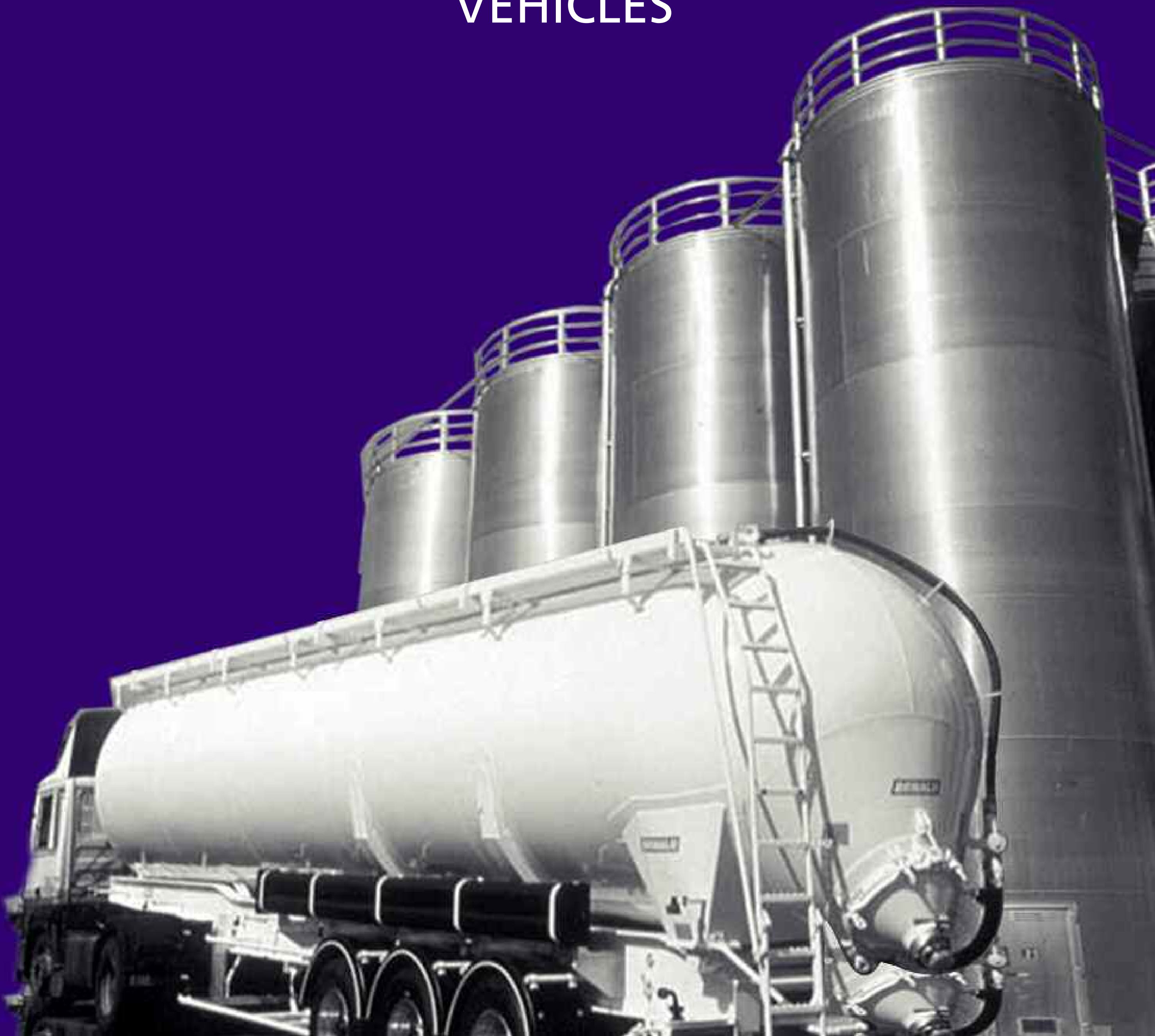
european
aluminium association

ALUMINIUM IN COMMERCIAL VEHICLES

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FOREWORD

Aluminium in Commercial Vehicles has been compiled by the European Aluminium Association in answer to the needs of manufacturers and users of commercial vehicles and accessories. It is a compendium of basic information on such aspects of aluminium as:

- The reasons for using it
- The main rolled, extruded and cast alloys available to manufacturers; their properties, mechanical characteristics etc.
- The design and calculation of structures, fatigue and collision behaviour
- The joining of semi-finished products: fabrication, welding and other joining techniques
- The corrosion resistance of aluminium alloys under service conditions
- Surface treatment
- Cleaning and repair

This guide will be of particular interest to design and process engineers, to repair and maintenance managers and more generally to anyone with an interest in the applications and development of aluminium in road transport.

Given the obvious limitations of a single volume, it has not been possible to deal with all aspects in detail. We have opted to present what we regard as the most up-to-date concepts and have indicated the most relevant standards which the reader can refer to for further information.

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A380
A380
AIRBUS

CHAPTER II

ALUMINIUM IN TRANSPORT

1. One century of aluminium in transport

Airbus A380

In 1903, the Wright brothers made aviation history when they achieved the world's first flight powered by a lightweight engine made with aluminium components. Today, aluminium is fundamental to the aviation industry. It accounts for more than 60% of the structural weight of the Airbus A380, and up to 80% of short- and mid-range aircrafts.

It was in the 1920s that aluminium shipping applications started to expand due to new alloys becoming available for marine applications.

Cruise ship with aluminium superstructure

Today, 1000 high-speed passenger ships are in service, most of them have a structure and superstructure made of aluminium. Cruise ship superstructures are commonly made of aluminium, while over half of all yachts are completely made out of aluminium.

These ships take full advantage of aluminium's lightness and strength, as well as its corrosion-resistance, an indispensable property for marine environments.

Catamaran UAI 50 (Babcock)

TGV Duplex (Alstom-SNCF)

In the 1980s, aluminium emerged as the metal of choice to lower running costs and to improve acceleration of metros, tramways, intercity and high speed trains. In 1996, the TGV Duplex train was introduced, transporting 40% more passengers while weighing 12% less than the single deck version, all thanks to its aluminium structure. Today, aluminium metros and trams operate in many cities and aluminium trains are used all over the world.

Aluminium bonnet

In 1899, a small sports car with an aluminium body was unveiled at the Berlin international car exhibition. In 1948, Land Rover started using aluminium outer skin sheets.

Today, besides well-known aluminium-intensive cars like the Audi A8, many cars contain significant amounts of aluminium.

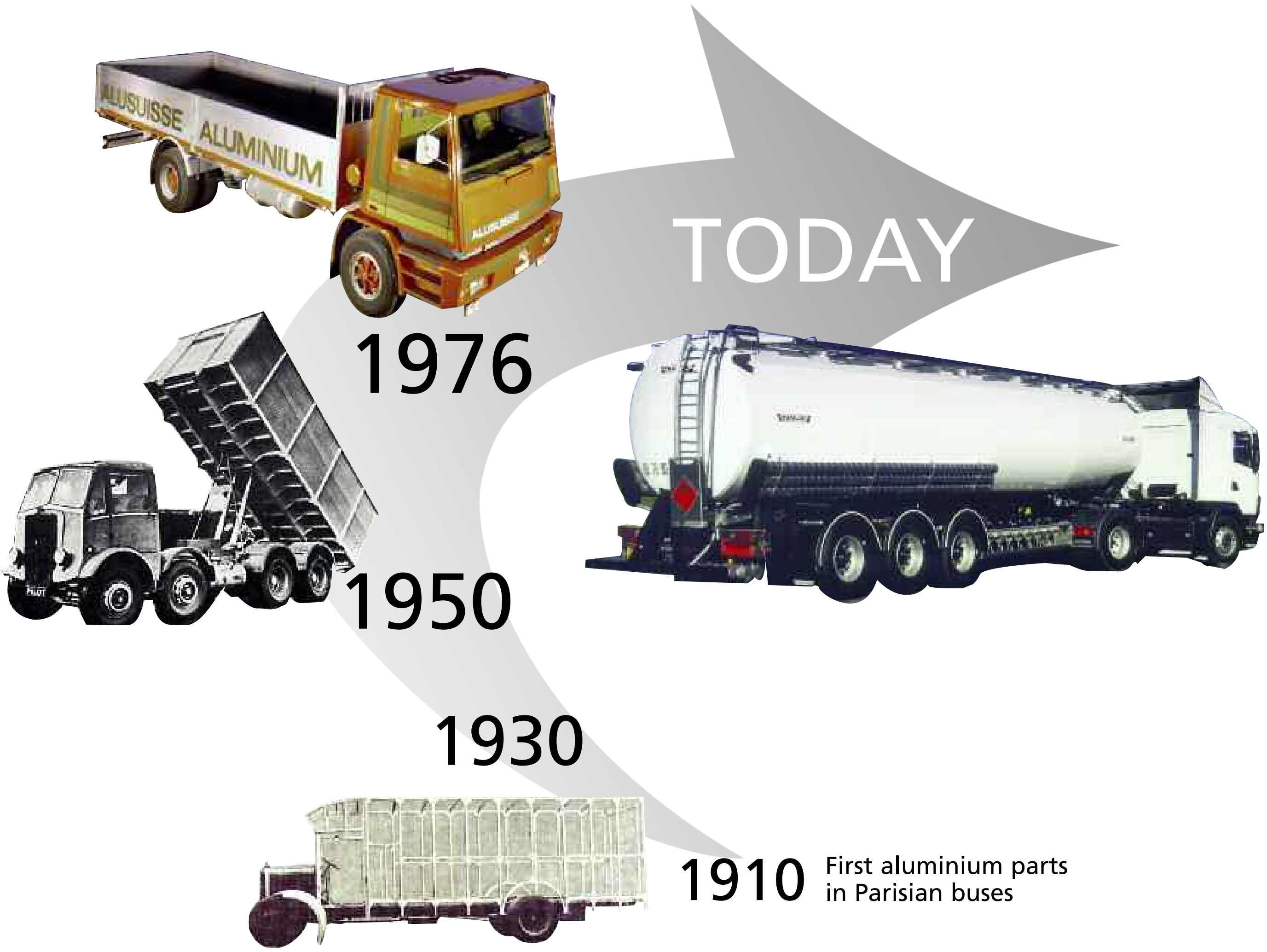
The average volume of aluminium used in passenger cars was already 131kg in 2005.

The same year, one car in every four produced in Europe had an aluminium bonnet and around one third of European cars were already equipped with aluminium bumper systems.

Aluminium bumper system prepared for crash test

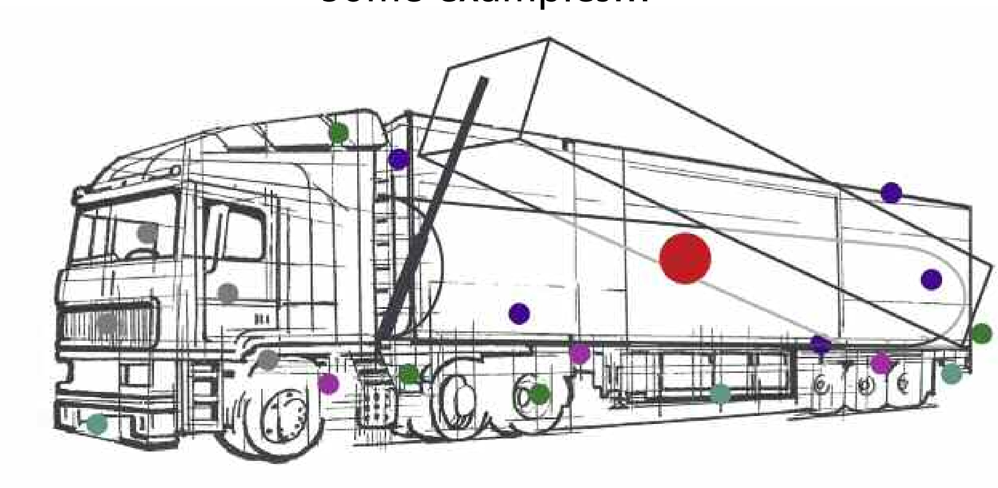
2. Evolution of commercial vehicles

Having made its debut in Parisian buses in 1910, aluminium was used for a variety of elements in commercial vehicles in the 1930s. The 1950s saw the first aluminium tankers, vans and tipping vehicles. Today, most tankers and silo semi-trailers are made entirely of aluminium. It is also frequently used for vans, tipping or self-discharging bodies and a multitude of components. Considering today's European fleet, aluminium saves on average 800kg per articulated vehicle.



