TALAT Lecture 2102.04

A Compressed Air Tank for a Lorry

28 pages, 30 figures

Basic Level

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Objectives:
This chapter is an example of product development. The goals are:
to impart knowledge about:
- rolling aluminium
- deep-drawing aluminium
- welding aluminium (MIG and TIG)
- choice of alloy - rolling/deep-drawing/welding

to provide insight into:
- how to develop a product using the general specificiations and the interaction between form, material and processing chain
- the importance of being thoroughly familiar with the different design materials, their processing possibilities and properties.

Prerequisites:
The lecture is recommended for those situations, where a brief, general background information about aluminium is needed as an introduction of other subject areas of aluminium application technologies.

This lecture is part of the self-contained course „Aluminium in Product Development“ which is treated under TALAT lectures 2101 and 2102. It was originally developed by Skanaluminium, Oslo, and is reproduced for TALAT with kind permission of Skanaluminium. The translation from Norwegian into English was funded within the TALAT project.

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2102.04 A Compressed Air Tank for a Lorry

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Introduction

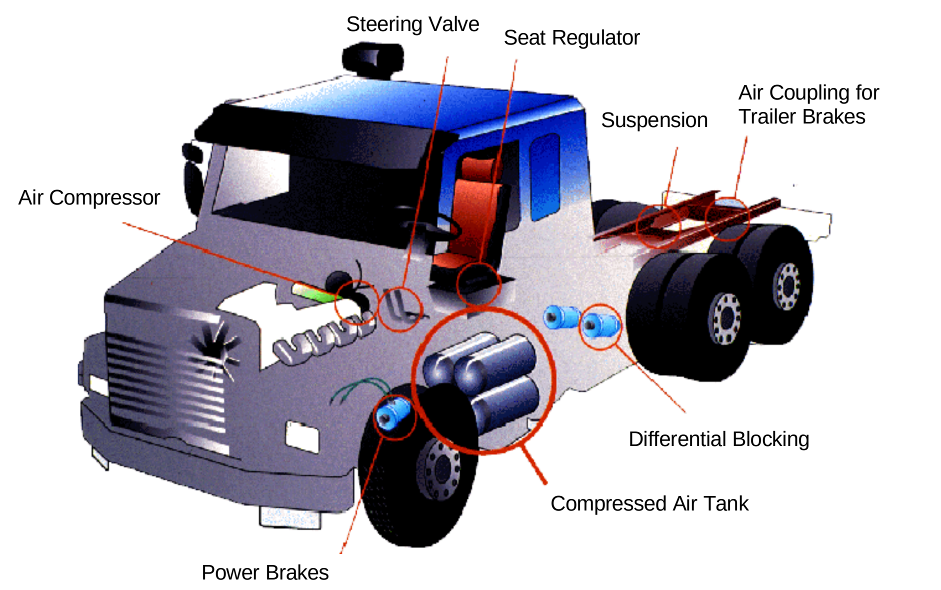
Drivers of heavy vehicles such as lorries and buses require extra power to perform certain functions, including:

Braking
Steering
Gearing and differential blocking
Clutching
Exhaust braking
Seat suspension/regulation
Suspension
Braking the trailer (see **Figure 2102.04.01**)

Pneumatic, hydraulic and electrical systems are all used to provide the added power needed. Pneumatic power-enhancement is commonly used for the braking systems of lorries due to its:

Reasonable cost
Excellent reliability
Long life
Simple maintenance
Familiar technology

We are going to manufacture a container for the storage of compressed air in a pneumatic braking system for buses and lorries.



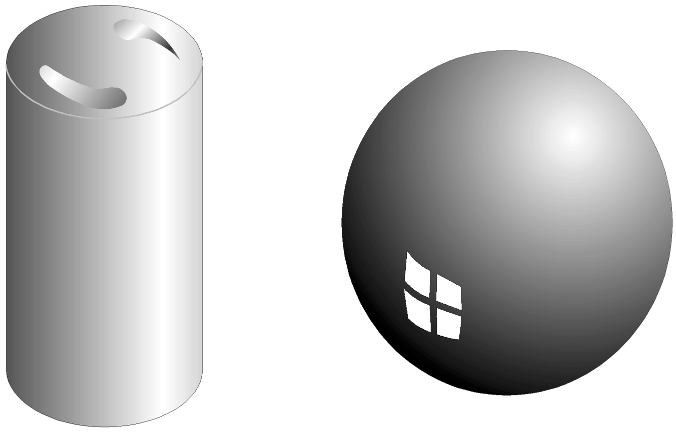
TALAT	Compressed Air Tank for a Lorry	2102.04.01

Basic Specifications

The compressed air tanks used in braking systems are crucial to vehicle safety. Consequently, the design, size and choice of materials are largely determined by the certifying authorities of the countries in which the vehicles will be used.

The primary function of the product is to store compressed air.

A compressed air tank must be either spherical or cylindrical with rounded ends (see **Figure 2102.04.02**). The design possibilities are therefore extremely limited. The figure shows an outline of the two alternative shapes.



TALAT | Forms | 2102.04.02

Based on this, we can go one step further in setting up functional requirements, shown in **Figure 2102.04.03**. As mentioned earlier, a number of requirements apply to such compressed air tanks. In this case, we shall follow the European norms (CEN) (cf. **Figure 2102.04.04).**:

Functions:

- Store Compressed Air
- Release / Accept Compressed Air
- Withstand Pressure

TALAT | Functions | 2102.04.03

Requirements

European Norm (CEN)

- Materials Allowed
  A: Soft, unalloyed Steel
  B: Unalloyed or Non-Heat-Treatable Annealed Aluminium Alloys
- $V_{tank} \times P_{max} \leq 0.15$ MPa m³
- $P_{max} = 3.0$ MPa
- Joining by Welding
- Working Temperature -50°C to 100°C
- $A_5 \geq 16\%$ in the Rolling Direction
  $A_5 \geq 14\%$ Across the Rolling Direction
- $R_m \leq 350$ MPa
- Minimum Wall Thickness:
  2 mm for Steel
  3 mm for Aluminium
- Max. Working Stress:
  $0.6\ R_{ET}$ or $0.3\ R_m$

TALAT Training in Aluminium Application Technologies | Requirements | 2102.04.04

Note the requirement limiting the choice of materials to unalloyed aluminium or non-heat-treatable aluminium alloys (provided aluminium is chosen). This extra safety precaution is due to two conditions:

- Over a long period of time, working temperatures of up to 100 °C could weaken the effect of the age hardening treatment in a heat-treated material.
- If an age-hardened alloy were welded, the welding seam could represent a weak spot. That will not happen with an annealed, non-age-hardened alloy (see TALAT lecture 2101.01).

In this case, the automotive manufacturer has posed an additional requirement (see **Figure 2102.04.05**).

