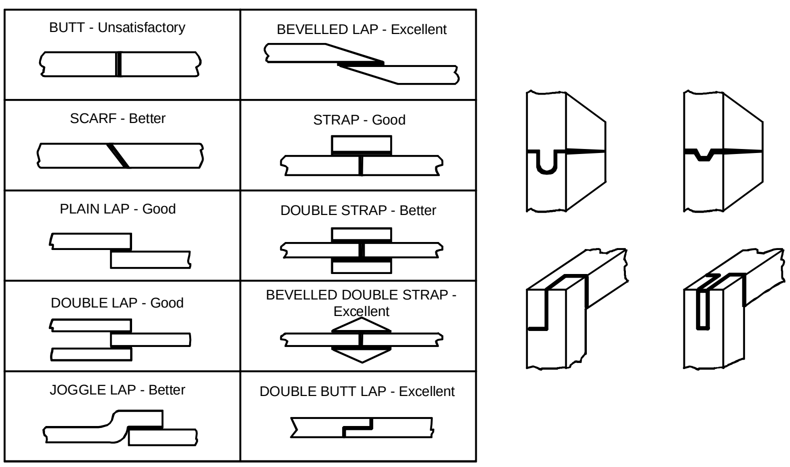
An adhesive joint should not be directly redesigned from a similar bolted connection. The bonded joint will always have strong and weak operational sides and it is important to take all possible advantages of the strong, and avoid the weak sides.

The four principal types of stress are shown in **Figure 2203.01.06**. The main working stress should lie in shear or tensile stresses and cleavage or peel stresses should be avoided as far as possible.



TALAT Adhesive Bonding: Principle Types of Stress 2203.01.06

Some examples of different types of joints and their functionality in a stress situation are given in **Figure 2203.01.07**.



TALAT Adhesive Bonding: Design of Optimum Joints 2203.01.07

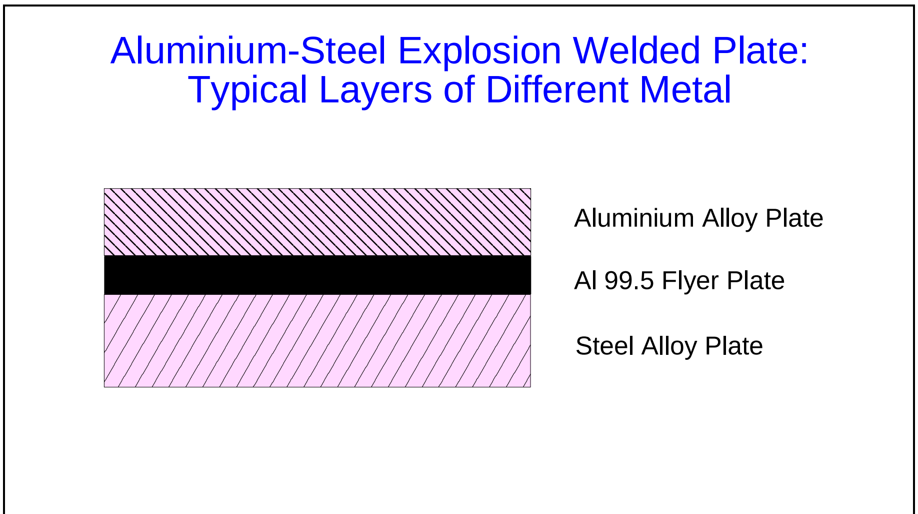
Explosion Welded Connections

Explosion welding can be explained as the metallurgical bonding between two metal plates as they are accelerated towards each other into a high velocity collision by the use of explosives. A number of different metal alloys can be joined by using this method, such as steel to copper, aluminium, molybdenum, silver, and also combinations such as aluminium/copper, nickel/titan etc.

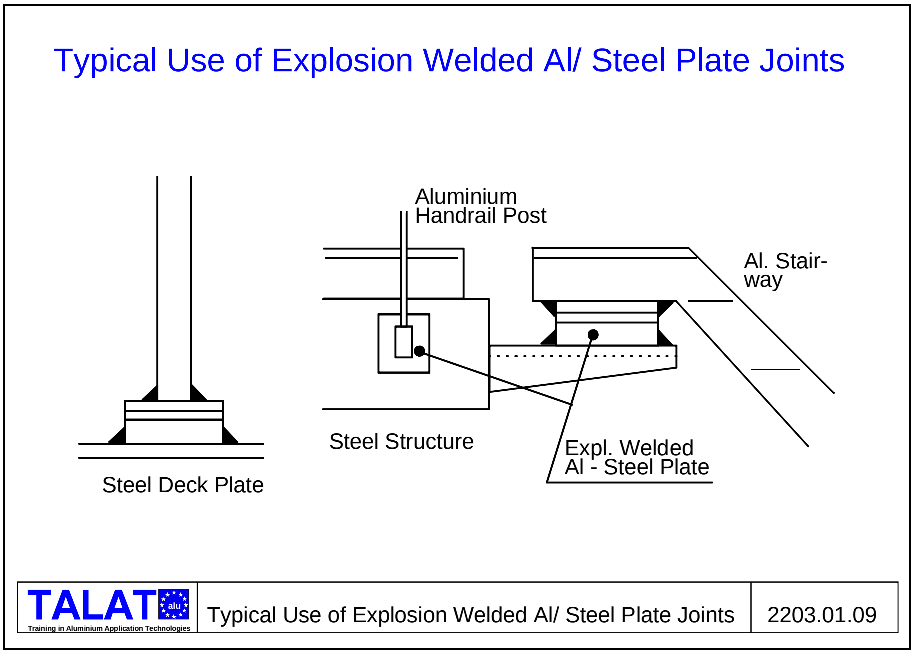
This method allows the practical use of mixed material combinations in products where ordinary welding or other joining methods are unsuitable or impossible. Some examples for such connections are copper pipe joints to structural steel liner plates in boilers and heat exchangers, aluminium/copper electrical contact arrangements and aluminium/steel plate joints.

Explosion welded aluminium/steel transition joints are normally used to weld aluminium constructions to steel constructions. The advantage is that the explosion welded plates can be pre-welded to the aluminium construction in indoor workshop facilities, and thereafter welded to the steel construction on site. A typical example is the assambly of aluminium superstructure components to steel hulls and decks on ships, and also aluminium gangways, platforms, stairways, handrails etc. to offshore steel platform structures (see **Figure 2203.01.08** and **Figure 2203.01.09**).

To produce explosion welded plates of steel and aluminium, it is normally necessary to make a triple alloy connection: the alloyed aluminum plate on top, a thin unalloyed aluminium plate in the middle, and the alloyed steel plate as a base.