3. Aluminium applications and weight savings

Some examples...



Components for tractors & rigid trucks
- cabin & door: -200kg
- chassis: -350kg
- powertrain parts: -125kg
- suspension parts: -110kg

Complete superstructures
- rigid body: 90m2 = -800kg
- tipping body: -800 to -2200kg
- ADR fuel tank: 43000l = -1100kg
- self-discharging body
- silo

Components for superstructure
- curtain rails: 2x13.5m = -100kg
- front wall: -85kg
- rear door: -85kg
- side boards: 600mm = -240kg
- stanchions: 10x600mm = -50kg
- reefer floor

Safety parts
- front bumpers : -15kg
- rear bumpers : -15kg
- side bumpers : -20kg
- front and rear under-run protections

Trailers sub-structures
- chassis: 13.5m = -700kg
- chassis: 6m = -300kg
- chassis+floor: 13,5m = -1100kg
- legs: -35kg

Accessories
- air pressure vessels: 6x60l = -54kg
- diesel tank: 600l = -35kg
- toolbox: -15kg
- tail lift: -150kg
- wheels: 14 rims = -300kg

4. Today's concerns

The key concern of transport companies is profitability.

The rising diesel price and the investment in new engine technologies increase costs, while it is hard to increase transport prices due to the high competition between operators.

Any investment must therefore have a very short payback time.

Consequently, vehicle manufacturers must constantly improve their performance at minimum costs. The choice of a material will therefore depend on its price, its mechanical properties and its impact on vehicle production costs.

From a society point of view, energy efficiency, reduction of greenhouse gases and road safety are in the priority list of European authorities.

Chapter III explains how aluminium helps to take up these challenges.

CHAPTER III

WHY USING ALUMINIUM

1. Short pay-back

1.1. Increased payload + Higher residual value = Additional incomes

Aluminium reduces dead vehicle weight. When transporting high-density freight, which usually saturates the maximum gross vehicle weight, aluminium allows the loading of more goods. This translates into additional income and/or better competitiveness.

Furthermore, used aluminium vehicles have a lot of success on the second, and even third hand market, where they are usually sold for a very good price. Finally, when they have reached the end of their long service life they still have a high scrap value. This is due to the fact that aluminium is easily recycled, without losing any of its quality and saving 95% of the primary energy input.

1.2. Fuel saving + long life + reduced maintenance = Cost savings

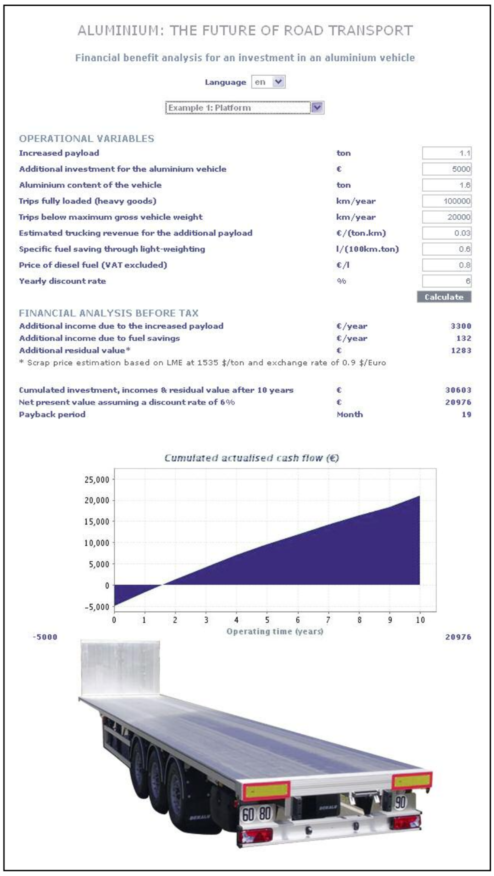
A study conducted by the IFEU[1] in cooperation with the TU-Graz[2] concluded that 1 ton saved on the total weight of an articulated truck leads to a fuel saving of 0.6 litres /100 km.

This saving occurs during trips made below the maximum gross vehicle weight, i.e. when transporting low-density goods, for partly loaded or empty trips.

Aluminium's well-known corrosion resistance is an obvious advantage in road transport: It contributes to a long service life, especially in vehicles which work in conditions that can cause serious corrosion problems. No painting or other surface protection is required and it is easy to clean. Maintenance is therefore kept to a minimum.

1.3. Make your own calculation on www.alutransport.eu

Make your own payback calculation on www.alutransport.eu and have a look at the example beside.



1. Institut für Energie und Umwelt Forschung, Heidelberg, Germany
2. Technical University of Graz, Austria

Road toll station

1.4. Coping with road tolls

According to the "user pays" principle, an increasing number of countries are introducing road tolls that increase cost per kilometre. On the other hand, increasing payload with aluminium allows spreading this extra cost over a bigger tonnage of goods.

In countries where road toll is limited to the heaviest vehicle category, "mini-semi-trailers" are built using a substantial amount of aluminium allowing the operator to keep a good payload while not exceeding the weight limit where a toll is applicable.

1.5. Reduced risk of work accident

Mobile parts that are manipulated at each delivery, like drop-side walls or rear doors, are lighter to move when made out of aluminium. This saves a lot of effort for the drivers.

Using extrusions with rounded edges or folded sheets with round corners for the floors of box vans reduces the risk of injuries.

Mini-trailer (Tang Fahrzeugbau GmbH)

2. Aluminium performance properties

2.1. High strength-to-weight and high stiffness-to-weight ratios

Aluminium alloys used in commercial vehicles have strength-to-weight and stiffness-to-weight ratios comparable with the most advanced metals like high strength steel and titanium.

These properties, among many others, are taken into account when designing a vehicle.

No weight saving can be obtained with aluminium if the design is simply copied from steel.

Designs optimised for aluminium are based on specific sections (20 to 40% higher beams), smooth transitions and clever joints, which normally give 40-60% weight saving over competing metals, as explained below.

To illustrate the upper and the lower limits of aluminium lightweighting, let's analyze two extreme equivalence philosophies "equal strength" and "equal stiffness" to traditional chassis beam.

Comparison of weight-optimised designs made with 3 different metals and 2 design criteria

DEFINITION			
	Standard steel	High strength steel	Aluminium alloy
Yield strength (MPa)	350	760	250
E-Modulus (MPa)	210000	210000	70000
Density (kg/m^3)	7800	7800	2700

EQUAL STRENGTH					
	Standard steel		High strength steel		Aluminium alloy
Strength	1	=	1	=	1
Stiffness	1	>	0.30	<	0.56
Weight	1	>	0.71	>	0.42
Section height	1	>	0.65	<	1.18

EQUAL STIFFNESS					
	Standard steel		High strength steel		Aluminium alloy
Strength	1	<	2.17	>	1.54
Stiffness	1	=	1	=	1
Weight	1	=	1	>	0.55
Section height	1	=	1	<	1.40

Unfair comparison!

Unpainted aluminium patrol boat
(All American Marine)

At equal strength:
• The aluminium beam is the lightest, but has a lower stiffness than the standard steel beam.
• The high-strength steel beam ranks second for lightness, but its stiffness is also the lowest!
• The aluminium solution is about 60% lighter than the standard steel one (0.42 vs. 1) and still 40% lighter than the high strength steel one (0.42 vs. 0.71).

At equal stiffness:
• The aluminium beam is the lightest, with 45% weight saved (0.55 vs 1).
• The high strength steel beam weighs the same as the standard steel beam, because, based on the same parent metal, both materials have identical elastic properties (E-modulus).
• Compared to the standard steel beam, the aluminium one is about 50% stronger, and the high strength steel one about 120%.

Comparing an aluminium beam designed for equal stiffness to a standard steel beam and a high strength metal beam designed for equal strength to that standard steel beam, only shows small weight saving for aluminium (0.55 vs. 0.71) but that **comparison is unfair**, as the latter will have a much higher strength (1.54 vs. 1) and a much higher stiffness (1 vs. 0.30).

Last but not least, we should underline that further weight optimisation is possible with aluminium because:
• The above comparison is based on a standard beam design, the so-called "double T"
• Finite element modelling allows a more precise definition of most favorable section's geometry;
• These sections, even if very complex, can easily be produced with the aluminium extrusion process.
• For parts where strength is the leading criteria, high-strength aluminium alloys can also be used and provide further weight savings

2.2. Durability

Some operators still fear problems with aluminium trailer chassis in heavy duty applications, but they should know that the lifespan is not material related if properly designed.

Experienced manufacturers optimize their design for the material they use and are able to produce aluminium chassis offering an equivalent or longer lifespan but at a much lower weight than conventional models.

It is also important to underline that aluminium vehicles often operate in transport segments where the load factors are the highest (solid and liquid bulk, public works etc…). In other words, they are much more intensively used than conven-

tional ones, and this fact is taken into account in the design of aluminium vehicles.

Correctly used, aluminium alloys have been developed to offer optimum corrosion resistance in all environments. Just one example: the widespread use of unpainted aluminium in marine applications.

2.3. Stability

Achieving IRTE[3] Class A[4] tipping stability standard for an aluminium tipper chassis is no problem. Aluminium, according to tests carried out in the summer of 2002 has no issues with flexing and easily provides the equivalent rigidity of steel.

Indeed, a full-aluminium vehicle, significantly lighter than others, passed the IRTE Class A test at 44 tonnes with its standard chassis, reminding everyone that an appropriate design leads to both lightness and torsional stiffness.

Tipping stability test (STAS)

2.4. Diversity & functionality of semi-finished products, castings and forgings

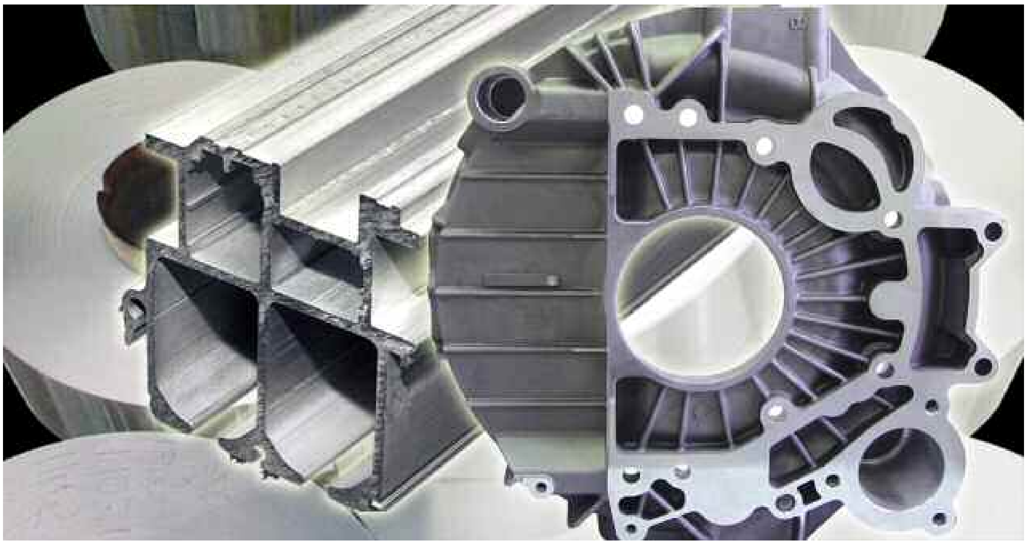
Vehicle designers and manufacturers have a wide range of aluminium alloy semi-finished products from which to choose:

- Rolled semis: sheets, tread plates (floor plates), pre-painted sheets
- Extruded semis: hollow or solid shapes, standard or customized
- Castings and forgings

3. Institute of Road Transport Engineers, UK.

4. "Class A" standard states that a trailer should be able to tilt sideways 7° without falling with a fully loaded and raised body.

Various aluminium products



This diversity of semi-finished products makes it possible to:

- Design structural elements with special functions such as shapes with grooves for screw heads, hydraulic circuits, inertia shapes, snap-locks, welding flanges etc.
- Save on time and cost for assembly and finishing. This can compensate for the added raw material cost of structures made from aluminium alloys compared with equivalent steel structures.
- Reduce stress due to welding by placing castings at assembly intersections or using special extrusions to divert welding stresses into less stressed areas of a fabricated structure.
- Design complex cast or forged shapes.

2.5. Easy to work with

Aluminium alloys used in the manufacture of commercial vehicles and their accessories are easy to process. They lend themselves to a variety of shaping and joining techniques that will be reviewed in chapters 7, 8 & 9.