Requirements from the Automotive Manufacturer

- Max. Working Pressure 1.0 MPa
- Test Requirement:
  No Visible Leaks at a Pressure of 1.3 MPa

TALAT	Requirements from the Automotive Manufacturer	2102.04.05

The automotive manufacturer has also specified a number of properties into consideration (**Figure 2102.04.06)**: not all properties will be accorded equal importance. We will give the highest priority to the conditions that affect safety.

Properties

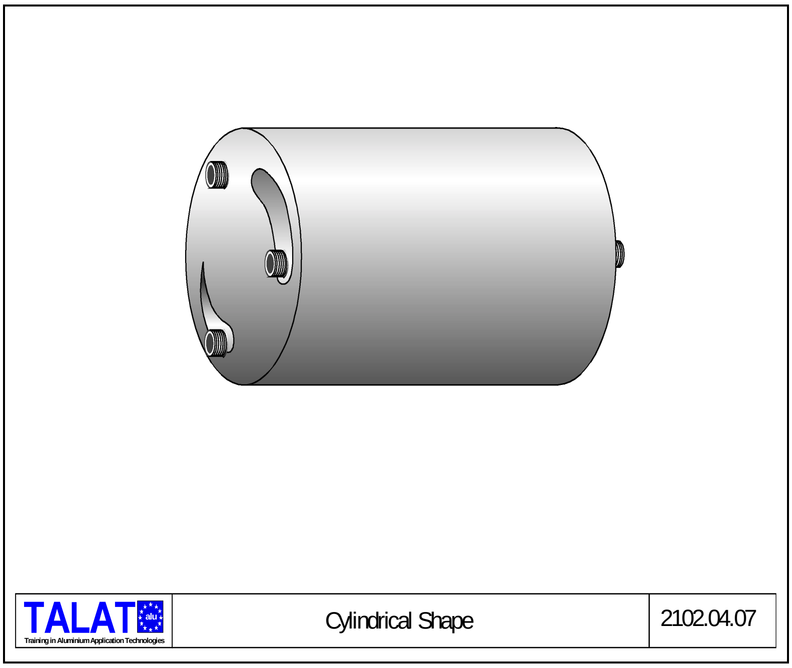
- Good Resistance to External Corrosion
- Good Resistance to Internal Corrosion
- Good Impact Resistance
- High Reliability Throughout the Lifetime of the Vehicle
- Secure Connections to the Rest of the Pneumatic System
- Light Weight
- Ease of Placement and Installation in Vehicle
- Lowest Possible Price

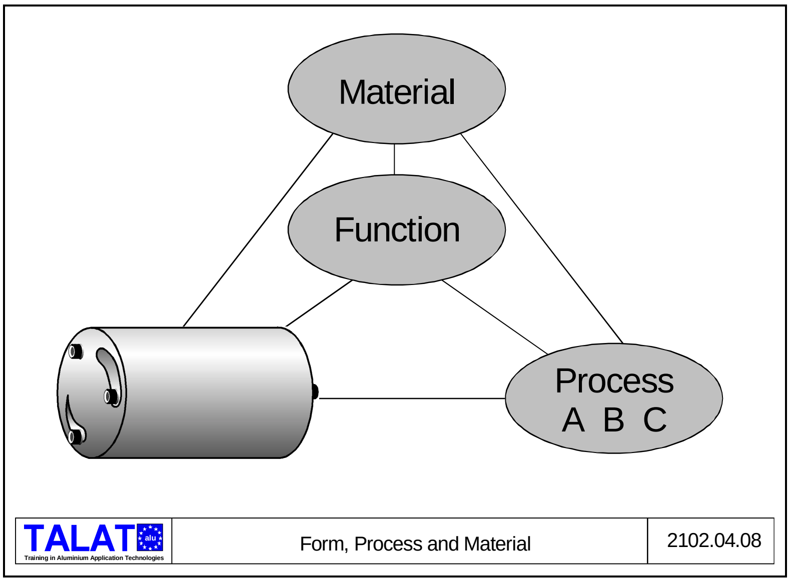
TALAT	Properties	2102.04.06

Form, Process and Material

(**Figure 2102.04.08**)

There are only two possibilities as far as form is concerned, a sphere or a cylinder. Based on the criterion concerning ease of placement and installation in vehicles, we will select the cylindrical shape (see **Figure 2102.04.07**).



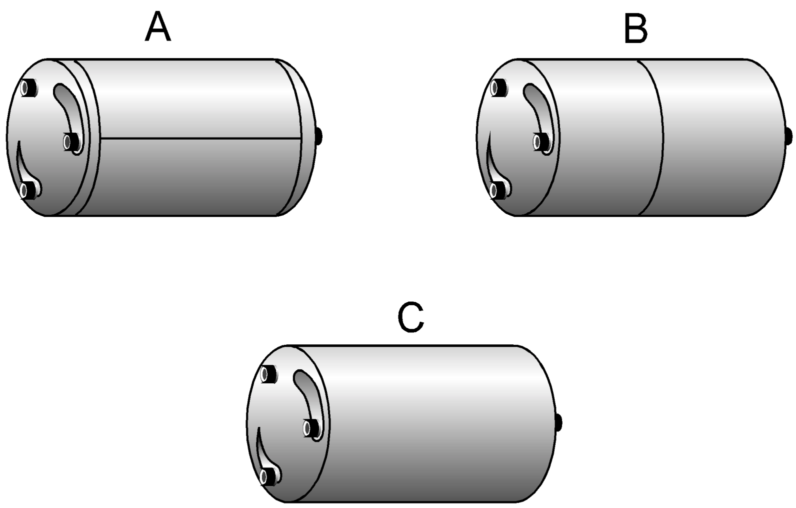


Since we have now decided on the form of the product, it seems natural to take a closer look at potential production processes (**Figure 2102.04.09**):

A. Two shallow ends could be fabricated in a simple tool. There would be a minimum of scrap if we use two small circular blanks and a rectangular sheet. This solution involves welding around the diameter of the container twice and making one lengthwise seam.

B. The tank can also be fabricated by extending the end pieces, which would also eliminate the need for the rectangular sheet. This solution calls for just one welding seam.

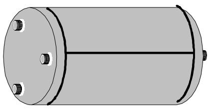
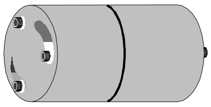
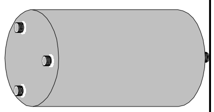
C. We might also envision a solution whereby welding is avoided completely. In this case a cylindrical container (with a bottom) would be drawn up, then the open container would be closed in a spinning operation.
It is impossible to take any decision on these options without first taking the time to consider which material we will use. Our options are steel and aluminium **(Figure 2102.04.10)**.