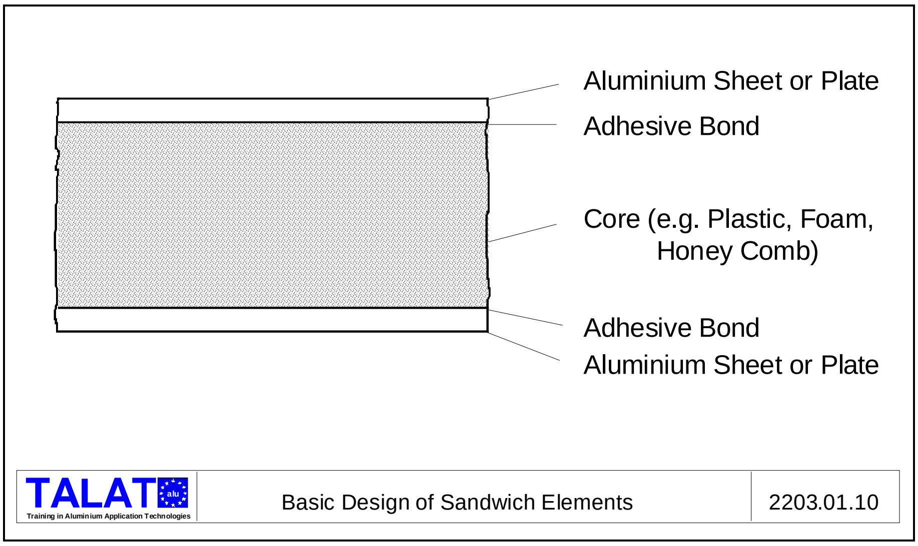
Aluminium-Steel Explosion Welded Plate: Typical Layers of Different Metal 2203.01.08



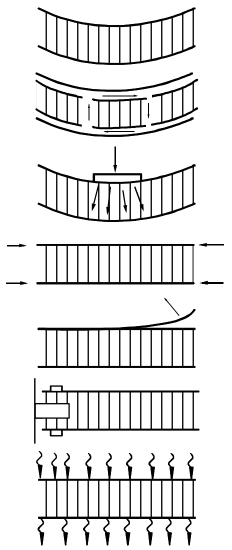
Sandwich Element Construction

The sandwich element technology is well known and widely used by a lot of different industries, such as aerospace, aircraft, transport, shipbuilding and architectural industries.

The basic idea is an element of low weight combined with high bonding stiffness and thermal insulation abilities, and the element construction consists in a light material core with different kinds of plate or sheet material adhesively bonded on both faces (**Figure 2203.01.10**).



All the involved materials in a sandwich element have their special properties and behaviour under different working conditions, and the designer of such elements should know the materials very well and also consider their working performances in a material combination situation. **Figure 2203.01.11** illustrates some examples of such issues.



TALAT Training in Aluminium Application Technologies | Performance Orientated Design of Sandwich Elements | 2203.01.11

Surface Treatment

There are many finishing methods for aluminium, and the choice of method is basically an aesthetic, functional and economic issue.

Some of the methods are:

Organic finishes:
- Chemical treatment and paint

Electrolytic oxide finishes:
- Clear anodizing
- Colour anodizing
- Hard anodizing (both clear and colour)

Mechanical finishes:
- Polishing
- Scratchbrushing
- Abrasive blasting
- Trumbling

Chemical finishes:
- Caustic etch (Frosted)
- Chemical brightening
- Conversion coatings
- Zincating

Electrochemical finishes:
- Electropolishing
- Electrobrightening

Electroplating:
- Copper plating
- Copper-nickel-chromium

Porcelain enamelling

Painting or anodizing are the basic finishing methods used on structural components and systems. The anodized surface is not suitable for welding, and the finishing layer has to be either mechanically or chemically removed near the joint before any welding can take place. This is both costly and normally aesthetically often not acceptable. As a consequence, anodized components are usually joint by the use of other methods than welding.

Examples of such products are window frames, doors, curtain walls and different kinds of decorative components. Structural components and larger constructions such as bridges, towers, ships, deckhouses and similar structures are normally welded constructions, and if any surface finishing is required, prime coating and painting is the commonly used finishing method.

2203.02 Joining by Welding

- Background
  - Chemical properties of aluminium
  - Physical properties of aluminium
- The welding process
  - The inert gas welding process
  - The basic MIG method
  - Pulsed arc MIG welding
  - Plasma MIG welding
  - The TIG method
  - Comparison of some structural welding methods
- Filler materials
- Weldability of aluminium alloys
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- Backing methods
- Cleaning before welding
- The shielding gas
- Welding technique
- Pre-heating
- Weld Cracks
  - Solidification cracks
  - Solution cracks
- Weld imperfections
- The welding process economy
- Distortion by welding
- Rectification of distortion
- Inspection and testing methods
  - Non-destructive testing or examination (NDT/NDE)
  - Destructive testing
- Quality Control Aspects

Background

Like other construction materials, aluminium has unique properties which also influence the welding process. The welding precautions, procedures and techniques should, therefore, be optimally adapted to these properties to attain the best possible weld quality.

The metal properties can be divided into two categories: the *chemical* and the *physical properties of aluminium*. The outstanding factors from each of these categories are listed below.

Chemical Properties of Aluminium

Oxide formation and related factors

Aluminium has a spontaneous reaction to oxygen, and as soon as it is exposed to air a thin, hard and transparent oxide film forms on the surface. If this film is scratched off, another film forms immediately: after some minutes of exposure to air the film's thickness is about 0,01 microns and continues to grow to a thickness of 0,1 micron or more.

The aluminium oxide (Al_2O_3) has some remarkable properties, such as:

Hardness:	The hardest material known after diamond.
Melting point:	2052 °C
Nature:	Very stable and inert. Ceramic type.
Electrical:	In natural thickness (3,5 microns), the oxide film is not sufficient to prevent initiation of an electrical welding arc, but when anodized with film thickness up to 50 microns, or even more, initiation of a welding arc should be difficult.
Surface quality:	As the oxide film grows in thickness, the surface becomes gradually more porous. It will retain moisture and contaminants which reduce weld quality. The result is an increased porosity in the weld.
	Hydrogen is highly soluble in molten aluminium.
	Hydrocarbons, such as oil and grease on the metal surface or enclosed in the oxide pores can cause hydrogen gas pores in the weld.

Physical Properties of Aluminium

Melting point:	620 - 660 °C
Thermal conductivity:	225 W/m°C. This is about 4 - 5 times that of steel.
	Together, these factors give as a result that the necessary heat input to produce efficient melting must be more intense for aluminium than for steel.
Strength reduction:	Unless the base metal is in the annealed or as-cast condition, fusion welding decreases the strength of both

heat treatable and non-heat treatable alloys in the heat affected sone (HAZ).

Additionally, the high electrical conductivity of aluminium is unfavourable for resistance spot welding since the necessary heat input for welding depends strongly on the electrical resistance of the material.

The Welding Processes

Aluminium and aluminium alloys can be joined by most fusion and solid state welding methods, such as:

Fusion welding:

- Metal Inert Gas (MIG) and pulsed MIG welding
- Tungsten Inert Gas (TIG) welding
- Plasma MIG and TIG welding
- Seam welding
- Electron beam and laser beam welding
- Ultrasonic welding

Solid state welding:

- Explosion welding
- Friction welding

Each method has normally technical and economical advantages and disadvantages, but the most commonly used method for manual welding of structural components and constructions is the MIG or the pulsed MIG arc welding.

The plasma MIG or TIG methods can be very effective, and usually give also excellent weld quality, but both methods are best for mechanised welding. The equipment is somewhat more expensive.

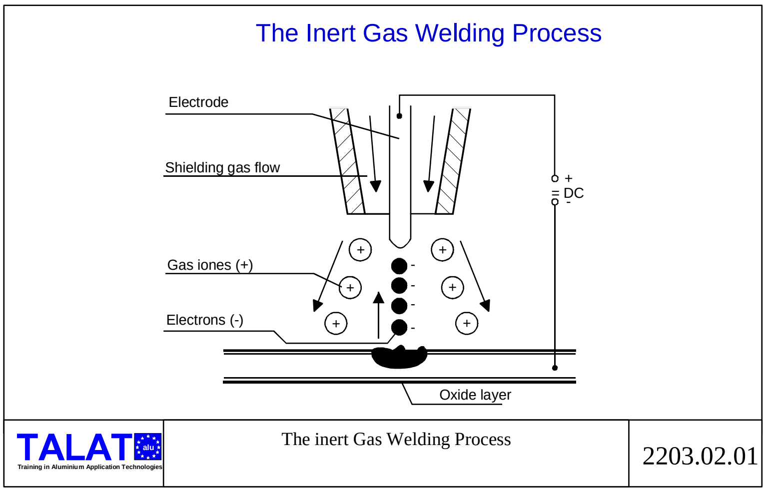
The other methods have a varying range of use, mostly in connection with manufacture of special products. Explosion welded aluminium/steel units have been used for many years to connect aluminium constructions to steel constructions by welding aluminium to aluminium and steel to steel.