In a nutshell, aluminium can easily be

- cut: sawing, shearing, water jet, laser or plasma cutting
- machined: milling, drilling
- bent
- joined: welding, adhesive bonding, bolting and riveting

Furthermore, being light, aluminium is easy to handle in the workshop.

3. Environmental and social Benefits

3.1. Aluminium reduces CO_2 emissions

To achieve emission reductions, it is not only important to develop low-emission engines, but also to use them in the most rational way possible. Saving weight with aluminium is a good way of achieving this objective as explained below.

Aluminium contributes to the reduction of CO_2 emissions from road transport as follows:

- When carrying heavy goods, it increases the load capacity of vehicles and therefore improves transport performance, allowing more goods to be carried per trip. In this case, one ton saved on the dead weight of an articulated truck saves 1,500 liters of diesel fuel over 100,000 km.
- When carrying voluminous goods, it reduces the overall weight, lowering fuel consumption per kilometer. In this case, one ton saved on the dead weight of an articulated truck saves 600 liters of diesel fuel over 100,000 km.
- When carrying passengers, it reduces the overall weight and lowers fuel consumption. One ton saved on an urban bus saves between 1,700-1,900 liters of diesel fuel per 100,000 km.

Taking primary production, use stage and end-of-life recycling into account, **life-cycle savings** have been estimated as follows:

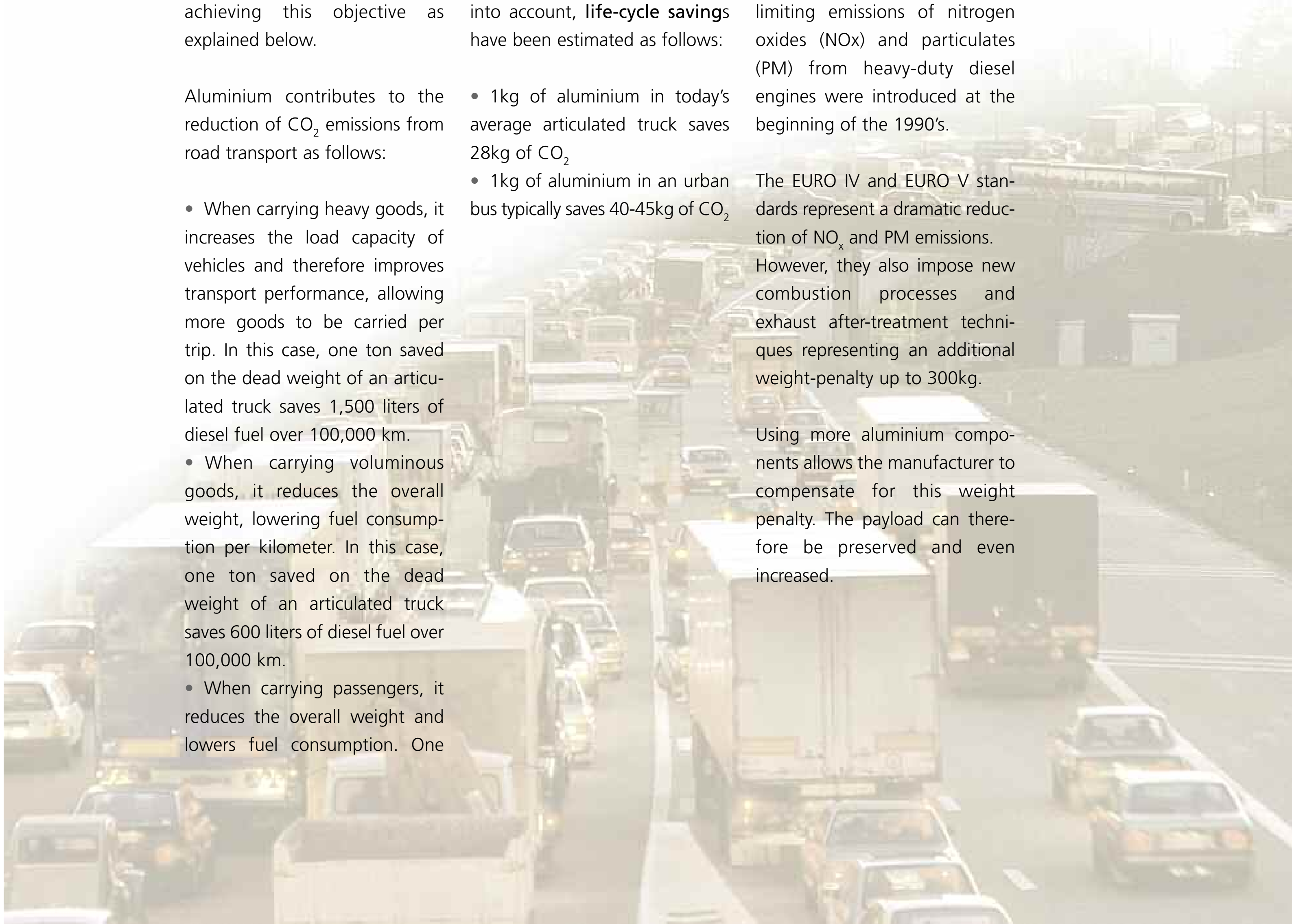
- 1kg of aluminium in today's average articulated truck saves 28kg of CO_2
- 1kg of aluminium in an urban bus typically saves 40-45kg of CO_2

3.2. Aluminium as a complement to EURO IV & EURO V engines

The European Environment Directives for trucks date back to 1988, while the first standard limiting emissions of nitrogen oxides (NOx) and particulates (PM) from heavy-duty diesel engines were introduced at the beginning of the 1990's.

The EURO IV and EURO V standards represent a dramatic reduction of NO_x and PM emissions. However, they also impose new combustion processes and exhaust after-treatment techniques representing an additional weight-penalty up to 300kg.

Using more aluminium components allows the manufacturer to compensate for this weight penalty. The payload can therefore be preserved and even increased.



Truck with crash-module

3.3. Aluminium improves road safety

In the context of its Road Safety Action Programme, the European Commission is looking into the introduction of crash energy absorption criteria for trucks. The aluminium industry has already developed several solutions for the automotive and railway sectors and would be ready to take up this challenge for trucks.

Regarding metal deformation that energy-absorbing elements undergo upon impact, aluminium systems make it possible to absorb significantly more crash energy per unit of weight than traditional systems. As a rule of thumb, the light-weighting potential exceeds 40%.

For this reason, aluminium is very well suited for front, rear and side bumpers.
Aluminium elements can also be used to improve the energy absorbing potential of front and rear end under-run protection devices, and may also be used to build soft deformable truck noses.

Last but not least, extra safety features always mean additional weight, which can be balanced by replacing heavy materials by aluminium.

Aluminium tipper on scrap yard (Galloo recycling)

3.4. Aluminium is easily and economically recycled

Unlike traditional vehicles that are exported to end their life a long way from Europe, aluminium-intensive trailers generally spend their entire life in our continent, where they are eventually dismantled[5]. Due to the high value of aluminium scrap, the motivation to sell to a scrap merchant is very high and landfilling is avoided.

Recycled aluminium does not loose any of its quality and saves 95% of the primary production energy input. The energy required to produce primary aluminium is not lost: it is "stored in the metal".

5. "The fate of aluminium from end-of-life commercial vehicles", Université de Technologie de Troyes

8 years old aluminium tipping body
re-used on a new truck

4. On the road…

4.1. Looking good forever

The modern commercial vehicle cannot escape the pressures of industrial design. Operators want their vehicles to look good with clean, pleasing lines, something which aluminium alloy semis are ideal for producing.

For example, using functional extrusions and plain or pre-painted aluminium sheet that is easy to shape, it is a straightforward matter to produce vans with rounded body corners both inside and out.

With tippers and self-discharging bodies, this makes for a smooth unloading and easier cleaning. In addition, using double wall aluminium extruded boards allows the preservation of a perfect exterior surface over the time. Image conscious operators appreciate this type of construction very much.

Aluminium is used to produce the lightest, the strongest and the most beautiful wheels.

Last but not least, no corrosion will appear after impact on aluminium parts, therefore preserving the image of the company.

Double wall extruded boards for tippers

4.2. Aluminium is easy to repair

Few people know that Land Rovers have had aluminium closure panels since 1948, and in the last 50 years, nobody has ever complained about repair problems. This illustrates the fact that repair is possible, but aluminium repair techniques are definitely different from those of steel. Leading chassis manufacturers have set up a European dealer network where an efficient repair service is offered.

Forged aluminium wheel

Repair
of an aluminium tipper
(Benalu)

CHAPTER IV

FREQUENTLY ASKED QUESTIONS

Aluminium bodied truck

1. Aluminium

1.1. What are the advantages of an aluminium vehicles?

Truck fleet operators benefit from a better performance of their fleet.
There is a significant payload increase which makes the fleet much more profitable. Another fact is cost savings that result from smaller fleets with less staff, lower fuel bills and lower road toll costs.

Trailer rental companies can offer operators semi-trailers with a better performance. Due to the higher payload, the longer life and the higher residual value of the equipment these companies can generate more profit by using state-of-the-art equipment.

1.2. Is there an additional cost for an aluminium vehicle?

Yes, aluminium vehicles are slightly more expensive than equivalent steel designs. If we analyse the difference in detail, we can see that, when heavy goods are transported, the additional investment is paid back after less than two years. Make your own calculations on www.alutransport.eu.

1.3. What are the main benefits for the environment?

Aluminium contributes to the reduction of CO_2 emissions from road transport as follows:

- When carrying heavy goods, it increases the load capacity of vehicles and therefore improves transport performance, allowing more goods to be carried per trip. In this case, one ton saved on the dead weight of an articulated truck saves 1,500 litres of diesel fuel over 100,000 km.
- When carrying voluminous goods, it reduces the overall weight, lowering fuel consumption per kilometre. In this case, one ton saved on the dead weight of an articulated truck saves 600 litres of diesel fuel over 100,000 km.

Taking primary production, use stage and end-of-life recycling into account, life-cycle savings have been estimated[1] that 1kg of aluminium in today's average articulated truck saves 28kg of CO_2.

1. *CO_2 reduction potential of aluminium for articulated trucks*, EAA (European Aluminium Association), 2005

Repair of an aluminium tipper (Stas)

1.4. Is it necessary to paint an aluminium vehicle?

No, it is not. Aluminium with its natural «alumina» layer has an excellent protection performance. If an operator chooses to pay extra money (and weight too!) for the paint finish, the motivation to do so lies in having a fleet with a particular branding.

1.5. Is it possible to repair an aluminium vehicle?

It is often said that aluminium vehicles cannot be repaired, however this is totally wrong.
Few people know that Land Rover cars have had an aluminium body since the end of world war two, and in the last 50 years nobody has ever complained about repair problems.
This illustrates the fact that repair is possible as for any other materials, but aluminium repair techniques are definitely different from those of steel.
Please refer to the Chapter XIV for detailed information.

Leading chassis manufacturers have set up a European dealer network where an efficient repair service is offered.

1.6. Does aluminium burn?

NO, aluminium and its alloys are, under atmospheric conditions, totally non-combustible and do not contribute to the spread of fire.

Aluminium alloys will however melt at around 650°C, but without releasing harmful gases.

2. Aluminium chassis

2.1. How is an aluminium chassis designed and what are the weight savings achievable?

Leading European trailer manufacturers are using strength, stiffness and durability criteria.

No weight saving can be obtained with aluminium if design is simply copied from steel. Designs optimised for aluminium are based on specific sections (20 to 40% higher beams), smooth transitions and clever joints, which normally give 40-60% weight saving over competing metals (see Chapter III), as explained below.

1) A good light-weight trailer has to be as strong as a traditional model. If this would be the sole criteria, the weight saving obtained with aluminium would be maximized (up to 60%) and high strength steel solutions would provide about half the weight saving achievable with aluminium (about 30%).

Chassis for aluminium tipper (Benalu)

2) A minimum stiffness is generally required.

• If this stiffness has to be equal with standard steel models, weight savings obtained with aluminium will be around 45% with a superior strength, but high strength steel cannot achieve any weight saving.

• If the minimum stiffness required is lower than the one of standard steel models, weight savings obtained with aluminium will be somewhere between 45% & 60% and weight savings obtained with high strength steel somewhere between zero and half of what can be achieved with aluminium.