TALAT Training in Aluminium Application Technologies	Three Different Designs	2102.04.09

Alternative Solutions

Material and Design

			
Aluminium		+	
Steel	+		
Plastic			+

TALAT	Alternative Solutions, Material and Design	2102.04.10

Steel: Compressed air tanks are usually fabricated of unalloyed steel. The material's excellent weldability favours welding over deep drawing. This means that alternative A is preferable, although alternative B is also a possibility.

Aluminium: Aluminium can also be fabricated as illustrated in alternative A. Considering that it takes more preparation to weld aluminium, alternative B would be preferable with this material.

Alternative C could also be fabricated in aluminium. This model requires no welding. Consequently, it would lend itself to the use of a heat-treatable alloy (see TALAT lecture 2101.01). Then the shaping could be completed while the material is in a soft state and its strength could be enhanced by subsequent heat-treatment. It would certainly be possible to meet the strength requirements for the tank by using significantly thinner materials than the 3 mm thickness of aluminium prescribed by the European norms. This alternative features interesting aspects which would certainly have been worth exploring had we not been subject to the limits imposed by the European norms. This is a prime example of how the formulation of requirements can present an obstacle to innovation. Had the requirements been formulated to focus on strength and safety, alternative C would still have been a viable option.

We might also picture solution C in fibreglass-reinforced epoxy or polyester. Those materials are lightweight and offer excellent corrosion resistance. They are also very strong, but not particularly ductile, so they do not satisfy the European norms. Alternative C must therefore be eliminated in this case.

Choice of Materials/Production Technique

We are thus left with two alternatives (see **Figure 2102.04.11**):

Choice of Solution

Material	Design	Reason
Steel	Alternative A	Low Production Costs
Aluminium	Alternative A	Lengthwise Welding Seam not Adviseable
	Alternative B	Less Welding than A
	Alternative C	Technically Possible, but Difficult and not Economic Today
Plastic	Alternative C	Not CEN Approved Materials

TALAT Training in Aluminium Application Technologies | Choice of Solution | 2102.04.11

Steel has been, and still is, by far the most commonly used material in air tanks for pneumatic brakes. The choice of steel is mainly due to low material and fabrication costs. Steel is easy to process and weld. If steel is chosen, alternative A would be the best solution.

The European norms require that steel be given a good anti-corrosion treatment. That kind of protection calls for surface treatment of the steel. The tanks must also be given an anti-corrosion treatment on the inside, as condensation could result in the formation of rust. Rust is also a risk factor because it could lead to valve malfunction, etc. Figure xx shows that apart from its low price, steel does not score very highly in relation to the properties we set up. It might therefore be wise to determine whether aluminium might be a better alternative.

Aluminium has a number of properties which, in this case, could be used to our advantage. Its light weight and good corrosion resistance are both important. The weight savings in this case would amount to nearly 50 per cent and have an effect on the total weight of the vehicle. The weight savings for lorries have sometimes been estimated as being worth as much as US $ 1/kg, but this figure can vary considerably. Nonetheless, the fact remains that a lighter weight structure can be considered even if it costs more to produce. Lighter weight also eases the installation of the tanks. Growing consideration for the health and welfare of factory workers means this this characteristic is becoming increasingly more important.

Good corrosion resistance is essential for safety. Aluminium also possesses excellent formability, which opens up the possibility of deep drawing (cf. Special Study on Deep

Drawing) in a case like this. Consequently, we choose alternative B for production in aluminium. The tool costs for this production technique will be relatively high. That, added to the relatively high cost of aluminium, will result in considerably higher production costs than would have been the case had we elected to use steel.

Figure 2102.04.12 indicates how aluminium scores in an evaluation of the functional requirements.

Evalution of Steel versus Aluminium

	Steel	Aluminium
Weight	-	+
Corrosion - Res.	-	+
Surface Treatment	-	+
Reliability	-	+
Maintenance	-	+
Price	++	--

Choice: Aluminium is Preferable, Provided one is Prepared to Pay the Price

TALAT Training in Aluminium Application Technologies | Evalution of Steel versus Aluminium | 2102.04.12

Conclusion: Both solutions satisfy our requirements. Our choice will therefore depend on how we choose to rank the evaluation criteria. In this case, weight savings, reliability and low maintenance costs weigh so heavily that we opt for aluminium.

Choice of Alloy

The CEN norms preclude the use of anything but unalloyed aluminium or non-heat-treatable aluminium alloys. This limits us to the AA 1000 series (unalloyed or pure aluminium), the AA 3000 series (AlMn) and the AA 5000 series (AlMg) (**Figure 2102.04.13**).

Possible Alloys

AA 1XXX	Pure Aluminium
AA 3XXX (Al Mn) AA 5XXX (AlMg)	Non-Heat-Treatable Alloys

Adding Mn and / or Mg Increases Strength and Decreases Formability

The Choice of Alloy will be a Compromise Between the Strength and Formability Requirements

TALAT Training in Aluminium Application Technologies | Possible Alloys | 2102.04.13

All the alloys in these groups possess good corrosion resistance and weldability. On the other hand, strength and formability vary significantly. The addition of Mn and/or Mg increases strength and reduces formability. High strength means we can use thin materials, which would enable us to cut down weight and save on the consumption of materials. (Remember the CEN norms require a wall thickness of at least 3 mm). We must also choose a material that satisfies the high formability requirements posed by two-step deep drawing (see Special Study on Deep Drawing). The choice of alloy will therefore involve striking a compromise between strength and formability.

Before proceeding, we have to calculate the stress in the tank at maximum pressure, cf. the requirements which state that the maximum working stress shall be 0.6 R_{ET} or 0.3 R_m. R_{ET} is the proof stress at the highest working temperature. For our range of potential alloys, $R_m > 2 \times R_{ET}$. Thus the requirement that the stress must not exceed 0.6 R_{ET} will guide our choice of sheet thickness.

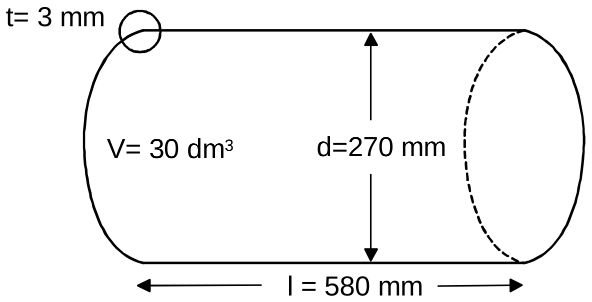
We can illustrate this point by considering a tank with the following dimensions:

Tank volume:	V	=	30 litres
Tank's thickness:	t	=	3 mm
Internal diameter:	d	=	270 mm
Length:	l	=	580 mm
Max. pressure:	p	=	1 MPa
The tangential stress is:	σ_t	$\leq$	$0.6R_{ET}$

(σ_t is twice as high as the axial stress and thus determines the dimensions, cf. also **Figure 2102.04.14**).