The Inert Gas Welding Process
(**Figure 2203.02.01**)

To secure an acceptable weld quality, there are two basic factors to be considered:

- To break loose and remove the oxide film.
- To prevent the formation of new oxide during the weld process.

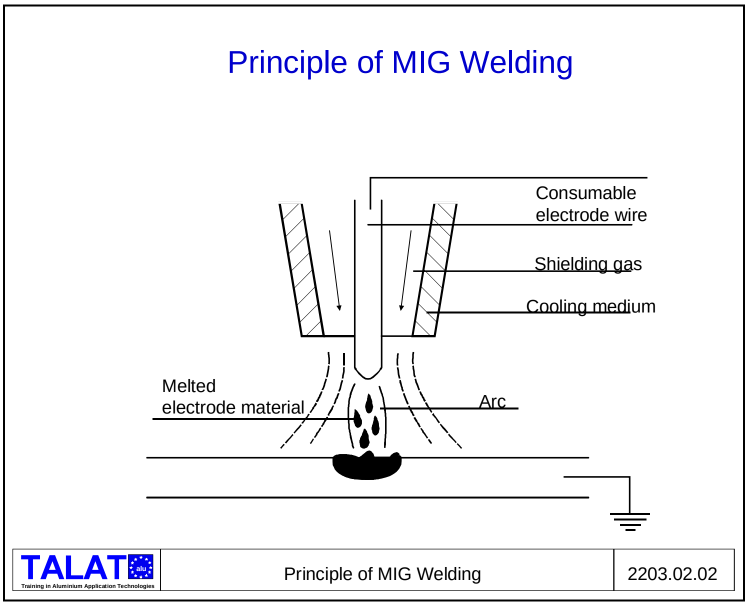
The usual way to meet these issues is:
By using direct current with positive connection to the electrode, and negative to the work piece; a stream of negative electrons will pass from the work piece to the electrode. The electron stream breaks loose the oxide and transports it to the electrode. To prevent new oxide from forming a shield gas is necessary to keep the oxygen out of the weld bead. The type of gases used for this purpose are the inert gas types and, in practice, the actual types are argon and helium, or a mixture of these two.



The Basic MIG-Method

(**Figure 2203.02.02**):

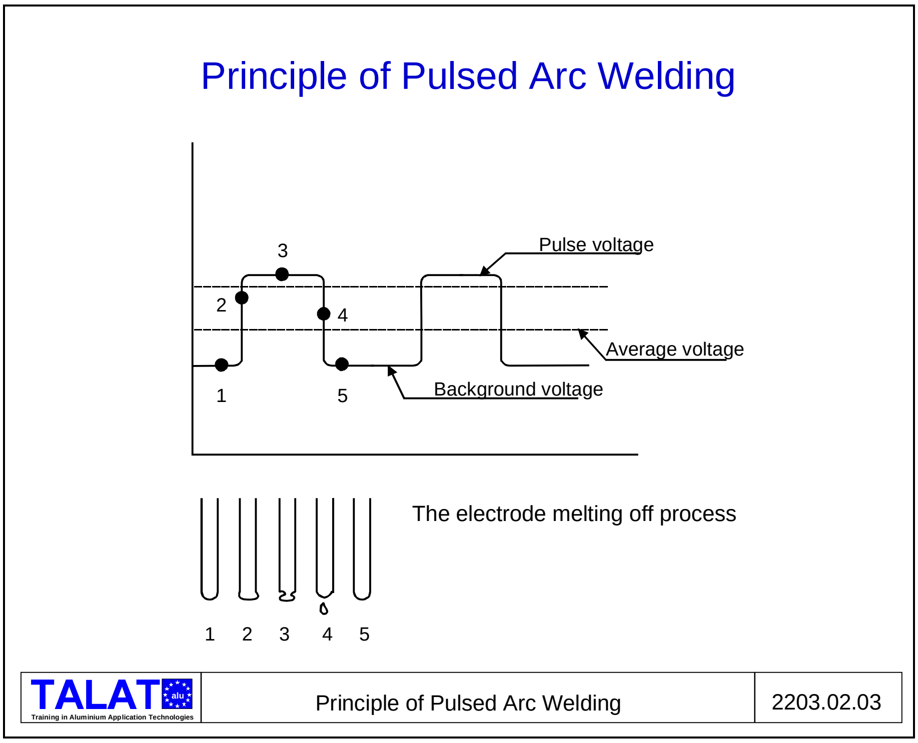
The conventional MIG welding is used on material thicknesses form 3 to 50 mm, and the process is about 2 - 3 times faster in use than the TIG-method. The normal electrical connection arrangement is direct current with positive electrode.



The filler metal wire is located centric in the weld gun nozzle and it also works as welding electrode. The wire is mechanically pushed or pulled forward (or both) and the wire is kept on spool, either in the basic weld equipment unit or in the weld gun. When using a positive electrode, the gas nozzle area will reach the highest temperature. About 2/3 of the heat will be produced in this area. This means that the gas nozzle has to be cooled, either by circulating water or by air.

Pulsed Arc MIG Welding
(**Figure 2203.02.03**):

This method is based on conventional MIG welding. In pulsed arc welding, pulses are superimposed on a low level constant background current. By this, it is possible to obtain spray transfer at an average current which is below the threshold value for the wire size being used. Metal transfer is actually controlled by the frequency and level of high pulses. The result is an intermittent or controlled spray transfer.



The main advantages with this method are:

- The use of a thicker wire than with conventional MIG welding gives better and more secure wire feeding and also lower wire costs.

- Less heat transfer to the work piece opens for welding on thinner material (2 mm) and also results in less heat deformation problems.
- Better weld contours, and less spatter problems.
- Uniform through-thickness welding is possible up to a 5 mm material thickness without using backing for weld pool containments.
- Better metal transfer when welding in difficult positions.

The welding equipment is somewhat more expensive than for conventional MIG welding, but the method has so many advantages that they often pay for the extra costs.