3) Vehicles durability must be insured. As aluminium vehicles are much more intensively used than conventional ones, their resistance to fatigue must be higher. This result is obtained with a proper design. Among of a lot of others, higher sections, smooth transitions and clever joints are keys to success.

Chassis for aluminium tipper (Leciñena)

2.2. Are there different aluminium chassis designs?

Each manufacturer has its own design, which to a high degree depends on the working conditions the vehicle is made for and on the specific manufacturing experiences of the chassis producer (e.g. some prefer fully welded constructions whereas others prefer mixed welded and bolted constructions). It is also important to underline that aluminium vehicles are much more intensively used than conventional ones, and this fact is taken into account in the design of vehicles. Apart from that, there are two dominating design philosophies in the chassis world.

In countries like Italy, where equal stiffness with steel models seems to be a must, deflection is the main criteria, and this generally leads to longer lifetime than conventional models, coupled with an attractive weight saving.

In other countries, equal lifetime with steel models will be the main criteria. A good design will lead to, at least, an equivalent lifetime, stiffness within requirements (even though it may be slightly lower than steel models), but the weight saving will be maximized.

In any case, they will usually be stronger than classic models, and the risk for starting yield failure from static overload will be lower for aluminium chassis.

Bolted aluminium chassis for tipper (Menci)

2.3. Is the life of an aluminium chassis shorter than a steel chassis?

The lifespan of a chassis is a design issue and not a material issue.
Aluminium chassis are mostly used in transport segments where the load factors are the highest (solid & liquid bulk tanks, tippers), nevertheless well designed vehicles can easily exceed 20 years of service life.

2.4. How does aluminium compete with high strength steel?

We should make a distinction between pure aluminium and aluminium alloys.
Pure aluminium is never used in commercial vehicles. A wide variety of aluminium alloys do exist, including high strength solutions.

What is seldom communicated is that all alloys based on the same parent metal have nearly the same elastic properties.

This means that if someone is looking for a lightweight alternative to a standard chassis while keeping the same stiffness, the only solution is to change the material e.g. switching from steel to aluminium (see Chapter III).

3. Aluminium tippers

3.1. Are there different aluminium tipping body designs?

Yes, there are a lot of tipper variants and all of them can be built using dedicated aluminium semi-products that offer high productivity for manufacturers, as well as increased payload, low running costs and a great fleet image to operators. For more details, please have a look at Chapter VI.

3.2. What about the wear resistance of aluminium tipping bodies

The wear condition can vary extremely from one load to another. Therefore it is not always possible to link the actual hardness of an alloy to the wear resistance. It was found out that for a very large extent, the type of load is a decisive factor.

The choice of material for the construction of tipping trailers is nowadays often a question of specific experiences, material availability and manufacturer's specific production methods.

Typical bottom plate material is:

- 5083 H32, H321, H34
- 5086 H24
- 5383 H34
- 5454 H22, H24
- 5456 H34

or other, mill-specific alloy types.

Typical values for bottom plate thickness are listed below:

- 6 mm for light-duty operations like agricultural products, coal or sand transport
- 8 mm for medium-duty service like recycling products
- 10 mm for heavy-duty transport like gravel
- Up to 12 mm in extreme cases

Please refer to Chapter VI for more details.

IRTE tipping stability test (STAS)

3.3. What type of chassis is needed for an aluminium tipper body?

Some operators still fear problems with aluminium trailer chassis in heavy-duty applications, but they should know that strength is not material related. Indeed, strength, like stiffness and lifetime, are only design criteria. Experienced manufacturers are able to produce aluminium chassis offering the same performance but at a much lower weight than conventional steel models.

3.4. What about tipping stability?

It is often said that achieving the IRTE[2] Class A[3] tipping stability standard for an aluminium tipper chassis would be difficult simply because "it flexes too much" or that, to provide the equivalent rigidity of a steel chassis "the lightness benefit would be practically eliminated", but tests run during summer 2002 confirmed that both statements were totally wrong.

Indeed, a full-aluminium vehicle, significantly lighter than others, passed the IRTE Class A test at 44 tonnes with its standard chassis reminding everybody that an appropriate design leads to both lightness and torsional stiffness.

2. British Institute of Road Transport Engineers (IRTE)

3. IRTE's "Class A" stability standard for tipping on uneven ground states that a trailer should be able to tilt sideways 7° without falling with a fully loaded and raised body.

4. Aluminium tankers

4.1. How should a tank for the transport of dangerous goods (ADR) be designed?

Tanks for the transport of dangerous goods have to be built according to the rules defined in the following agreement and standards:

- ADR: Agreement for the transport of Dangerous goods by Road[4]
- EN 13094 "Tanks for the transport of dangerous goods - Metallic tanks with a working pressure not exceeding 0.5 bar - Design and construction"
- EN 14025 "Tanks for the transport of dangerous goods - Metallic pressure tanks - Design and construction"

More details are given in Chapter VI.

4.2. Which alloys are suitable for ADR tanks?

Suitable aluminium alloys for that application are listed in standard EN 14286 "Aluminium and aluminium alloys - weldable rolled products for tanks for the storage and transportation of dangerous goods" as well as in chapter V.

Aluminium suppliers are listed in the "links" section of the website www.alutransport.org .

4. See *ADR, Annex A, Part 6, Chapter 6.8*: http://www.unece.org/trans/danger/danger.htm

Aluminium road tanker (Schrader)

CHAPTER V

ALUMINIUM ALLOYS FOR COMMERCIAL VEHICLES

1. Foreword

Aluminium in its pure form is a very soft metal and hence not suited for structural applications. Thanks to the addition of alloying elements such as copper, manganese, magnesium, zinc etc… and thanks to adequate production processes, the physical and mechanical properties can be varied in a great range making it possible to have suitable alloys for literally all applications.

As the Aluminium Industry is a global industry there is the enormous chance, that the product designation is uniform almost all over the world. Company specific trade names are often complemented by the standardized designation.

All relevant standards are listed at the end of this chapter.

Aluminium rolling mill

2. International product designation

In order to identify the various alloys, 4-digit numbers have been standardized for wrought alloys (see EN573-1) and 5-digit numbers for cast alloys.
A list of all registered wrought alloys and their chemical composition can be found in EN 573-3 for Europe and in the so-called "Teal sheets[1]" at international level.
A list of all standardized cast alloys can be found in EN 1706.
A selection of alloys for use in commercial vehicles will be presented in section 6.
The first digit of the alloy number indicates the dominant alloying element; the remaining digits are just numbers for identification purposes (Table V.1). Just in the case of pure aluminium the last two digits of the 4-digit number indicate the percentage of purity above 99.0%. E.g. 1070 means aluminium with at least 99.70% of aluminium or, in other words less than 0.30% impurities.

TABLE V.1

CATEGORIES OF ALUMINIUM ALLOYS

Dominant alloying element	wrought alloy	cast alloy
None ("pure aluminium")	1xxx	
Copper	2xxx	2xxxx
Manganese	3xxx	
Silicon	4xxx	4xxxx
Magnesium	5xxx	5xxxx
Magnesium and Silicon	6xxx	
Zinc and Magnesium (with or without copper)	7xxx	7xxxx
Other elements (e.g. Iron or Lithium)	8xxx	

From these eight categories are three families so called "non heat treatable", or "work hardening" alloys (1xxx, 3xxx, 5xxx) and four "heat treatable alloys" (2xxx, 4xxx, 6xxx, 7xxx). The 8xxx family cannot be attributed to one or the other group.
The alloy number can be preceded by a letter X which indicates that it is an experimental alloy, or followed by a letter A which says that this is a national variation of the basic alloy.

The physical and mechanical properties of these alloys not only depend on their chemical composition but also to a great extent on the manufacturing process in the aluminium plant and on the transformation process of the semi-finished to the finished product. These processes are characterized with the so called "temper designation" which attends the alloy number. When alloy number and temper designation are indicated, the metal is clearly identified and its properties defined.

1. The latest edition of the *Teal Sheets* is available for free download from the EAA website
http://www.eaa.net/en/about-aluminium/standards/international-registration/

3. Basic temper designations

- **F - as fabricated:** this condition designates products made by plastic deformation without any particular control of the rates of hardening or softening by deformation or any heat treatment.
- **O - fully annealed:** this condition is the most ductile and is obtained by the process of annealing without any subsequent work-hardening or by hot rolling at temperatures above the recrystallisation temperature.
- **H - strain-hardened and possibly partially softened:** this relates to strain-hardened products with or without subsequent holding at a temperature high enough to induce partial softening of the metal.
- **T - heat treated:** heat treatment can combine some or all of the following operations: solution treatment, quenching, age hardening, artificial ageing and possible plastic deformation.

For more details, please refer to EN 515.

4. Subdivisions of H temper designations

The **first digit** after H indicates the specific combination of basic operations:

- **H1X:** work-hardened only. These designations identify products that are work-hardened to obtain the desired strength without supplementary heat treatment.
- **H2X:** work-hardened and partially annealed. These designations apply to products which are work-hardened more than the desired final amount and then reduced in strength to the desired level by partial annealing.
- **H3X:** work-hardened and stabilized. These designations apply to products which are work-hardened and whose mechanical properties are stabilized either by a low temperature heat treatment or as a result of heat introduced during fabrication.

For more details, please refer to EN 515.

The **second digit** following the letter H indicates the final degree of strain hardening, as identified by the minimum value of the ultimate tensile strength.

- 8 has been assigned to the hardest temper normally produced.
- Tempers between O (annealed) and HX8 are designated by numerals 1 to 7.
- **HX4** designates tempers whose ultimate tensile strength is approximately midway between that of the O temper and that of the HX8 tempers.
- **HX2** designates tempers whose ultimate tensile strength is approximately midway between that of the O temper and that of the HX4 tempers.
- **HX6** designates tempers whose ultimate tensile strength is approximately midway between that of the HX4 tempers and that of the HX8 tempers
- HX1, HX3, HX5, HX7 designate tempers intermediate between those defined above. Note: These temper designations are not included in EN 515. Mechanical properties of these tempers shall

Extrusion press

be agreed between the manufacturer and the customer.

The **third digit**, when used, indicates a variation of a two-digit temper.

- **HX11** applies to products that incur sufficient strain-hardening after the final annealing such that they fail to qualify as annealed but not so consistent an amount of strain-hardening that they qualify as HX1.
- **H112** applies to products that may acquire some strain-hardening from working at an elevated temperature or from a limited amount of cold work, and for which there are no upper mechanical property limits.
- **H116** applies to products, made of those alloys of the 5XXX group in which the magnesium content is 3% nominal or more. Products are strain hardened at the last operation to specified tensile property limits and meet specified levels of corrosion resistance in accelerated type corrosion tests. Corrosion tests include inter-granular and exfoliation. This temper is suitable for continuous service at temperatures not higher than 65°C.

5. Subdivision of T temper designations

The **first digit** following the letter T is used to identify the specific sequences of basic treatments. Numerals 1 to 10 have been assigned as follows:

- **T1:** Cooled from an elevated temperature shaping process and naturally aged to a substantially stable condition
- **T2:** Cooled from an elevated temperature shaping process, cold-worked, and naturally aged to a substantially stable condition
- **T3:** Solution heat-treated cold-worked, and naturally aged to a substantially stable condition
- **T4:** Solution heat-treated and naturally aged to a substantially stable condition
- **T5:** Cooled from an elevated temperature shaping process and then artificially aged
- **T6:** Solution heat-treated and then artificially aged
- **T7:** Solution heat-treated and over-aged/stabilized
- **T8:** Solution heat-treated, cold worked and then artificially aged
- **T9:** Solution heat-treated, artificially aged and then cold-worked
- **T10:** Cooled from an elevated temperature shaping process, cold-worked, and then artificially aged.

For more details, please refer to EN 515.

6. Typical alloys for commercial vehicles

Out of the vast variety of known alloys as listed in EN 573-3 and in the Teal Sheets, just a few are of importance for the manufacture of commercial vehicles. Selection criteria are:

- availability of semi-finished products
- mechanical properties
- physical properties
- suitability for fabrication
- weldability
- corrosion resistance

In the following tables the most widely used alloys for the application in commercial vehicles are presented.

Aluminium coils

Aluminium rolling slabs

6.1. Flat rolled products

In commercial vehicles, the most commonly used alloys are 3003, 5005, 5059, 5083, 5086, 5088, 5182, 5186, 5383, 5454, 5456, 5754, 6061 and 6082.

The mechanical properties of these alloys can be found in the standards listed in Table V.2 and Table V.3 gives indications on engineering suitability.