The requirement is that the yield point for the highest working temperature must be greater than or equal to 75 Mpa.

Example Requirement for R_{ET} at a Temperature of 100 °C



$$\sigma_t = \frac{p \times d}{2 \times t} = \frac{1\ \text{MPa} \times 270\ \text{mm}}{2 \times 3\ \text{mm}} = 45\ \text{MPa}$$

$$\sigma_t = 0{,}6\ R_{ET}$$

$$R_{ET} \geq \frac{\sigma_t}{0{,}6} = 75\ \text{MPa}$$

TALAT (Training in Aluminium Application Technologies)	Example Requirement for R_{ET} at a Temperature of 100 ° C	2102.04.14

The table (**Figure 2102.04.15**) lists alloys of the AlMg (the AA 5000 series) group and their values in an annealed temper for $R_{p0.2}$, R_{ET} (at 50 °C and 100 °C), and the maximum working temperature according to the CEN standard). Alloys of the AA 1000 and AA 3000 have less strength than AA 5000, so they have not been included.

ISO	International Designation (AA)	$R_{P0.2}$ (MPa)	R_{ET} (MPa) 50°C	R_{ET} (MPa) 100°C	Max. Working Temp. (°C)
AlMg2.5	5052	60	60	57	100
AlMg2Mn0.8	5049	80	80	70	100
AlMg3	5754	80	80	70	100
AlMg3Mn	5454	90	90	90	100
AlMg4.5Mn0.7	5083	125	125	(120)*	65

*) For Interpolation Only, Temperature Limit 65°C

Choice: AlMg2Mn0.8

TALAT (Training in Aluminium Application Technologies)	Strength Values of Different Alloys	2102.04.15

We must rule out AlMg4.5Mn0.7 because the maximum working temperature is too low. The auto manufacturer's specification is +100 °C, which is also the CEN norm's maximum working temperature. Of the other alloys, only AlMg3Mn satisfies the requirement that R_{ET} must be greater than 75 MPa. This calculation is based on a wall thickness of 3.0 mm. By increasing the wall thickness, we decrease the stress and the R_{ET} requirement. If t = 3.25 mm, the requirement becomes $R_{ET} \geq 69$ MPa. This requirement is fulfilled by the more lightly alloyed alloys, AlMg2Mn0.8 and AlMg3. The disadvantage of choosing any of these is that we are left with a higher weight and more consumption of materials. The advantage is better formability. The advantage wins in this case and, after testing, we decide on AlMg2Mn0.8. The choice between AlMg3 and AlMg2Mn0.8, which score almost equally in strength and formability, was made on the grounds that AlMg2Mn0.8 has slightly better weldability.

In actual practice, the chosen sheet thickness is roughly 3.7 mm. This is necessary because deep drawing reduces the thickness in certain areas and the minimum thickness requirement has to be satisfied all over.

Manufacture of the Compressed Air Tank in Aluminium

We have decided that we want to manufacture the tank in aluminium; we have chosen the alloy which best fits the specifications and we have decided to deep draw the two halves of the tank and weld them together in the middle. This production process starts with a circular blank made from aluminium sheet.

Before proceeding, we should take a brief look at the fabrication of the sheet, the punching of circular blanks and the deep drawing of aluminium.

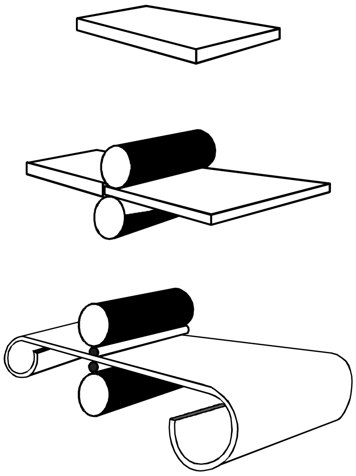
SPECIAL STUDY: Rolling Aluminium

Sheet is manufactured in a rolling mill. The basic material is die-cast ingot or continuous strip coils. The ingot is a cast material scaled to fit the rolling process and it is usually 200 - 600 mm thick (see ***Figure 2102.04.16****). Prior to rolling, the surface must be milled to remove the casting skin. Then the ingot is heated to hot-rolling temperature, about 550 °C. Heating is necessary to reduce the deformation force required and to prevent strain hardening or cracking.*

Hot rolling

Hot rolling *involves rolling passes with reductions of 10 - 30 mm, depending on thickness and alloy, down to a final thickness of less than 8 mm. The width remains fairly constant. Sheet of this thickness can be coiled. Hot rolling breaks down the cast structure. Hot-rolled materials have a somewhat broader range of dimensional* *tolerance than cold-rolled ones, and their surface is duller. The ultimate thickness of the hot-rolled material depends on the properties desired in the final material, which are usually determined by cold rolling and possibly heat-treatment.*

Sheet



PROCESS	PRODUCT
Cast	Ingot 300mm thickness
Hot rolling	5mm thickness Wide tolerance Coarse surface
Cold rolling 50% reduction per pass	3mm thickness Narrow tolerances Smooth surface

TALAT Training in Aluminium Application Technologies | Sheet | 2102.04.16

Cold rolling

Cold rolling *is done in a four-high rolling mill. The roll stand consists of two small diameter work rolls flanked by two large back-up rolls. The small diameter of the work rolls reduces the roll surface and thereby also the deformation force required. It also allows a larger per pass reduction of the material being rolled. The back-up rolls prevent the work rolls from bending.*

Cold rolling usually reduces thickness by roughly 50 per cent per pass. Hardness increases in direct proportion to the degree of rolling and the material is assigned a characteristic hardness designation as shown in ***Figure 2102.04.17****.*

Temper

Cold Reduction (%) (Approximate)	Temper Designation	
20	H 12	Quarter- Hard
33	H 14	Half-Hard
50	H 16	Three-Quarter Hard
67	H 18	Hard
80	H19	
Soft Annealed at 380°C	O	Annealed

TALAT Training in Aluminium Application Technologies | Temper | 2102.04.17

To obtain a combination of high strength and elongation values, it is possible to cold roll a material to achieve some hardness, then heat it for a brief period at 250 °C - 350 °C. This is called partial annealing. The process results in a controlled softening (reduction of hardness) and a significant improvement in the elongation properties. In this temper, the materials are designated as H22, H24 and H26, where the R_m *values correspond to H12, H14 and H16.*