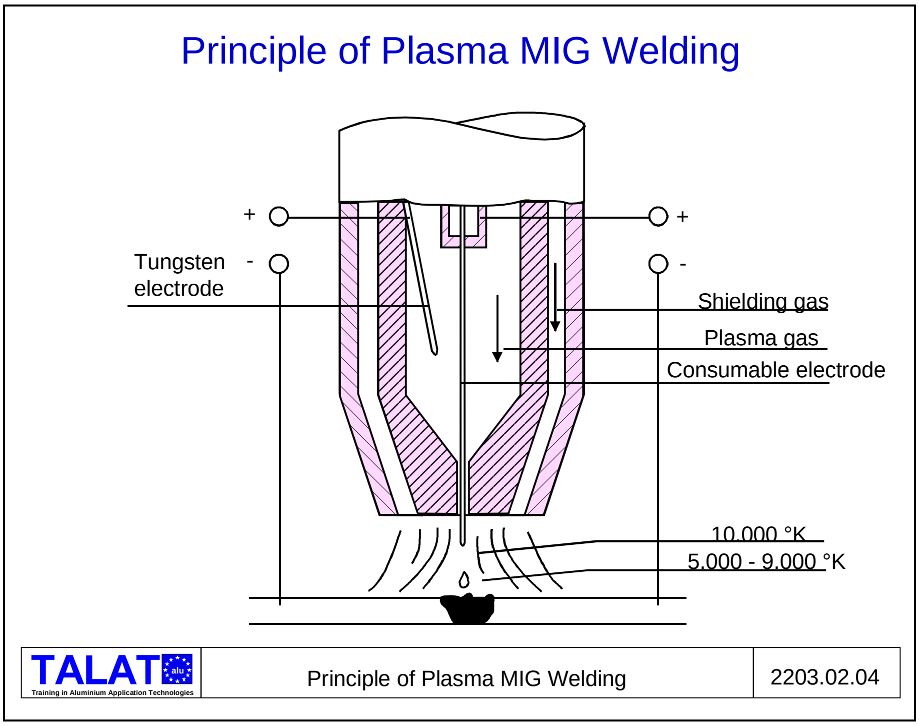
Plasma MIG Welding

(**Figure 2203.02.04**)

This method should not be confused with the plasma arc welding (PAW) methods, such as the plasma TIG and the plasma TIG keyhole method. The plasma MIG welding is a hybrid arc welding process of MIG and TIG. A consumable electrode and the arc between it and the work piece are surrounded by an arc plasma.

The plasma is established by the arc from a non-consumable electrode (Tungsten). Additional shielding gas is supplied by an external gas or gas mixture. For welding aluminium, normally both the plasma and the shielding gas is argon or argon/helium.

The temperature near the consumable electrode tip can reach 9000 - 10000 °C, and 5000 - 9000 °C near the work piece. This opens for a very effective welding process especially on thick materials.



Another advantage is the very high quality of the weld.

The method is best suitable for mechanical/automatic welding, and is absolutely best for horizontal welding position.

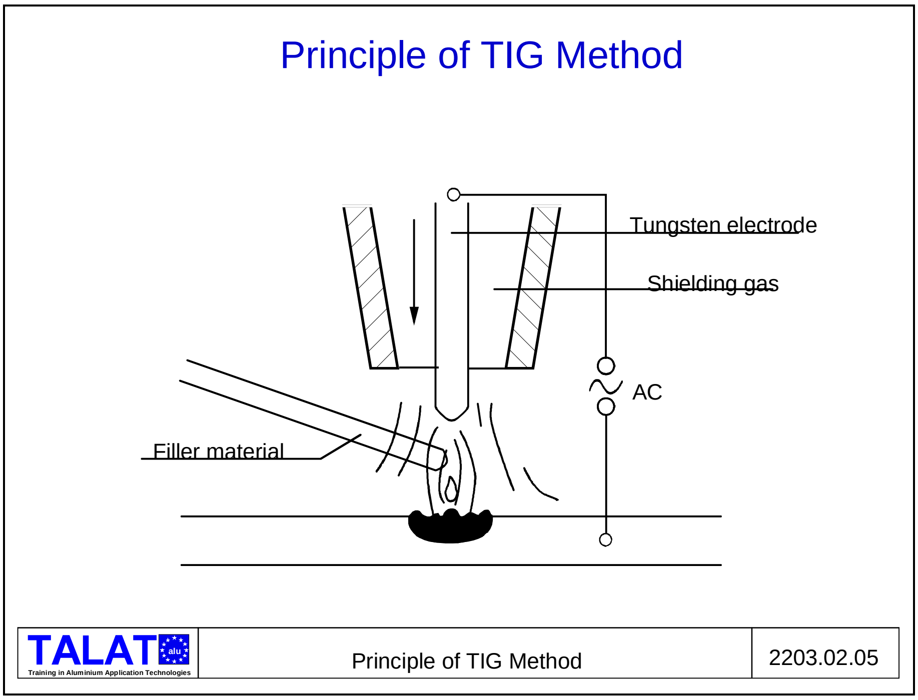
The equipment is relatively expensive and heavy.

The TIG-method
(**Figure 2203.02.05**)

To use DC (direct current) and positive electrode, such as for MIG welding, is not suitable for the TIG method. The main reason is that the tungsten electrode could reach a temperature where it starts feeding its own material into the weld beam.

For TIG welding it is normal, therefore, to use AC (alternating current). The diameter of the electrode is usually about 2,5 mm and the method can be used with or without filler metal. When filler metal is used, the wire is fed into the weld bead from outside, the same way as for steel gas welding.

TIG welding is relatively easy and gives the welder a very good control, but the welding speed is normally a lot lower than for MIG welding. The weld quality is normally very good, and pores in the weld is not the same problem as for MIG. The method can be used on material thicknesses of 0,1 - 25 mm, but the normal range for manual welding is 1 - 2 mm, and sometimes up to 10 mm. Pure argon is best as shielding gas.



Comparison of Some Structural Welding Methods

Several important application characteristics of MIG, Plasma TIG and TIG welding methods are listed and compared in **Figure 2203.02.06**.

Comparison of Welding Methods

	MIG	Plasma MIG	TIG
Control of heat input	Good*	Excellent**	Very good**
Burn in	High	Can be controlled	Low
Material thickness:			
1 mm	No	Possible	Good
2 mm	Difficult***	Good	Very good
4 mm	Very good	Very good	Possible
6 mm	Very good	Very good	Very slow
Weld quality	Good ****	Very good	Very good
Demand for welders competence	Low	Medium	Higher
Equipment costs	Moderate	High	Moderate
Welding speed	High	High/very high	Low
Manouverability	Limited	Low	Good

* Dependent of filler wire feeding speed
** Can be controlled undependently of filler wire feeding speed
*** Better with Pulsed MIG
**** Difficult to avoid pores in the weld bead.

TALAT Training in Aluminium Application Technologies | Comparison of Welding Methods | 2203.02.06

Filler materials

The filler metals are classified by the same four-digit system as used to designate wrought and cast aluminium alloys. The four-digit number is prefixed with the letter E to indicate suitability as only an electrode, with R for a welding rod, or with ER for both applications.

Weldability of Aluminium Alloys

The **1000, 3000, 5000** and **6000** series are all recommended for welding. In the **7000** series there are both weldable alloys and alloys not recommended for welding. One of the best known weldable alloy in this group is the 7020 (AlZn4,5Mg1).

Heat treatable and non-heat treatable alloys can be age hardened or cold formed to raise the strength, and both types will loose strength if they are exposed to high temperatures, such as by welding. The strength reduction will appear in the heat affected zone (HAZ) on both sides of the welded joint. The degree of strength reduction is dependent on the original temperor the degree of cold forming. The strength will remain lost in the HAZ, but for the exception of the AlZnMg alloys: for these alloys natural age hardening at ambient temperature, or artificial age hardening will produce a degree of recovery of the strength. This is a remarkable advantage of these alloys, but one of the main reasons why they are not widely used in structural components is their disposition for stress corrosion.