TABLE V.2

REFERENCE STANDARDS FOR MECHANICAL PROPERTIES OF WROUGHT ALLOYS – FLAT ROLLED PRODUCTS

Alloy	Standards[2]
3003	EN 485-2
5005	EN 485-2
5059	EN 485-2 and EN14286
5083	EN 485-2 and EN14286
5086	EN 485-2 and EN14286
5088	EN 485-2 and EN14286
5182	EN 485-2 and EN14286
5186	EN14286
5383	EN 485-2 and EN14286
5454	EN 485-2 and EN14286
5754	EN 485-2 and EN14286
6061	EN 485-2
6082	EN 485-2

2. See standards denominations at the end of this chapter section 9.

TABLE V.3

ENGINEERING SUITABILITY FOR ROAD TRANSPORT APPLICATIONS – FLAT ROLLED PRODUCTS

Alloy	Temper	Shaping	Welding	Anodizing	Corrosion resistance
3003	H14,H24,H16	B	A	A	A
5005	H14,H24	B	A	A	A
5059	O, H111	B	A	A	A
5083	O,H111	A	A	A	A
	H116,H22,H24, H34	C	A	A	A
5086	O,H111	A	A	A	A
	H116,H22,H24	C	A	A	A
5088	O, H111	A	A	A	A
5182	O, H111	A	A	A	A
5186	O, H111	A	A	A	A
5383	H22, H32	B	A	A	A
5454	O,H111	A	A	A	A
	H22,H24	B	A	A	A
5456	H34	C	A	A	A
5754	O,H111	A	A	A	A
	H22,H24	B	A	A	A
6061	T4	C	A	A	A
	T6	D	A	A	A
6082	T4	C	A	A	A
	T6	D	A	A	A

A = very good; B = good; C = fair; D = poor, to be avoided

Aluminium extrusion billets

6.2. Extruded products (forged products)

In commercial vehicles, the most commonly used alloys are 6060, 6005A, 6008, 6106, 6082, 6061 and 7020.

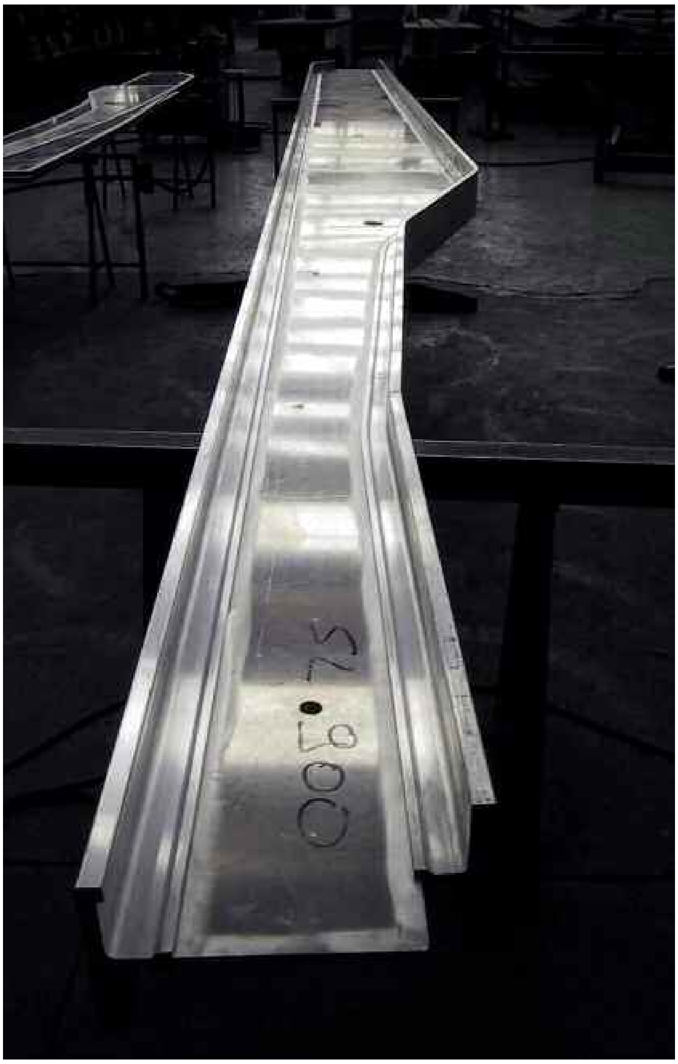
The mechanical properties of these alloys can be found in standard EN 755-2 and Table V.4 gives indications on their engineering suitability.

TABLE V.4

ENGINEERING SUITABILITY – EXTRUDED & FORGED PRODUCTS

Alloy	Temper	Welding	Anodizing	Corrosion resistance
6060	all	A	A	A
6005A	all	A	A	A
6008	all	A	A	A
6106	all	A	A	A
6082	all	A	A	A
6061	all	A	A	A
7020	T6	A	A	C
7003	T6/T7	A	A	B
7108	T6/T7	A	A	B

A = very good; B = good; C = fair; D = poor, to be avoided



Semi-trailer chassis beam made out of two extruded flanges and a sheet as web

Extruded rail for sliding curtain

6.3. Castings

In commercial vehicles, the most commonly used alloys are 21100, 42000, 42100, 43000, 44000.
Their chemical composition and mechanical properties can be found in standard EN 1706 and Table V.5 reflects their casting characteristics.

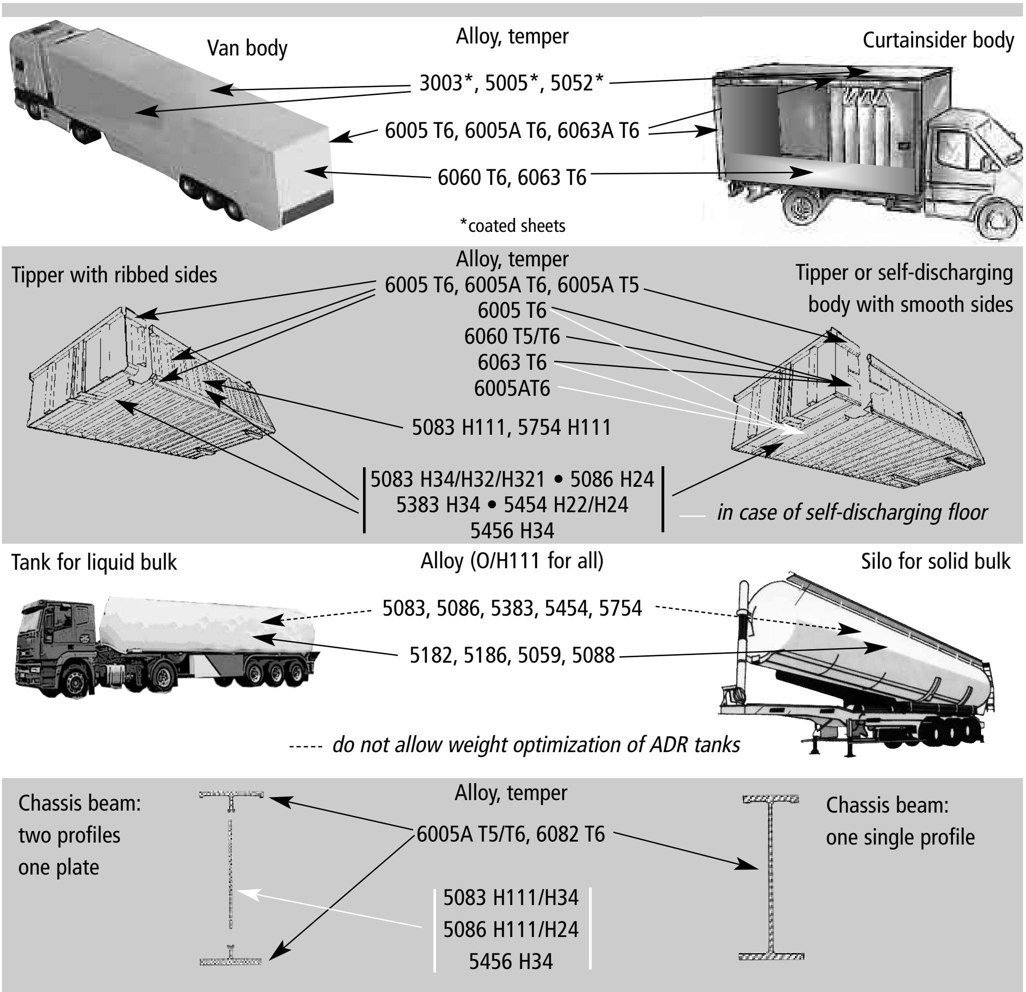
TABLE V.5

CASTING CHARACTERISTICS

Alloy	Fluidity	Resistance to hot tearing	Pressure tightness	Machinability	Corrosion resistance
21100	C	D	D	A	D
42000	B	A	B	B	B/C
42100	B	A	B	B	B
43000	A	A	B	B	B
44000	A	A	A	C	B

A = very good; B = good; C = fair; D = poor, to be avoided

6.4. Selection guide for the different alloys (indicative)



OTHER APPLICATIONS

Application	Alloy	Application	Alloy
Wheels	6061, 6082	Bumper beams, crash boxes & roll over protections	7003, 7108
Diesel fuel tanks	5052, 5754	Suspension parts	21100
Tail lifts	6005A	Structural components-Hinges-Supports	42000, 42100
Floors	6082, 5086, 5754	Complex shapes with medium strength	43000
Framing for buses	6060, 6005A	Very complex shapes without structural function	44000
Sides & roofs for buses	3003, 5005		
Crash modules	6008		

Beside these well known alloys it is possible to define, in cooperation with the supplier of the semis, tailor made products that offer best performance for the foreseen purpose.

7. Influence of temperature on mechanical properties

Aluminium alloys change their mechanical and corrosion resistance properties when subjected to temperatures other than ambient temperature. Tables V.6 & V.7 show the interrelationship between service temperature and mechanical properties. In Figure V.1 this is shown for one alloy graphically.

TABLE V.6

CHANGE IN MECHANICAL PROPERTIES OF 5086 O AFTER HOLDING AT TEMPERATURE FOR 10,000 HOURS

Temperature	Mechanical properties (*)		
°C	R_m (MPa)	$R_{p\ 0,2}$ (MPa)	A%
-196	390	140	34
-80	280	120	26
-28	270	120	24
+20	270	120	22
+100	270	120	26
+150	210	110	35
+200	155	105	45

TABLE V.7

CHANGE IN MECHANICAL PROPERTIES OF 6082 T6 AFTER HOLDING AT TEMPERATURE FOR 10,000 HOURS

Temperature	Mechanical properties (*)		
°C	R_m (MPa)	$R_{p\ 0,2}$ (MPa)	A%
-196	380	330	16
-80	330	295	13
-28	330	285	12
+20	320	285	12
+100	300	265	15
+150	240	220	18
+200	130	105	28

(*) Mean values. These properties are measured at test temperature.

7.1. Elevated temperature

The loss in strength at higher than ambient temperatures is negligible for temperatures up to 100°C (short time exposure) or 80°C (long time exposure).

When subjected to even higher temperatures, then the loss in mechanical properties is moderate for non-heat treatable alloys in the O/H111 temper and for heat treatable alloys in the T1/T4 temper.

The loss in mechanical properties at temperatures above 100°C is very pronounced for non heat treatable alloys in the H12, H16 temper as well as for heat treatable alloys in the T5/T6 temper.

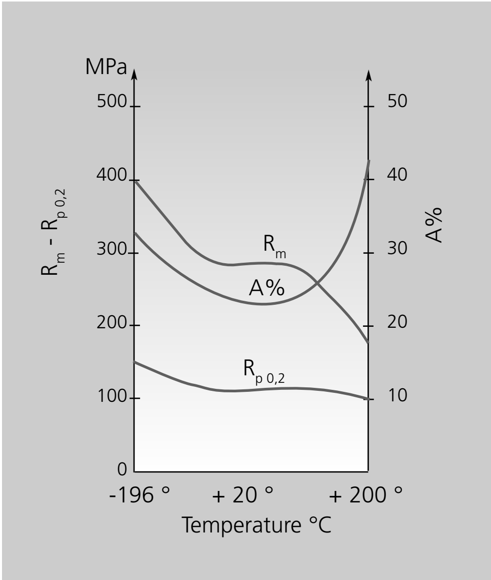
7.2. Low and very low temperatures

Contrarily to most other engineering metals, the mechanical properties improve at low temperatures and especially the elongation, which makes aluminium an ideal metal for severe winter conditions and even cryogenic applications (see Figure V.1)

Further examples can be found in standard EN 12392 "Aluminium and aluminium alloys - Wrought products - Special requirements for products intended for the production of pressure equipment".