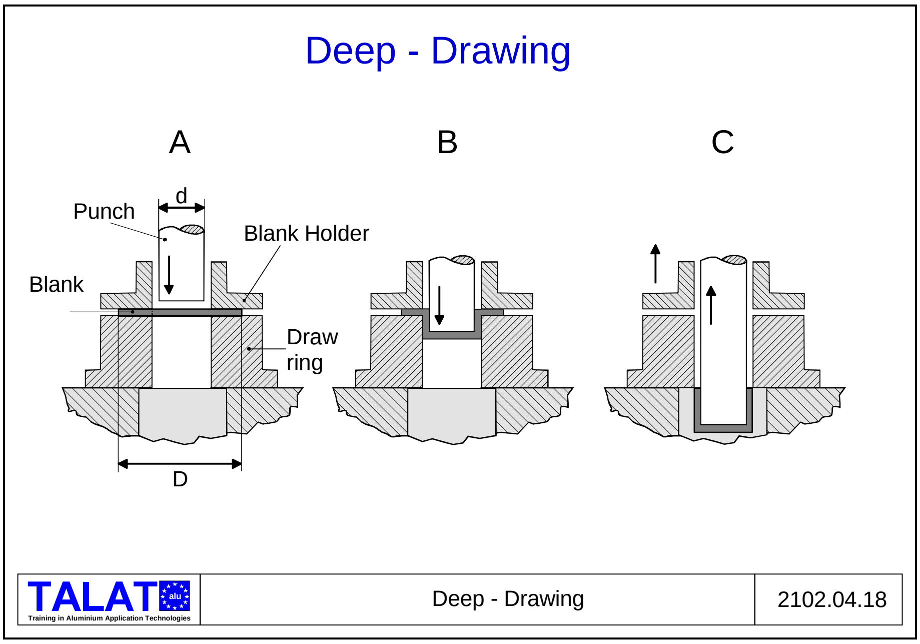
Circular blanks

***Circular blanks** are round pieces punched out of sheet. Their mechanical properties are identical to those of the sheet. Punching is accomplished by pressing out a blank against holes in a counterdie. Tool clearance is very important in punching operations. If the gap between the punch and the counterdie is too wide, the material will tear, leaving a jagged edge. A closer fit (down to 0.1mm clearance) will result in smoother edges and fewer burrs, but creates more noise during fabrication. Close fits call for precision tooling. The tools used are usually equipped with pillar die sets. The blanks are subjected to a softening anneal after punching.*

SPECIAL STUDY: Deep Drawing

Drawing is a forming technique which allows a sheet to be shaped into a cup-shaped vessel in the cold condition. Deep drawing is the name of the technique used when the height of the "cup" is so great that the sheet has to be held in place by blank holders to prevent wrinkling during the shaping process.

Figure 2102.04.18 *illustrates how this drawing process works:*



A) The blank holder secures the circular blank.

B) The drawing punch draws the sheet down into the draw ring. The material must flow over the edge of the draw ring and be subjected to heavy bending dominated by radial stretching. This can lead to a certain thinning of the sheet material in the bottom, particularly in the transition zone between the bottom and the sides of the cylinder. The reduction in the thickness of the bottom will be more marked if the bottom is rounded (as is the case with our compressed air tank).

The diameter of the flange is reduced during drawing. This compresses the flange in the direction of the tangent, the thickness increases and the material gets harder.

If the drawing ratio, i.e. the ratio between the diameter of the blank and that of the punch, is too great, the deformation resistance in the flange will increase and cause fractures during drawing.

C) The last phase of the drawing process returns the blank holder and punching die to their original positions, and a deflector device pushes the circular blank off the punching die.

The maximum drawing ratio depends on the sheet material, the shape of the die, lubricant, drawing speed, etc. For the most commonly used annealed aluminium alloys, *we can allow a maximum drawing ratio of 1.9. The maximum drawing ratio will be lower for subsequent drawing operations.*

***Figure 2102.04.19** shows the maximum deep-drawing ratios of some non-heat-treatable alloys in various tempers when drawing cylindrical components. We can obtain a drawing ratio higher than 1.9 by drawing in several operations. As the table shows, intermediate annealing may be necessary.*

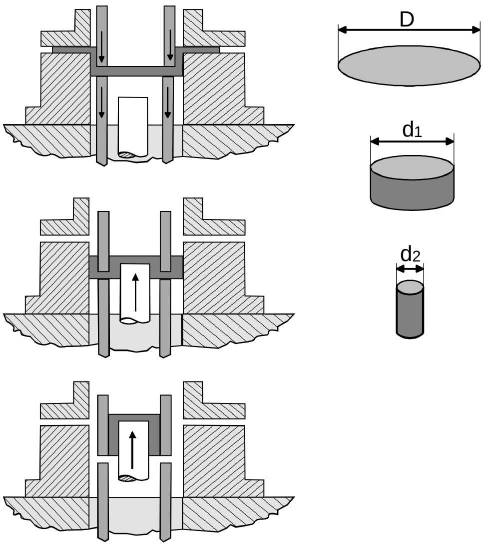
Maximum Drawing Ratios of Some Non-Heat-Treatable Alloys Al99.5, Al99.0, AlMg2.5, AlMn in Different Tempers when Drawing Cylindrical Details:

Temper	Drawing Ratios D/d Operation Nr. 1	2	3	4
O, H12, H14	1.9	1.4	1.3*	1.2*
H16, H18	1.4	1.3	-	-

* AlMg2.5 Usually Calls for an Intermediate Anneal

TALAT Training in Aluminium Application Technologies | Drawing Ratios | 2102.04.19

Reverse drawing can also be employed to draw a cup shape into a deeper, narrower cup shape in a single operation, i.e. it is a so-called double process. ***Figure 2102.04.20*** *outlines the principle behind this.*



Maximum Drawing Ratios

Step 1: D/d_1 = app. 1.9

Step 2: d_1/d_2 = app. 1.4

Total : $D/d_1 \times d_1/d_2$ = app. 2.7

TALAT Training in Aluminium Application Technologies | Reverse Drawing | 2102.04.20

The advantage of reverse drawing is that two drawing operations are completed in one and the same machine operation. The table shows that we can expect a maximum total deep-drawing ratio of 1.9 x 1.4 = 2.7 (if we assume the material is in a soft state). The cup can be drawn using a mechanical or a hydraulic press. More complex operations like reverse drawing demand precision adjustment of the drawing parameters, so a hydraulic press is preferable.

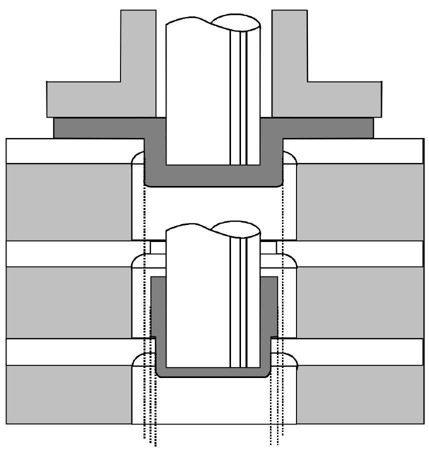
Combination tools for the 1st and 2nd drawing steps are often complex and call for multi-functional presses. Tool design is of great importance to the process. The drawing radius is especially important as it allows the work piece to move with minimal friction. If friction becomes too great, the work piece could quickly become overloaded and break. A larger drawing radius will facilitate the process.