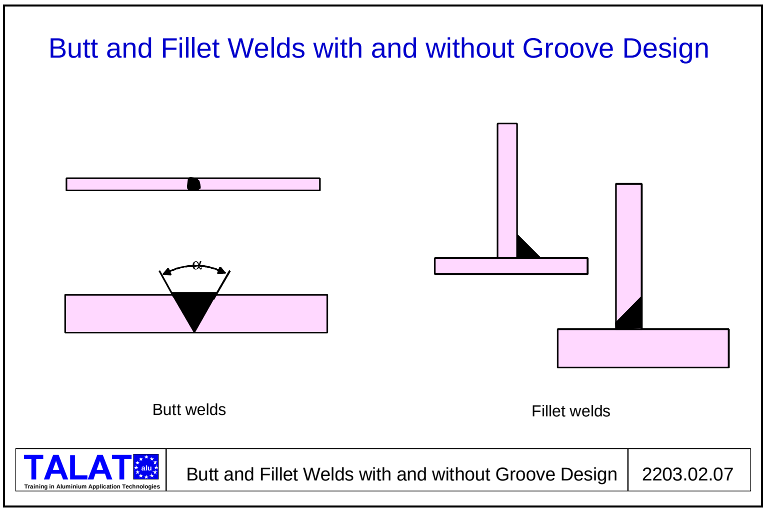
Joint Design

When doing design and engineering work on welded constructions, it is important to choose the right types of joints, and it is also important to find their best possible localization in the construction.

Some other important factors also to be considered are:

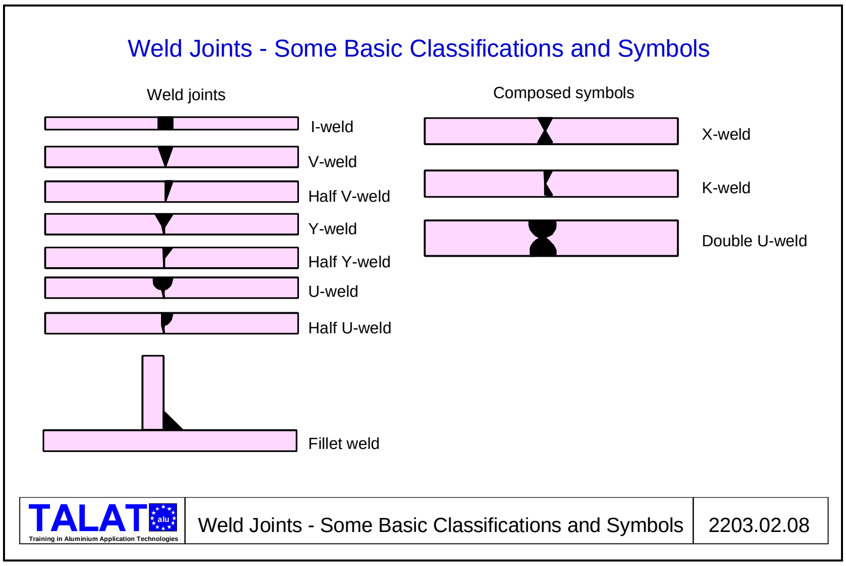
- The external and internal structural loads
- Choice and function of the filler materials
- The fabrication workshop facilities
- The local constructions welding access possibilities
- Economical factors, etc.

The two main joint types are the butt welds and the fillet welds. In both cases it is possible to weld with or without the use of a groove design (**Figure 2203.02.07**).

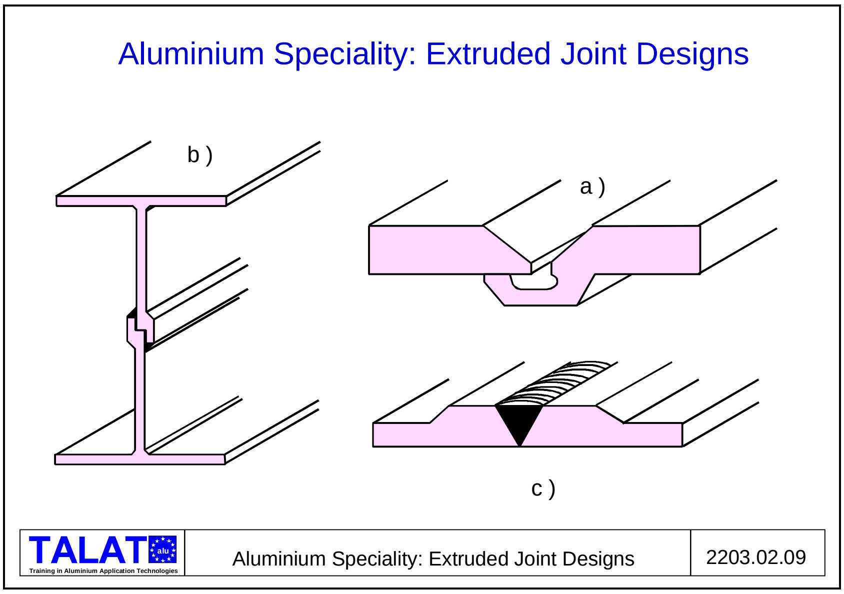


The local joint groove design and preparation of aluminium welded joints are more or less the same as for steel, but it is normally an advantage to increase the aluminium groove opening angle by about 10 - 20 degrees compared to the steel groove geometry. By this, the shielding gas protection will be better, besides, due to the wider liquid weld bead, hydrogen gas bubbles will easier escape from the bead. These factors will again reduce the potential number and size of pores in the weld.

The basic joint classification and its symbols are the same as for steel welded joints (**Figure 2203.02.08**).



In longitudinal welding of aluminium extrusions special joint designs enable the integration of edge geometry and a permanent groove backing in the cross-section (**Figure 2203.02.09**). Equally, the effect of strength reduction in the HAZ can be compensated by putting the weld where stresses are low and by increasing the material thickness in the weld zone. This can be done very effectively by using extruded profiles with special design.



Backing Methods

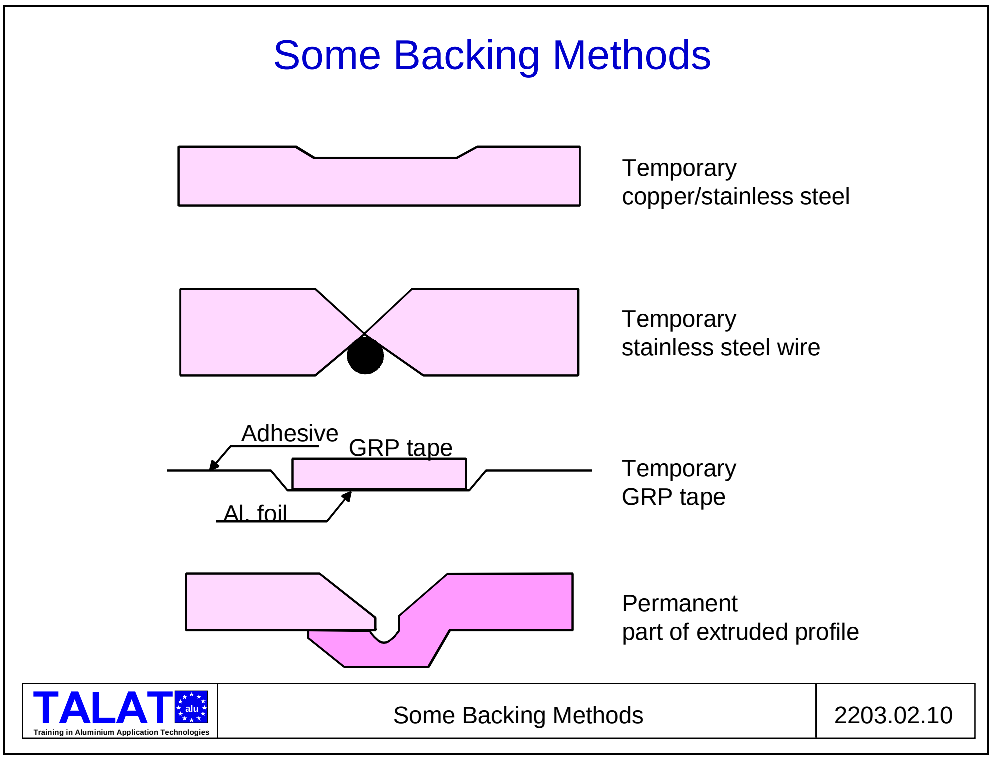
When fusion welding is used only from one side, some type of backing may be desirable to control the amount of root reinforcement and the shape of the root surface.