FIGURE V.1

CHANGE OF MECHANICAL CHARACTERITICS AS A FUNCTION OF TEMPERATURE FOR ALLOY 5086 O



8. Influence of fabrication on the properties of the alloys

8.1. Work hardening of non-heat treatable alloys

Hardening is achieved by cold deformation, known as work hardening, that improves the physical properties and the hardness of the metal. It also reduces the metal's capacity for deformation and its ductility (Figure V.2). The greater the deformation or higher the work hardening rate, the more pronounced is the effect. It is also governed by the composition of the material.

The 5083 alloy, for example, which contains between 4 and 4.9% of magnesium, acquires a great hardness but its capacity for deformation is less than that of the 5754 alloy which contains between 2.6 and 3.6% Mg. Work hardening is a general phenomenon that takes place whatever the method of deformation used: rolling, deep drawing, folding, hammering, bending, pressing, etc. This means that it will also occur during fabrication in the workshop.

8.2. Softening by annealing and recovery

It is possible to restore the ductility of the work hardened metal by heat treatment known as "**annealing**" (partial or full annealing). In this process, which takes place at temperatures between 150°C and 350°C, the hardness and mechanical characteristics of the metal slowly begin to decrease: this is the **recovery** phase [A-B] (Figure V.3). At lower annealing temperatures this leads to medium-strength material properties. They then fall away more rapidly at high temperatures above 280 °C during **recrystallization** [B-C] and eventually attain a minimum value that corresponds to the mechanical characteristics of the **fully annealed** metal [C-D].

Restoration and annealing are accompanied by a change in the texture and size of the grains of metal observed under a microscope with X50 magnification. The texture can change from a fibrous structure to a fully recrystallized structure (Figure V.3).

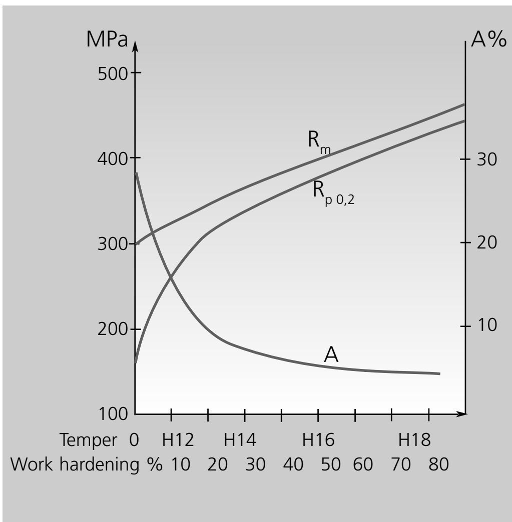
The grain can grow in size during recrystallization and annealing. This growth is revealed during subsequent working, e.g. folding, by the rough "orange peel" effect on the surface of the metal. Grain growth above around 100 microns reduces the deformation capacity of work hardening aluminium alloys.

The following conditions are essential if a fine-grained annealed structure is to be achieved:

• The metal must have undergone a sufficient rate of deformation corresponding to a rela-

FIGURE V.2

WORK HARDENING CURVE OF ALLOY 5083



tive reduction in section of at least 15%. This is “critical work hardening”. If this condition is not met, then heat treatment must be restricted to restoration without recrystallization,

• A rapid temperature gradient of 20 to 60°C per hour,
• Temperatures over 350 to 380°C must be avoided,
• Holding times must be limited to 2 hours maximum.

For 5000 series alloys, annealing is usually performed between 320°C and 380°C for 30 to 120 minutes.

Note: Non-heat treatable alloys in the annealed temper (O, H111) can only be brought to higher strength by work hardening.

8.3. Heat treatable alloys

If some plastic deformation must be done on products of heat treatable alloys, it should be carried out in the T4 temper; first the allowable degree of deformation is bigger than for the T6 temper and second there is a moderate effect of work hardening. If for the final product e.g. a bent extrusion in a 6XXX alloy T6 temper is needed, age hardening can be carried out. Table V.8 gives an indication how to proceed, using typically a hot air furnace.

FIGURE V.3
HARDNESS CURVE DURING ANNEALING

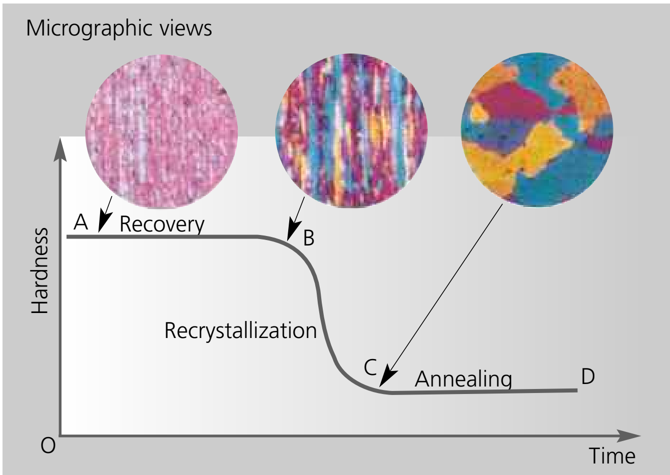


TABLE V.8 (typical)
6000 SERIES ARTIFICIAL AGEING

Alloy	Initial temper	Artificial ageing	Final Temper*
6060	T1 - T4	6 h at 185°C or 8 h at 175°C	T5 - T6
6005	T1 - T4	8 h at 175°C	T5 - T6
6106	T1 - T4	8 h at 175°C	T5 - T6
6061	T4	8 h at 175°C	T6
6082	T1 - T4	16 h at 165°C or 10 h at 170°C or 8 h at 175°C	T5 - T6

* T5, for an initial temper of T1, T6 for an initial temper of T4.

Flywheelhouse casting
for truck engine (Brabant Alucast)

8.4. Castings

Casting is the shortest path from molten metal to the finished product. It is recommended for geometrically-complex parts. It is advantageous to involve the foundry from the conceptual phase into the design process. The expert of the foundry, knowing the plants equipment, the process of making the mould, the flow of metal into the mould, the cooling and shrinking of the cast piece etc. can be of great help during the design phase. When the design of a casting is optimized in view of its production it is in most cases possible for the foundry to guarantee much better mechanical properties than those listed in standard EN 1706, especially with respect to elongation.

The Table V.5 (see section 6.3) merits some explanation.
The alloy 21100 needs very careful design of the pieces with respect to the casting process and, in addition to that, the metal treatment in the foundry, especially the degassing of the molten metal, must be carried out very carefully in order to minimize micro-porosity.
The index B or C in the column "Machinability" has been put because of the wearing of the cutting tools due to the high silicon content of the alloys.
The corrosion resistance of cast pieces with the as-cast surface is better than for machined surfaces of the same piece due to the much thicker oxide layer.

Design of casting parts

Generally speaking it is essential to be aware of production possibilities and limitations from the initial development stage of a new component, not just in terms of the choice of alloy and casting technique but also in terms of design. There are a number of basic rules which designers should follow:

- Sections should be kept uniform and thickness transitions should be smooth, avoiding a build-up of metal at intersections so as to reduce the risk of shrinkage porosity during cooling,
- For the same reason, isolated bosses should be avoided and walls must be correctly sized to assist running,
- There should be a fillet at every inside corner to avoid cracking during the casting operation (this is particularly important for 21100 alloys),
- The filling design should be somewhat asymmetrical to ensure controlled solidification and uniform feed,
- The number of intersections and undercuts should be kept to a minimum as they complicate tooling and the casting operation and hence increase the cost. This applies equally to deburring operations,
- The choice of dimensional tolerances must allow for the casting technique and any subsequent heat treatment deformation can occur during solution treatment and quenching.

9. List of standards

- EN 485 *Aluminium and aluminium alloys – Sheet, strip and plate*
  - Part 1: Technical conditions for inspection and delivery
  - Part 2: Mechanical properties
  - Part 3: Tolerances on dimensions for hot rolled products
  - Part 4: Tolerances on dimensions for cold rolled products

- EN 515 *Aluminium and aluminium alloys – Wrought products – Temper designations*

- EN 573 *Aluminium and aluminium alloys – Chemical composition and form of wrought products*
  - Part 1: Numerical designation system
  - Part 2: Chemical based designation system
  - Part 3: Chemical composition
  - Part 4: Forms of products

- EN 755 *Aluminium and aluminium alloys – Extruded rod/bar, tube and profiles*
  - Part 1: Technical conditions for inspection and delivery
  - Part 2: Mechanical properties
  - Part 3: Round bars, tolerances on dimensions and form
  - Part 4: Square bars, tolerances on dimensions and form

- EN 1706 *Aluminium and aluminium alloys – Castings – Chemical composition and mechanical properties*

- EN 12392 *Aluminium and aluminium alloys – Wrought products – Special requirements for products intended for the production of pressure equipment*

- EN 14286 *Aluminium and aluminium alloys – Weldable rolled products for the storage and transport of dangerous goods*

Registration record series *Teal Sheets*: *International alloy designations and chemical composition limits for wrought aluminium and wrought aluminium alloys* available for free download from the EAA website: http://www.eaa.net/en/about-aluminium/standards/international-registration/

CHAPTER VI

DESIGN AND CALCULATION

1. Introduction

The new European design code for aluminium structures is used as a basis for this chapter. The name of this standard is:
EN 1999 Eurocode 9: Design of aluminium structure

Part 1-1 General structural rules
Part 1-2 Structural fire design
Part 1-3 Structures susceptible to fatigue
Part 1-4 Cold-formed structural sheeting
Part 1-5 Shell structures

Part 1-1 is used for all static design and Part 1-3 for all fatigue design shown in this chapter.
A new European standard for the execution of structural aluminium is under development and is soon ready for publication. It is recommended to use relevant parts of this standard for execution of aluminium components for use in commercial vehicles. The name of this standard is:
EN 1090-3: Execution of steel structures and aluminium structures – Part 3: Technical requirements for aluminium structures

2. Possibilities with aluminium

The advantages of designing with aluminium are:
- High strength-to-weight ratio
- Possibilities to create your own cross-sections with the extrusion technique
- Good corrosion resistance
- Long vehicle life
- Easy to work with
- Easy to repair

Especially for product design, the use of tailor-made profiles is a great advantage for aluminium compared with other metals. In profile design the material can be placed where the effect of the material is optimal regarding resistance. Details can be made in such a way that it will ease the fabrication and assembling of the components.

3. Symbols

Frequently used symbols are defined in this section:
f_o characteristic value of 0.2 % proof strength
f_u characteristic value of ultimate tensile strength
f_{ub} characteristic ultimate tensile strength of bolt
E modulus of elasticity
d bolt diameter
d_o hole diameter
t wall thickness
A cross section area
W section modulus
γ_M partial safety factor for resistance (see the definitions in section 5.2), in EN 1999-1-1:

Subscript $_{Ed}$ is used for factored load effects. It may be on axial force (N_{Ed}), bending moment (M_{Ed}), shear force (V_{Ed}), torsion (T_{Ed}) and forces in connection with bolted connections ($F_{v,Ed}$ for shear force and $F_{t,Ed}$ for tension force).

4. Aluminium versus Steel

Both steel and aluminium are metals with relatively high strength. Both materials are incombustible and will not contribute to a fire. For structural purposes the main differences are:

Elasticity: The modulus of elasticity (E-modulus) of aluminium is 1/3 of that of steel. This means that an aluminium beam with the same cross-section and the same loads as a steel beam will have a deflection 3 times that of the steel beam.

Weight: The density of aluminium is 1/3 of that of steel. This means that a steel beam will weigh 3 times more than an aluminium beam with the same cross-section.

Welding: When welding a hardened aluminium alloy some of the hardening effects will be lost. The strength in the heat affected zone (HAZ) will be reduced. This reduction depends on the alloy, temper, type of product and welding procedure. Ordinary steel has no strength reduction after welding.

Thermal elongation: The coefficient of thermal elongation of aluminium is twice that of steel. This means that an aluminium member will get twice the thermal elongation as a similar steel member with the same temperature difference. Since the elastic modulus of aluminium is 1/3 of steel, the stresses in an aluminium member with fixation are 2/3 of that in a similar steel member.