The surface of the work piece is also very important. During particularly demanding drawing operations which involve heavy loads, an uneven surface is preferable because it retains the friction-reducing film of lubricating oil better. High-viscosity lubricating oil that tolerates being pressed over large surfaces makes difficult drawing operations easier.

Pressing is a common forming method. he process offers great freedom of shape and it is very fast. Tool and die costs are often high, however, so the method is best suited to the production of large runs.

Pure deep drawing does not significantly alter wall thicknesses. However, it is common to combine deep drawing with a subsequent reduction of the wall thickness by an ironing process. The vessel is drawn by the punch through a number of drawings that successively reduce the wall thickness by up to 75 per cent (**Figure 2102.04.21**). *This technique is used for the production of soft drink and beer cans, cooking pots and pans, casings, etc.*

Drawing and Wall Ironing (DWI)



TALAT Training in Aluminium Application Technologies | Drawing and Wall Ironing (DWI) | 2102.04.21

We now return to the case of deep drawing the compressed air tank:

Deep Drawing the Compressed Air Tank

The tank will be fabricated by deep drawing two halves which will then be welded together. A cup as high as the one we need here cannot be fabricated in a single deep drawing operation. We saw in figure F-20 that it is possible to achieve a drawing ratio of roughly 2.7 by reverse drawing. In the case of the compressed air tanks, the reverse drawing process involves drawing ratios of approx. 1.7 and 1.3 in the two press operations. The total drawing ratio will thus amount to 1.7 x 1.3 = 2.2.

To start, we select a material that has been hot-rolled down to a thickness of about 5 mm, then cold-rolled to its final thickness. For a tank with a volume of 30 litres and a size as indicated in the example on p. xx, circular blanks with a diameter of 591 mm are needed. The circular blanks are annealed and lubricated before being further shaped in the reverse drawing process. We can also punch out holes for the tube connectors in the same process.

The material is cold-worked during drawing, so the tank parts are annealed before welding .

Before we are proceeding we should concern ourselves with the process of welding Aluminium.

SPECIAL STUDY: Welding Aluminium

Pure aluminium and most alloys are quite weldable. When welding aluminium, however, account must be taken of several of the characteristic features of this metal (see ***Figure 2102.04.22****):*

Aluminium has a low melting point, approx. 660 °C, compared with approx. 1460 °C for steel.

The heat conductivity of aluminium is high (three times that of steel). This means that heat is easily conducted away from the welding point. It is therefore essential that the heat source be powerful enough to reach the melting point.

Aluminium's coefficient of thermal expansion is high ($24x10^{-6}$/K, twice that of steel). Combined with its excellent heat conductivity, this can easily entail significant thermal dimensional changes during both heating and quenching. Consequently, special attention must be paid to ensuring that the structure is not subjected to excessive welding stress.

Aluminium has an especially strong affinity to oxygen, forming an oxide layer that can easily result in weld defects. It is therefore necessary to perform the welding operation in an oxygen-free atmosphere, e.g. in an atmosphere of inert gas such as helium, argon or mixtures of the two.

Welding Aluminium

Important Factors Compared with Steel:

	Aluminium	Steel
Melting Point	660°C	1460°C
Thermal Conductivity	100%	30%
Thermal Expansion	100%	50%
Affinity to Oxygen	High	Low
Change of Strength	Decrease	Increase
Solubility of Hydrogen in the Melt	High	Low

TALAT Training in Aluminium Application Technologies | Welding Aluminium | 2102.04.22

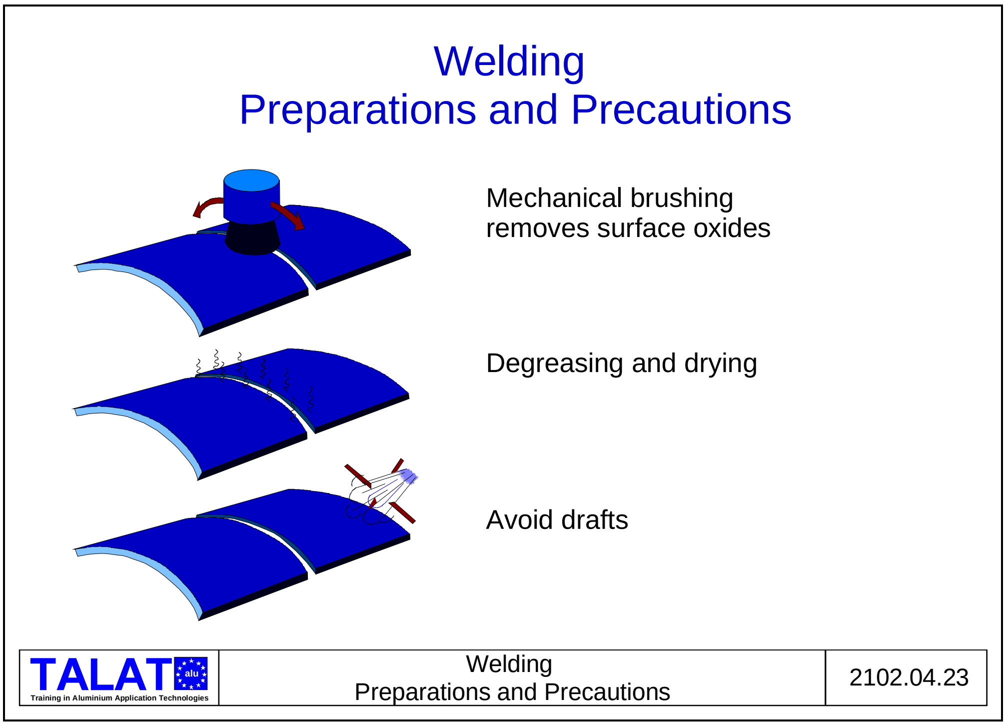
As opposed to steel, aluminium undergoes no thermal structural changes. Heating to near the melting point and subsequent cooling lead to a reduction in strength. In other words, the process does not resemble the welding of steel, where strength is achieved through structural change. While the welding of steel usually leads to an increase in the strength of the weld and the heat-affected zone, welding will weaken aluminium unless the metal has already undergone a softening anneal. When stressed, a welded aluminium structure will incur local deformation in the welded area first.

Aluminium has a high concentration of dissolved hydrogen in its molten state, and a lower concentration when solidified. This can cause porosity in the weld.

Preparations and Precautions

Welding aluminium calls for more careful preparation than welding steel. As mentioned earlier, this is mainly due to aluminium's strong affinity to oxygen and its high thermal conductivity.