Two types of backing may be used:

- Permanent backing
- Temporary backing

The permanent backing consists in an aluminium strip or extruded bar to be left on its place after welding, or it can be a special shaped edge detail on an extruded profile.The temporary type is normally incorporated in special tooling and inert gas may be fed into a groove in the backing material to protect the tool surface from oxidation.

Permanent backings sometimes cause a lack of fusion at the root, either by distortion or by unproper cleaning before welding. If the welded joint is to be exposed to corrosive environments, the narrow splits could be a seat for local and dangerous corrosion (crevice corrosion). In such cases, all crevices and splits should be properly sealed off. Some typical backing methods are (**Figure 2203.02.10**).



TALAT	Some Backing Methods	2203.02.10

Cleaning before Welding

Rule No. 1

To avoid weld porosity, aluminium must be both clean and dry when it is is welded.

If the metal has been exposed to contaminating material, these have to be removed before any welding operation proceeds. A cleaning solvent is often used, mainly of a hydrocarbon type. But as the types of solvents also contain hydrocarbons, it is important to let it dissolve completely before welding.

The following operation is the removal of the oxide, either by using a stainless steel brush or by milling. The use of a grinding disc to remove oxide is not recommended. The disk filler material can easily be left in the groove surfaces, and thereby cause reduction of the weld quality.

The Shielding Gas

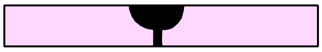
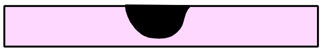
The main tasks of the shielding gas are to keep air or airborne humidity out of the welding process area, and also to stabilize the arc.

Argon is the commonly used gas, both for TIG and MIG welding, but a mixture of argon and helium is often used in connection with MIG welding on material thicknesses over 15 - 20 mm. The positive effect is a higher welding temperature, and thereby a better burn-in effect. This advantage is sometimes utilized to increase the welding speed on thinner material (**Figure 2203.02.11**).

Helium has a very low density, is lighter than argon and air, and is more expensive than argon. To compensate for the low density it is necessary to increase the gas flow or the gas volume consume, but this might have a negative effect on the welding economy. Other negative effects are that helium has a relatively poor stabilizing effect on the arc, compared with argon, and also that the weld pool cleaning effect is considerably lower.

Arc welding produces ozone gas, and this has been a potential environmental and health problem. During the last years, a new gas mixture has been used increasingly, mainly with MIG-welding of aluminium. This mixture is based on argon, with a content of approximately 0,03% nitrogen oxide. The manufacturers of this mixture claim that it gives off considerably less ozone.

Effects of Ar/ He - Ratios on Weld Pool Geometry

Gas	Gas flow l/min.	Geometry
Pure Argon	20	
70 / 30 % Ar/He	23	
30 / 70 % Ar/He	26	

TALAT Training in Aluminium Application Technologies	Effects of Ar/ He - Ratios on Weld Pool Geometry	2203.02.11

Welding Technique

A functional welding process is based on adapting hardware and human understanding of the equipment functions, the process and the metal. The workmanship experiences are also very important.

From the start of the aluminium welding process to its finish, there are some outstanding rules to consider to secure the best possible result. In short terms these rules are:

1. Preparatory control of all equipment functions, i.e.leakages in hoses and connections, clean electrical contact areas and satisfactory earth connections.
2. Control all welding procedure data: wire speed, gas flow, current, voltage, welding speed etc.
3. Cleaning of the joint areas
4. Stainless steel brushing
5. Filler metal wire: avoid the use of old wire, or wire that has been exposed to the workshop atmosphere over some time
6. Control the work-piece fixtures
7. Shielding gas: secure the gas flow from being disturbed by air draught
8. Always use highest possible welding speed
9. Take care of the environments and health: use best possible safety equipment, and secure the surroundings from air pollution and arc light disturbance.

Pre-Heating

If pre-heating is considered necessary, it is very important to keep absolute control over both heating temperature and exposure time. **Figure 2203.02.12** gives a direction on recommended values.

Temperature/Time Limits for Pre-Heating
Al-Alloys for MIG or TIG Welding

Alloy	Wall thickness (mm)	Max. temperature (°C)	Max. time (min.)
6060	5-12	180	60
6063			
6082	over 20	200	30
6005	over 20	220	20
7020	4-12	140	30
	over 16	160	20
5052	over 16	200	10
5083	6-12	200	10

TALAT alu Training in Aluminium Application Technologies | Temperature/ Time Limits for Pre-Heating Al-Alloys for MIG or TIG Welding | 2203.02.12

Weld Cracks

These types of cracks normally occur either in the weld metal or in the heat affected zone adjacent to the weld. Those formed in the weld seam can be longitudinal, transverse or crater cracks. They usually occur at temperatures near solidification. A number of releasing factors could be listed, but the most common reasons are:

Alloy prone to weld cracking
Unsuitable filler metal
Unsatisfactory welding techniques

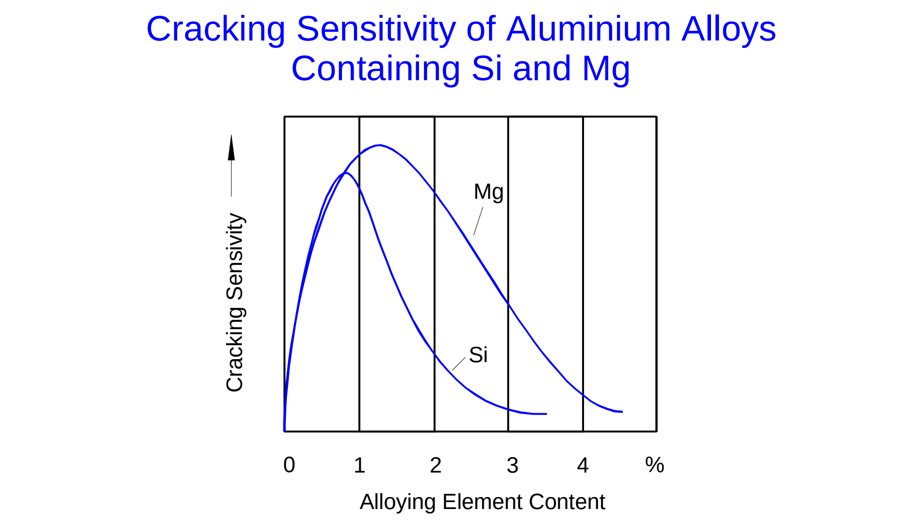
From a metallurgical point of view, such cracks can be classified in two main groups:

Solidification cracks
Solution cracks

Both categories have a connection with shrinkage stresses in the solidification phase, and both are initiated in the grain boundaries.

The solidification cracks

The solidification cracks are strongly related to the chemical composition of the base material, but the cracking sensitivity is also dependent of the metal grain sizes in the weld seam. It is normally the non heat treatable alloys that are sensitive to this type of cracking, such as the 5000 series alloys (AlMg). The sensitivity is normally greatest at approximately 1,5 % Mg-content (**Figure 2203.02.13**).



TALAT | Cracking Sensitivity of Al-Alloys Containing Si and Mg | 2203.02.13

The cracking sensitivity will be reduced by keeping the number of equivalent grains up to a maximum, and this can be done by using the highest possible weld speed with highest possible specific heat input. Pulses arc will also have a positive effect.