Most of the structural aluminium alloys have relatively high "strength-to-E modulus" ratio. This effect is especially clear when the aluminium alloy is strain-hardened or heat-treated. Structural aluminium alloys have roughly twice the "strength-to-E modulus" ratio than standard steel. However, when compared with high strength steels, structural aluminium alloys have about the same "strength-to-E modulus" ratio. It should also be noted that the elastic modulus of an alloy mainly depends on its parent metal. In other words, all aluminium alloys have very similar E-modulus, but this is also valid for steel alloys. Consequently, the so called "high strength steels" don't have better elastic properties than mild steel.

Steel designers often use the strength of the material as governing criteria when designing a steel structure and check afterwards whether the deflection is within the requirement.

When designing an aluminium structure, it will often be the deflection criterion that will be governing. For that reason, the design procedure will start with the deflection criterion and it will be checked afterwards if the stress or the resistance of the structure is within the limits.

The deflection of members under bending load depends on the modulus of elasticity (E) and on the moment of inertia (I) together with the load and the span. With the same span and load, it will be the product E x I that will determine the deflection.

To get the same deflection of steel and aluminium beams in bending, the moment of inertia of the aluminium beam must be three times that of steel. If the increase in the moment of inertia is to be done only by increasing the thickness of the web and flanges, the aluminium beam will have the same weight as the steel beam.

To save weight, the aluminium beams in bending have to be higher. An example will illustrate this:

An aluminium beam shall have the same deflection as an IPE 240 steel beam. The moment of inertia and the mass of the IPE 240-beam are

$I = 38.9 \cdot 10^6\ mm^4$.

mass = 30.7 kg/m.

The aluminium beam must have a moment of inertia of

$I = 116.7 \cdot 10^6\ mm^4$

to get the same deflection.

If the height of the aluminium alloy beam shall be 240 mm, this will be satisfied by an I-beam of

I 240 x 240 x 12 x 18.3

which has a moment of inertia and the mass of

$I = 116.6 \cdot 10^6\ mm^4$

mass = 30.3 kg/m

If the height of the aluminium alloy beam can be 300 mm, the deflection criteria will be satisfied by an I 300 x 200 x 6 x 12.9 which has a moment of inertia of

$I = 116.7 \cdot 10^6\ mm^4$

and a mass =18.4 kg/m

which is a weight saving of 40%.

An I 330 x 200 x 6 x 10 will have a moment of inertia of

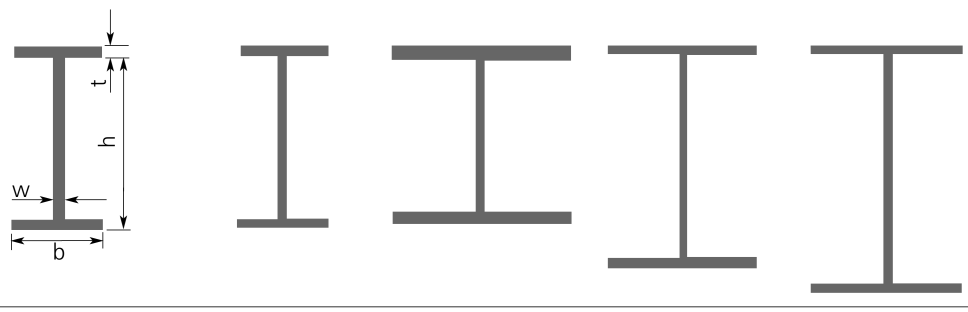
$I = 117.3 \cdot 10^6\ mm^4$

and a mass = 15.8 kg/m

which give a weight saving of 49%.

These three different aluminium beams will give the same deflection as an IPE 240 steel beam. It will be the shape and stability of the beam that will determine the weight of the beam. Table VI.1 shows the beams and the weight savings.

TABLE VI.1

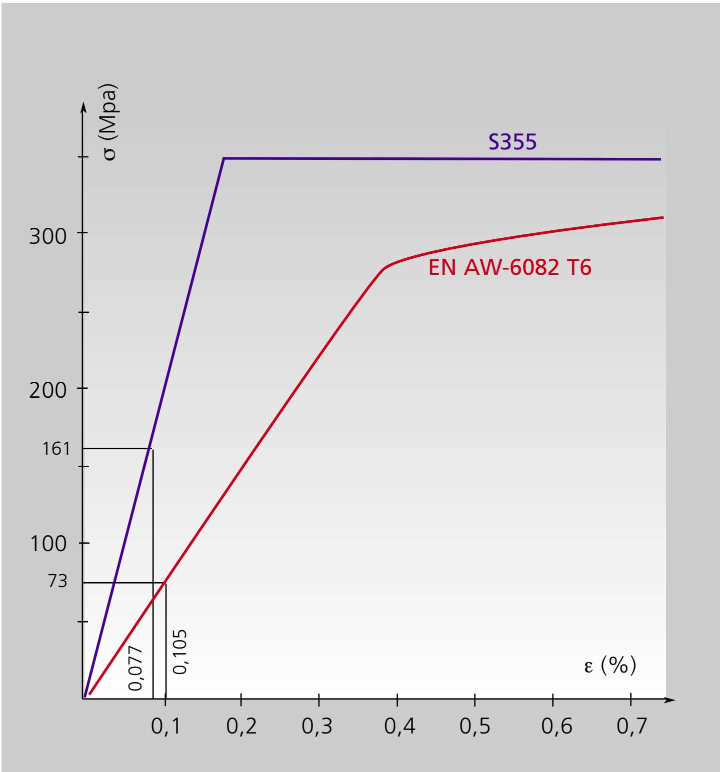


	Steel	Aluminium	Aluminium	Aluminium
Moment in inertia in mm^4	$38.9\ 10^6$	$116.6\ 10^6$	$116.7\ 10^6$	$117.3\ 10^6$
E x I (N/mm^2)	$8.17\ 10^{12}$	$8.16\ 10^{12}$	$8.17\ 10^{12}$	$8.21\ 10^{12}$
h (mm)	240	240	300	330
b(mm)	120	240	200	200
w (mm)	6.2	12	6	6
t (mm)	9.8	18.3	12.9	10
Unit weight (kg/m)	30.7	30.3	18.4	15.8
Weight in % of the steel beam	100 %	99 %	60 %	51 %

The stress in an aluminium structure designed according to deflection criteria is very often low. In the following example a steel beam, IPE 240 is compared with an aluminium beam I 330 x 200 x 6 x 10 (both beams are shown in the table VI.1). The deflection criterion is 1/250 of span (24 mm), the span is 6000 mm and the load is 11.6 kN/m. In the Figure VI.1. the stress-strain curves for steel S355 and aluminium EN AW-6082 T6 is shown. The stress and strain for both the steel and aluminium beam is also shown. With the same deflection, the same load and the same span, the steel beam has a bending stress of 161 MPa while the aluminium beam has a bending stress of 73 MPa. This is the maximum stress when the deflection is 24 mm for both beams.

FIGURE VI.1

STRESS COMPARISON BETWEEN ALUMINIUM AND STEEL BEAMS



Additional comparison of weight-optimized beams are also given in Chapter III, section 2.1

5. Limit state design

5.1. Philosophy

Limit state design and partial safety factor method are the methods that the new design standards are based on. In Europe the EN 19xx standards are the basis for this method for all structural materials in civil engineering. For aluminium the actual standards are:

EN 1990 Eurocode – Basis for structural design
EN 1991 Eurocode 1 – Actions on structures. All parts
EN 1999 Eurocode 9 – Design of aluminium structures

EN 1990 gives the partial safety factor on loads and rules for combination of loads to give the different action effects.

EN 1991 gives the characteristic loads for structures and buildings such as self weight, live loads, wind loads, snow loads, traffic loads etc.

EN 1999 gives the design rules for aluminium structures.

5.2. What is the ultimate limit state

The ultimate limit state is the condition where the safety of the structure is calculated. A structure shall not collapse and design in accordance with the ultimate limit state shall avoid structural failure.

The partial safety factor for the resistance (γ_M) shall take care of the scattering of the strength properties and the geometry of the cross section. For connections the partial safety factor shall in addition take care of uncertainties in the welds and in the bolts and bolt configuration. The partial safety factor for the load effects (γ_F) shall take care of the scattering of the determination of the loads and the probability in the combination of different loads. The partial safety factor is different for the different types of loads, their certainty and how they are combined. Dead loads (i.e. self weight of structure) have a low partial safety factor while the live load (i.e. all forces that are variable during operation, e.g. weight of goods, road vibrations etc…) has a higher partial safety factor.

The condition to be fulfilled is:

$$\frac{R_k}{\gamma_M} \geq \gamma_F \cdot E_k$$

where:

R_k is the characteristic value of the resistance; it may be axial tension or compression, bending moment, shear or a combined resistance.

E_k is the characteristic value of the load effects; it may be axial tension or compression, bending moment, shear or a combined load effect on a cross section or a connection.

γ_M is the partial safety factor for the resistance, also often called material factor.

γ_F is the partial safety factor for the load effects, also often called load factor.

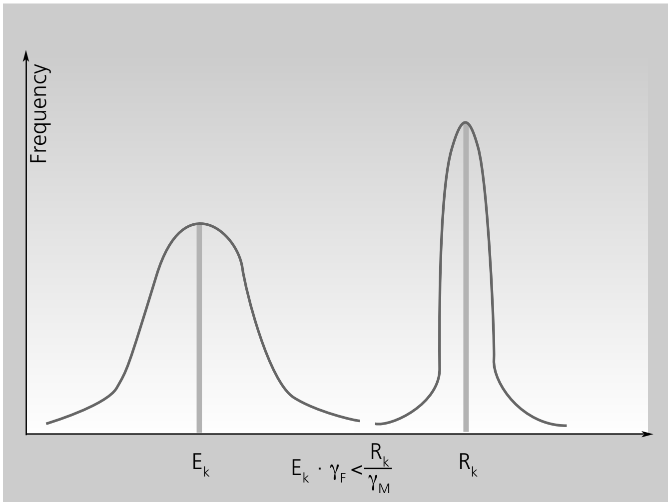
This relation is shown in the Figure VI.2.

Typical values for the partial safety factor for the resistance are 1.10 (γ_{M1}) for members and 1.25 (γ_{M2} and γ_{Mw}) for bolt and rivet connections and welded connections. These are the material factors for building and civil engineering and may also be used in all structural design because the material, the geometrical dimensions and the fabrication of connections are almost similar in all aluminium structures.

Typical values for the load effect factors in buildings and civil engineering are 1.2 for dead loads and 1.5 for live loads. For design of components for commercial vehicles the following load factors may be used:

Dead load: 1.1
Live load: 1.5

FIGURE VI.2



5.3. What is the serviceability limit state

The serviceability limit state is the condition where the serviceability criteria have to be satisfied. The most used serviceability criteria are:

- Deflection limits in all directions
- Dynamic effects like vibrations

In serviceability limit states both the partial safety factor for the resistance (γ_M) and the partial safety factor for the load effects (γ_F) are 1.0.

6. Serviceability limit state

All calculations in serviceability limit state are elastic calculations. Elastic deformations are calculated and compared with the limits for deflections. The sizes of vibrations have to be calculated in the same manner. If the vibration has a high number of cycles, the members and the connection details have to be checked for fatigue.

Normally the calculations of elastic deflections are based on the moment of inertia for the gross cross-section of the member. For members in cross-section class 4 (see section 7.2.4 in EN 1999-1-1) it is necessary to reduce the moment of inertia, if the stresses of the compression part of the cross section are higher than the stresses when local buckling occurs.

Moment of inertia for calculation of deflections for cross section class 4 members:

$$I_{ser} = I_{gr} - \frac{\sigma_{gr}}{f_o}(I_{gr} - I_{eff})$$

Where:

σ_{gr} is maximum compressive stress in serviceability limit state in the cross section, based on the gross cross-section properties (positive in the formula)

I_{gr} is the moment of inertia for the gross cross-section

I_{eff} is the moment of inertia of the effective cross-section in ultimate limit state, with allowance for local buckling

7. Ultimate limit state

7.1. Cross section classes

Cross-sections are classified in 4 classes. In Table VI.2 the different classes identify how the cross-section behaves during compression and bending. This is directly linked to the resistance (load bearing capacity) of the cross-section.

Thin parts of a cross-section may buckle at low stresses, and this will reduce the resistance of the cross-section. This is taken care of with the rules for cross-section classification.