It is important to establish a fixed routine for welding preparations (see ***Figure 2102.04.23****):*



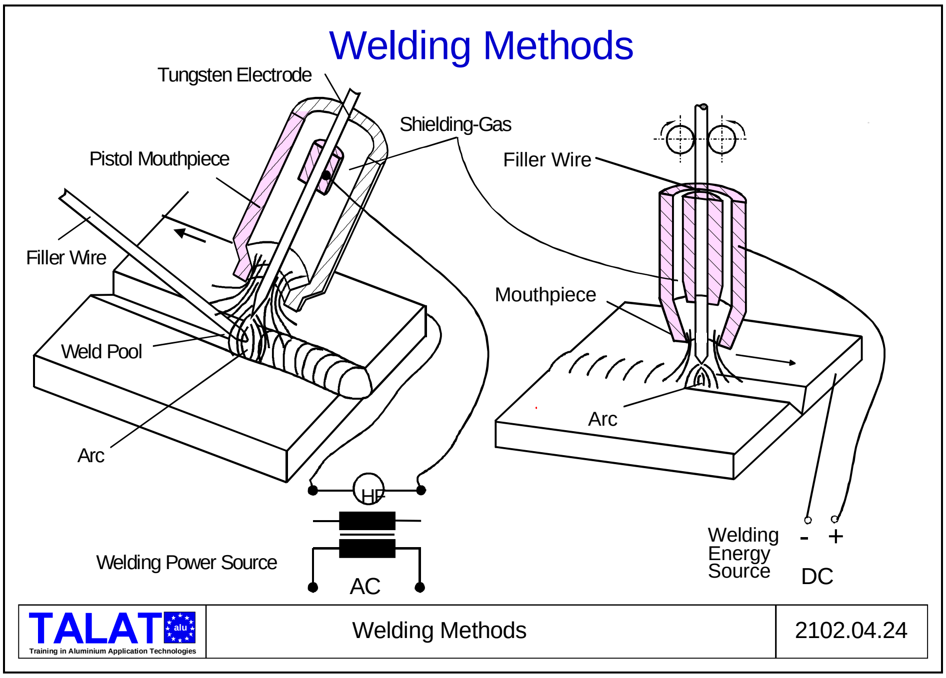
First, it is necessary to remove surface oxides by mechanical brushing, milling, etc.This is important in order to avoid oxide inclusions in the weld. The surfaces to be joined and the area around the welding zone (approx. 50 mm) must then be degreased. The area must be clean and completely dry. If not, grease or moisture could form gases in the presence of the heat from the welding arc and cause pores in the welded joint. Slow solidification due, for example, to a large weld pool or secondary heating, will give any gas bubbles more time to rise to the surface of the welded seam where they will do the least damage. It is essential to ensure that the filler wire is also clean and free of moisture and grease.

Avoid welding in draughty areas (outdoors). Draughts can easily reduce the inert gas protection and interrupt the electric arc, resulting in a sub-standard weld.

Arc Welding

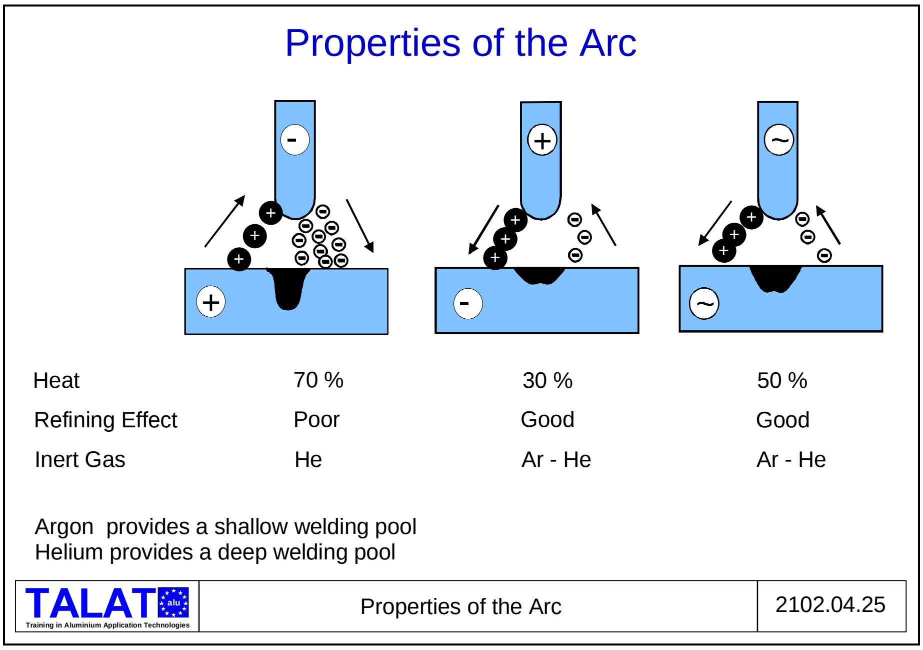
Electric arc welding is the most common welding method employed with aluminium. It is easy to use, attains a high temperature, provides high heat input and is easy to regulate. There are two different kinds of arc welding operations: MIG welding (Metal Inert Gas) and TIG welding (Tungsten Inert Gas), see ***Figure 2102.04.24****.*

In MIG welding, the electrode is the filler material. The electrode is usually positive and the strong heat generated on the electrode by the DC current provides large amounts of deposited metal. The method is quick and it can be automated. he main disadvantage of MIG welding is that it does not lend itself for use with thin materials.

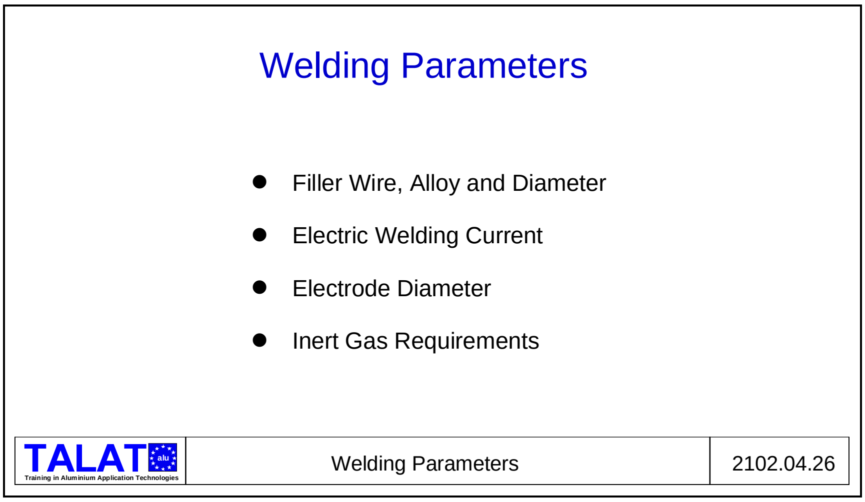


TIG welding uses a permanent electrode made of tungsten. AC current is usually used to prevent overheating. The method works well with thin materials. An added advantage is that it can be used with or without filler material. However, the AC current results in less welding strength than MIG welding.