The solution cracks

The solution cracks are normally occurring when welding the heat treatable alloys. The problem is connected to the ratio between the alloying components in the base material and the choice of the filler metal.

When welding the 6000 series alloys, there are normally three basic types of filler metal to be chosen:

4043 (AlSi5)
5356 (AlMg5)
5183 (AlMg4,5Mn)

The 4043 alloy has a lower cracking sensitivity, but also a lower tensile strength over the weld seam. The 5356 alloy, however, has a higher strength but also a higher cracking sensitivity.

The choice could seem difficult, but the 5356 alloy is widely used, and an educated and experienced welder will normally have no problem to reduce the problem to a minimum. The measures are more or less the same as those for avoiding the solidification cracking:

- highest possible welding speed
- highest possible specific heat input and
- similar effects to keep the number of equivalent grains in the weld bead up to a highest possible level.

Weld Imperfections

When welding aluminium and other metals, the product quality is dependent on basic factors, such as:

- Sufficient quality control procedures, good workmanship, local facilities, an also functional equipment.
- In addition to relevant certificates, a welder often needs months of relevant experience to be practical classified to weld critical structural welds.

Under all circumstances, there are possibilities of irregularities during the welding process, and weld imperfections can occur.

Common faults in the aluminium TIG and MIG welding process are:

- Pores and contaminations
- Insufficient bonding
- Too high or too low penetration effect
- Weld cracks
- Unsatisfactory surface, craters, sooty weld surface area etc.

And the usual reasons for such problems are:

- Unsatisfactory groove preparation, cleaning and gas protection
- Wrong welding parameters and unsatisfactory technique
- Wrong choice of filler metal
- Technical irregularities on welding equipment
- Unsatisfactory quality control procedures

The following listing gives an overview of the different typical imperfections and also possible fault reasons:

Imperfection	**Cause**
Pores *	**Unsatisfactory cleaning gas protection** Gas hose leakages Air draught Poor gas quality Weld position/root localization Damages gas nozzle Dirty or oxidized filler wire Pollution from environments Too short or too long arc
Too high penetration	**Heat input too high/too low**
Too low penetration	**Groove geometry**
Insufficient bonding	**Arc position welding parameters** Current Voltage Torch angle Welding speed Polluted groove surfaces Too low heat input Groove geometry
Contaminations	**Cleaning** Gas protection. Poor oxide break off effect Too high speed
Weld cracks	Start/stop craters Wrong filler metal. Groove geometry Wrong pre-fixture of work-piece.
Root defects	Too much oxide in the weld bead Too low current value Variable or too high speed Wrong root opening Wrong backing design

Surface irregularities, craters and crater cracks are normally results of poor workmanship

* Small and evenly distributed pores should normally have minor or neglectible effects on the mechanical properties of a weld joint.

The Welding Process Economy

Like in all other fabrication processes, a number of details has to be considered to get the best possible economic result.

A few factors:

- Do not overfill the groove. The price on filler metal is high.
- Do not use more gas than necessary. The price on gas is also high.
- If a gas mixture has to be used, choose the lowest possible content of helium.
- Always use the highest possible welding speed on shortest possible arc length.
- A good process planning always pays.

Distortion by Welding

Distortion is caused by inducing or relieving stresses within a member of the structure. Such stresses can be both induced and relieved by

- welding
- heating and cooling
- mechanical work

Welding stresses are mainly caused by

- Temperature exposure
- Resistance to free movement
- The materials coefficient of thermal expansion
- The difference in yield strength between the base and the filler material

The potential of weld distortions in aluminium can occasionally be somewhat bigger than for steel, and it is, therefore, even more important to consider the possibilities and to plan how to prevent such problems as far as possible.

However, since it is virtually impossible to eliminate distortion in welded structures entirely, it is important for the designer to clarify in advance what distortions can be permitted.

Some basic considerations that should be done both during the design and the fabrication processes are:

Design:

- Balance the welds around the metal or the construction axis.
- Use minimum size welds and as few welds as possible.
- Allow good access to the welds.
- Specify tapering of heavy sections at joints to thin sections.
- Place welds parallel to direction of stress.

Fabrication:

- Preset the components and allow movement within the jigging or clamping fixture.
- Restrain shrinkage by rigid jigging and do not remove until work is cool (can cause cracks).
- Use adequate tack welding.
- Use the highest possible welding speed.

Rectification of Distortion

If it is found necessary to correct distortion, this can be done by using a suitable former in hydraulic or mechanical presses and by inducting correcting stresses by heating.

Because of the high conductivity of aluminium, it is necessary to use an intense, localized heat source, such as the TIG arc to set up differential stresses. This requires a very high degree of skill and experience. Flame heating is recommended.

Due to the relatively high strength and also the low modulus of elasticity aluminium has a high resistance towards mechanical forces, and also a high spring-back tendency. Therefore, it can sometimes be very difficult to correct bigger construction parts by using traditional fabrication shop equipment.

Inspection and Testing Methods

The same methods as used on steel can also be used on aluminium, though some of the quality acceptance criteria may vary. There are two basic methods for testing, non-destructive testing or examination and destructive testing.

Non-Destructive Testing or Examination (NDT/NDE)

Visual inspection
Liquid penetrant test (Dye-pen)
Ultrasonic testing
Radiographic testing

Destructive Testing

Tensile test
Bend test
Break test
Metallographic test

Non-Destructive Testing

Visual Inspection:

The visual inspection normally includes control of welding parameters, equipment and filler metal. By this method it is possible to detect a number of weld faults:

Lack of root fusion
Spatter
Excessive dressing or overfilled groove
Undercut
Shrinkage grooves
Excess penetration
Root concavity
Incompletely filled grooves
Start and stop craters/cracks
Visual cracks in the weld

Liquid Penetrant Test (Dye-Penetration):

This method is used on the welding surface area and it is suitable to detect imperfections that are hardly or not visual, but still open to the surface. A liquid penetrant containing a visible dye is applied to the surface. The penetrant is drawn into any imperfection, and after a short time of function, the access penetrant is carefully removed, and a developer is sprayed on. Any surface imperfections will thereby be clearly visible.

Ultrasonic Testing:

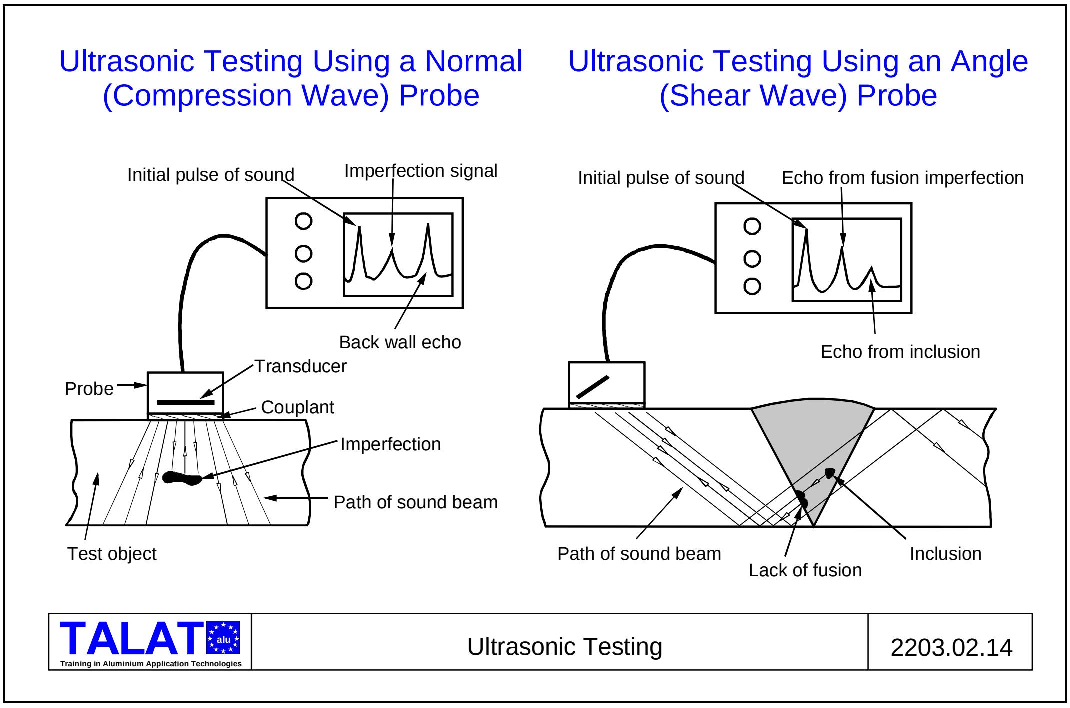
This method utilizes extremely high frequency sound waves, transmitted by a probe or transducer (**Figure 2203.02.14**). The waves pass into the material and are reflected off interfaces created by the presence of internal imperfections. Some of the reflected waves are detected by a receiving transducer which convents the wave into an electrical signal. This signal is displayed on a screen.

Advantages:

- Exposes most types of imperfections.
- Can be used without any danger to the environment and to the equipment operator.

Disadvantages:

- Generally not suitable on material thicknesses under 10 mm.
- Not suitable for examination of fillet welds.
- High level of preparatory arrangements, such as calibrating the equipment, cleaning etc.
- Relatively slow in operation.
- Normally no physical documentation/recording.
- Expensive equipment.



Radiographic Testing:

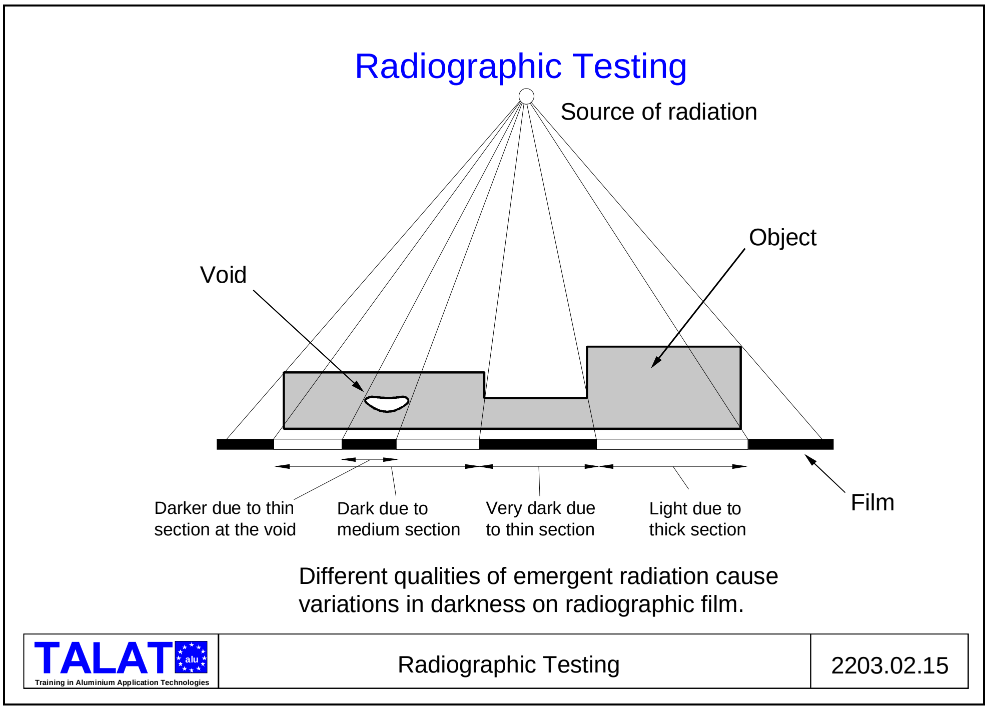
In this test (**Figure 2203.02.15**) the material is exposed on one side to ionising radiation from either an x-ray or a radioactive isotope. A film is placed on the opposite side of the weld to record the quantity of radiation transmitted through each part of the weld and the adjacent parent material. After exposure and development, the film will show in shades of grey and black the image of imperfections, and lack of fusion defects.

Advantages:

- Exposes both surface and inside weld imperfections.
- Less demand for preparatory arrangements than for ultrasonic tests.
- The test result is recorded on film, and can be used as quality documentation.

Disadvantages:

- Not suitable on fillet welds.
- The test area must be prohibitive barricaded, due to dangerous radiation possibilities.
- The inspector must wear protective clothing, and he should also have a high degree of training.
- The equipment is relatively heavy and expensive.



Destructive Testing

Tensile Testing:

The method is used to determine the strength of a welded joint, although it may also reveal the presence of defects in the test sample.

The geometry and dimensions of the test specimen are usually set in national or international standards.

The common type of tensile testing on aluminium weldments is taken transverse to a butt weld with the weld placed approximately in the middle of two pieces of a parent plate.

Bend Test:

The welded test specimen is placed in tension by bending over a former of specified dimensions. The test is done to assess the soundness and transverse ductility of the welded joint. The bend test is examined visually.

Break Test:

The method is used to reveal a presence of imperfections, such as inclusions, lack of fusion and porosity in butt and fillet welds. The welded test specimen is bent over by force until it fractures.

Metallographic Test:

Metallographic tests are carried out to reveal the macro- or microstructure, normally in the weld seam and the fusion area between the weld seam and the base material.

These tests require special etching and polishing equipment, and also a suitable microscope including photographic recording possibilities for documentation. This test method is often used to examine the prescribed welding data for setting a welding procedure specification or also as a documentation of the welding data being used.

Quality Control Aspects

To be able to take optimal advantage of the possibilities of using aluminium in welded constructions, all involved project participants should have the necessary and relevant understanding of both, the material and the fabrication processes. It is also very important that the internal and professional communication and understanding between these people is the best. The main QC-factors in the welding shop and during the welding process are:

The welding shop:

- All material surfaces and welding equipment components should be clean.
- Avoid dusty air and air draught.
- Always use clean clothing and gloves.
- Do not fabricate aluminium and steel in the same room or area.

The equipment and preparations for welding:

- Check the equipment. Avoid leakages in hoses and their connections.
- Keep the electrical contact areas clean, and check the earth connection to be satisfactory.
- Control all given welding/oxidized filler rod.
- Check all given fabrication tolerances.
- Plan the pre-setting or jigging of the welded component to avoid unacceptable distortions.
- Clean the welding groove area before welding start.
- Check all personal and environmental safety precautions.

The welding process:

- Use the highest possible welding speed.
- Try to keep the heat input in balance around the component gravity or construction axis, and also try to weld the longest seams first.
- Do not loosen the component pre-fixing until the metal temperature has fallen to a normal shop level.

2203.03 Literature

TALAT Lectures No.:

1301 Rolling: the Process and the Product

1302 Extrusions: Alloys, Shapes and Properties

4100 Mechanical Fastening Methods

4200 Arc Welding of Aluminium and Aluminium Alloys

4300 Beam Welding Processes

4400 Friction, Explosive and Ultrasonic Welding

4700 Adhesive Bonding of Aluminium

2203.04 List of Figures