*An inert gas such as argon or helium is used to protect the weld pool against oxidation. The inert gas is ionized and forms a plasma arc (**Figure 2102.04.25)**. Since helium has a higher ionization potential than argon, the energy in its welding arc is greater, so helium yields a higher temperature.*



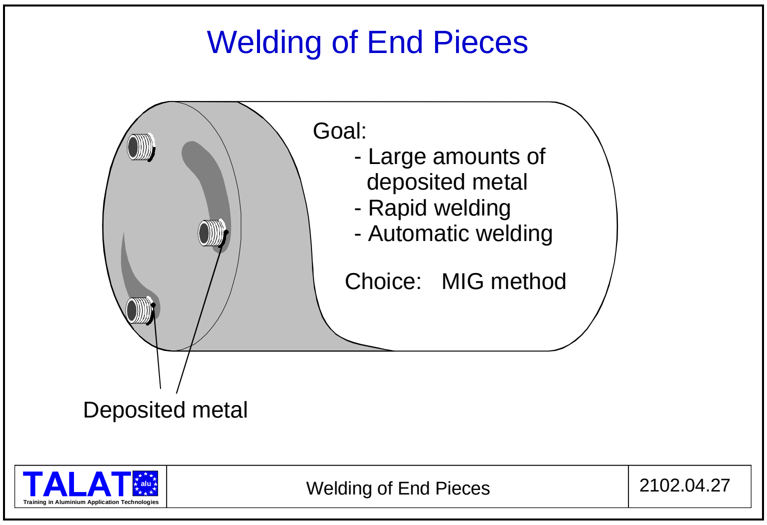
The energy of the welding arc also affects the form of the weld pool. Helium gives deeper penetration, while argon results in more shallow penetration but a broader weld pool. The disadvantage is that helium is very expensive so it is only used in special cases. MIG welding is often performed using a combination of argon and helium. There are manuals available that list the parameters that apply to welding aluminium. Important welding parameters are included in ***Figure 2102.04.26:***



We now return to the case of welding the compressed air tank.

Welding of Tube Connectors

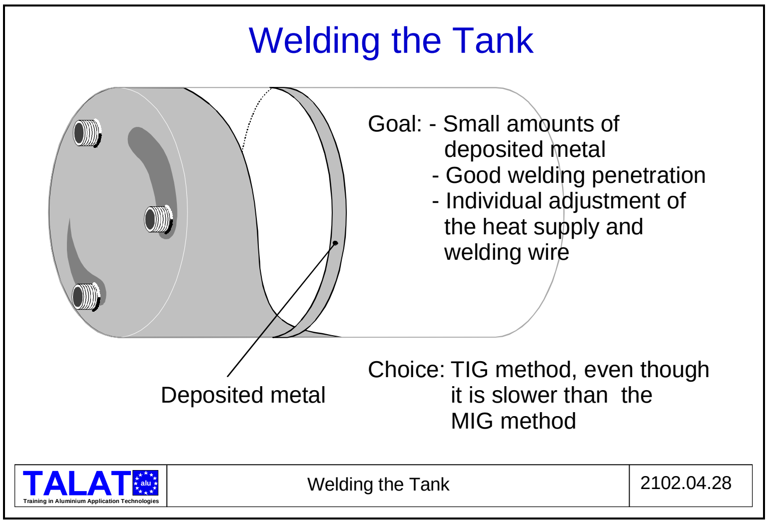
When we are ready to weld the tube connectors, we want to make a fillet in the transition between connector and tank. It is therefore natural to choose the MIG method. It provides plenty of filler material, is fast and lends itself to automation (**Figure 2102.04.27**).



Welding the tank (Figure 2102.04.28)

To weld the two halves of the tank together, we want a quick, automatic welding operation that provides a smooth, handsome appearance. It is important to avoid abrupt transitions that could initiate fatigue cracks. Large amounts of filler material are unnecessary. The parts should have a close fit before welding. Welding parameters must be adjusted to achieve thorough penetration, so it is necessary to adjust the heat supply and welding wire individually.

This favours the TIG method, even though it is slower than with MIG welding.



Product Control

Mass produced products, especially products classified as safety components, must be fabricated according to fixed procedures (**Figure 2102.04.29**). This is part of the product's quality assurance procedure. Following specific written procedures enhances safety because it ensures the product will possess specific properties and be ready at a given time and at a pre-calculated cost. Experience has shown that the cost of waste/rejects far exceeds the cost of implementing a quality assurance programme.

Two important aspects of quality control are the destructive and non-destructive testing of products. Non-destructive control can be conducted on up to 100 per cent of the products, while the destructive control is performed on random samples at a frequency relative to the consequences.

For the compressed air tank, the manufacturer has called for a leakage test carried out by submersion in water. The test is to be conducted on 100 per cent of the tanks and it requires no visible leaks at pressures up to 30 per cent higher than the maximum working pressure.

An example of destructive testing is when the tank is subjected to increasing pressure until it ultimately explodes. This test is chiefly used in connection with development and during the approval procedures. The test can also be used for spot checking (random sample control).

Quality Assurance - Product Control

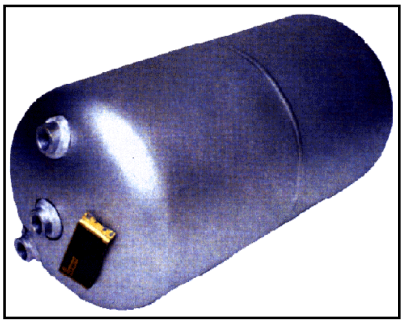
- Production According to Fixed Procedures
- All Units are Tested
  (Requirement: No Visible Leaks when Submerged in Water and Subjected to a Pressure 1.3MPa)
- Spot Checks:
  Apply Pressure until the Tank Bursts

TALAT Training in Aluminium Application Technologies | Quality Assurance - Product Control | 2102.04.29

Final Evaluation

Because of the complex requirements, we didn't have many alternatives to evaluate in this example. We looked at a solution in steel and one in aluminium, both of which satisfied the requirements. luminium was chosen because it could be used to make a product that performed its function better than steel. Although this solution is considerably more expensive to manufacture, it will save money in the long run. In view of the fact that we also achieve a higher level of safety, we have clearly selected the best solution (**Figure 2102.04.30**).

Using aluminium to manufacture compressed air tanks has turned out very well. The product example described here is still competitive.The product could probably be improved even further if the CEN standards had not limited our choice of alloy and material thickness.



Aluminium was chosen in spite of high costs because of:
- Good corrosion resistance
- Absolute reliability
- Low weight

TALAT Training in Aluminium Application Technologies	Photo of Air Tank	2102.04.30

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