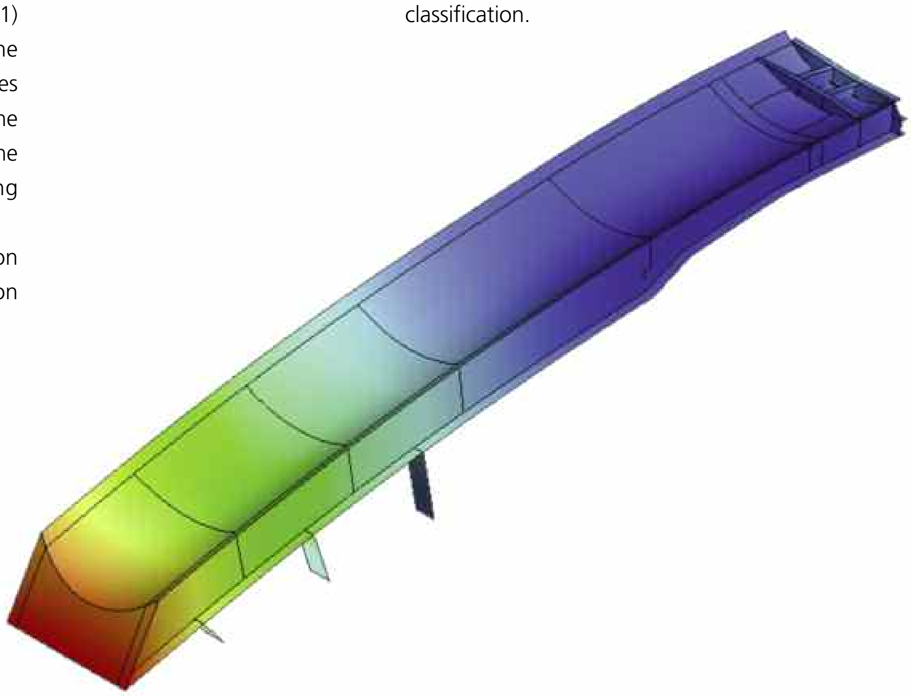


TABLE VI.2

Class 1	Class 2	Class 3	Class 4
Cross-sections that can form a plastic hinge with the rotation capacity required for plastic analysis without reduction of the resistance.	Cross-section that can develop their plastic moment resistance, but have limited rotation capacity.	Cross-section where the calculated stress in the extreme fibre of the aluminium member can reach its proof strength.	Cross-section that will get local buckling before attainment of proof stress in one or more parts of the cross-section.
The resistance may be calculated on the basis of plastic behaviour taking the material hardening effect into account. Rules are given in EN 1999-1-1. Annex F.	The resistance may be calculated on the basis of perfectly plastic behaviour for the material using the conventional elastic limit as the limit value. Rules are given in EN 1999-1-1. Annex F.	The resistance is calculated on the basis of elastic design.	The resistance is calculated on basis of an effective cross-section. Rules for calculating the effective cross-section are given in EN 1999-1-1, 6.1.5

EN 1999-1-1, 6.1.4 gives rules how to classify any cross-section. A β value (i.e. width to thickness ratio) is calculated as:

$$\beta = \eta \cdot \frac{b}{t}$$

where:
b = the width of a cross-section part
t = the corresponding thickness
η = a value depending on the stress situation and if the part is an outstand or an internal cross-section part

Limits are given for the β value for the different classes and for welded or unwelded parts and for outstand or internal parts.

Most aluminium structures in commercial vehicles will be optimised regarding weight. Cross section classes 1 and 2 will therefore seldom be used. Elastic design in cross section class 3 and 4 will be the normal situation.

7.2. Load bearing resistance

The load bearing resistance shall always be higher than the factored load effects.

EN 1999-1-1 gives rules for calculating the load bearing resistances for different kinds of members exposed by different load effects. In the Table VI.3, some of these rules are listed, and references are given:

TABLE VI.3

Situations	Ref. EN 1999-1-1	Resistance
Tension	6.2.3	The smaller of: $N_{o,Rd} = \frac{A_g \cdot f_o}{\gamma_{M1}}$, $N_{u,Rd} = \frac{0{,}9 \cdot A_{net} \cdot f_u}{\gamma_{M2}}$ or $N_{u,Rd} = \frac{A_{eff} \cdot f_u}{\gamma_{M2}}$ $N_{o,Rd}$ is the design resistance to general yielding. $N_{u,Rd}$ is the design resistance to axial force of the net cross-section at holes for fasteners or the effective cross-section at welds. A_g is the gross cross-section. A_{net} is the net area of cross-section. A_{eff} is the effective area of cross-section taking the HAZ effects into account.
Compression (with no buckling)	6.2.4	The smaller of: $N_{u,Rd} = \frac{A_{net} \cdot f_u}{\gamma_{M2}}$, $N_{c,Rd} = \frac{A_{eff} \cdot f_o}{\gamma_{M1}}$ $N_{u,Rd}$ is the design resistance to axial force of the net cross-section at holes for fasteners. $N_{c,Rd}$ is the design resistance to axial force at each cross-section. A_{net} is the net section area with deduction for holes and if required the effects of HAZ softening at the cross section with holes. A_{eff} is the effective section area based on the reduced thickness allowing for the effect of local buckling.
Bending moment	6.2.5 6.2.5.2 6.2.5.1	Bending moment resistance in a net section: $M_{u,Rd} = \frac{W_{net} \cdot f_u}{\gamma_{M2}}$ Bending moment resistance in each cross section: $M_{c,Rd} = \frac{\alpha \cdot W_{el} \cdot f_o}{\gamma_{M1}}$ W_{net} is the elastic modulus of the net section allowing for holes and HAZ softening. W_{el} is the elastic modulus of the gross section. α is the shape factor given in table 6.4 in EN 1999-1-1, 6.2.5.
Shear	6.2.6 6.7.4 6.7.5 6.7.6	The design value for shear resistance for non-slender sections: $V_{Rd} = \frac{A_V \cdot f_o}{\sqrt{3} \cdot \gamma_{M1}}$ A_v is the shear area. For slender webs and stiffened webs the rules for capacity of plate girder webs have to be used (plate buckling).

Situations	Ref. EN 1999-1-1	Resistance
Torsion	6.2.7 6.2.7.2 6.2.7.3	The design St. Venants torsion moment resistance without warping: $T_{Rd} = \frac{W_{T,pl} \cdot f_o}{\sqrt{3} \cdot \gamma_{M1}}$ $W_{T,pl}$ is the plastic torsion modulus For torsion with warping the capacity is the sum of two internal effects. For combined shear force and torsional moment the capacity is given by a reduced shear capacity.
Bending and shear	6.2.8	The shear force will reduce the moment resistance. If the shear force is less than half of the shear force resistance, the effect of the moment resistance is so small that it can be neglected.
Bending and axial force	6.2.9 6.2.9.1 6.2.9.2 6.2.9.3	Formulae are given for the combined effect of an axial tension and bending moments about one or two axis for: • open cross-sections • hollow sections and solid cross-sections • members containing localized welds
Bending, shear and axial force	6.2.10	The shear force will reduce the combined axial tension and moment resistance. If the shear force is less than half of the shear force resistance, the effect of the combined axial tension and moment resistance is so small that it can be neglected.
Web bearing	6.2.11	This is for design of webs subjected to localized forces caused by concentrated loads or reactions applied to a beam.
Compression (buckling resistance)	6.3	Members subject to axial compression may fail in one of the three ways listed below: • flexural • torsional or flexural torsional • local squashing The design buckling resistance of a compression member is: $N_{b,Rd} = \frac{\kappa \cdot \chi \cdot A_{eff} \cdot f_o}{\gamma_{M1}}$ κ is a factor to allow for effect of the HAZ at welds χ is the reduction factor for the relevant buckling mode A_{eff} is the effective area of the cross section. (For cross section class 1, 2 and 3 this is the gross cross-section, for cross section class 4 it is reduced for local buckling effects)

Situations	Ref. EN 1999-1-1	Resistance
Members in bending and axial compression	6.3.3	Members subject to bending and axial compression may fail in one of the two ways listed below: • flexural buckling • lateral-torsional buckling
	6.3.3.1	Combination formulas are given for members with axial compression in combination with bending about one or two axis and fail for flexural buckling. These formulas are given for: • open double symmetric cross-section • solid cross-section • hollow cross-section and tube • open mono-symmetrical cross-section
	6.3.3.2	Combination formula for open cross-section symmetrical about major axis, centrally symmetric or double symmetric cross-section is given for lateral- torsional buckling. Formulas are also given for calculation of the following effects:
	6.3.3.3	• members containing localized welds
	6.3.3.4	• members containing localized reduction of cross-section
	6.3.3.5	• unequal end moments and/or transverse loads
Plate girders	6.7	A plate girder is a deep beam with a tension flange, a compression flange and a web plate. The web is usually slender and may be reinforced by transverse or/and longitudinal stiffeners. Webs buckle in shear at relatively low applied loads, but considerably amount of post-buckled strength can be mobilized due to tension field action. Plate girders are sometimes designed with transverse web reinforcement in form of corrugations or closely-spaced transverse stiffeners (extrusions). Plate girders can be subjected to combinations of moment, shear and axial loading, and to local loading on the flanges. Because of their slender proportions they may be subjected to lateral torsional buckling, unless properly supported along the length. Failure (buckling) modes may be:
	6.7.2 & 6.7.3	• web buckling by compressive stresses
	6.7.4 & 6.8	• shear buckling
	6.7.6	• interaction between shear force and bending moment
	6.7.5	• buckling of web because of local loads on flanges
	6.7.7	• flange-induced web buckling
	6.1.5	• torsional buckling of flange (local buckling)
	6.3.2	• lateral torsional buckling

7.3. Welded connections

7.3.1. General

The rules given in EN 1999-1-1, clause 8.6, apply to structures welded by MIG or TIG and with weld quality in accordance with EN 1090-3. Certified welders are highly recommended.
Recommended welding consumables can be found in:
- Chapter VIII, section 3.8
- EN 1999-1-1, section 3.3.4
- EN 1011-4

When welding hardened aluminium alloys, part of the hardening effect will be destroyed. In a welded connection it can be three different strengths:
- the one of the parent (not heat affected) material (f_o)
- the one in the heat affected zone ($f_{o,HAZ}$)
- the one of the weld metal (f_w)

Normally it will be necessary to check the stresses in the HAZ and in the welds.
The strength in HAZ is dependent on the alloy, the temper, the type of product and the welding procedure. Values are given in Table 3.2 in EN 1999-1-1.
The strength in the weld (weld metal) is dependent on the filler metal (welding consumables) and the alloys being welded. Values are given in Table 8.8 in EN 1999-1-1.
Single sided butt welds with no backing is practically impossible to weld in aluminium. If single sided butt welds cannot be avoided, the effective seam thickness can be taken as:
- the depth of the joint preparation for J and U type
- the depth of the joint preparation minus 3 mm or 25%, whichever is the less for V or bevel type

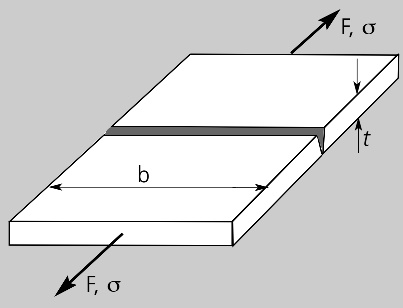
In addition to the single sided butt weld, a fillet weld may be used to compensate for the low penetration of the butt weld.
When designing a welded connection some few practical precautions should be taken into account.
- Provide good access to the welding groove. The “welding head” of the equipment used for welding aluminium is rather large, so there must be enough space around the weld.
- Good access is also needed for checking the weld. All welds shall be 100 % visually examined in addition to some non-destructive testing (NDT).
- Full penetration single sided butt welds are impossible to weld without any backing.

If possible, position the welds in areas where the stresses are low.

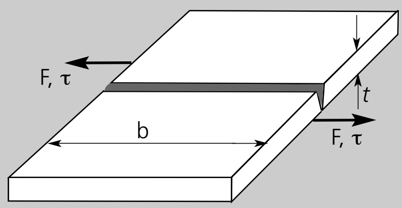
7.3.2. Butt weld

Heavy loaded members should be welded with full penetration butt welds. The effective thickness of a full penetration butt weld should be taken as the thickness of the thinnest connecting member. The effective length should be taken as the total length if run-on and run-off plates are used. If not, the total length should be reduced by twice the effective thickness. (Figure VI.3)

FIGURE VI.3



Butt weld subject to normal stresses



Butt weld subject to shear stresses

Design formulas for butt welds:
Normal stress, tension or compression, perpendicular to weld axis:

$$\sigma_{\perp} \leq \frac{f_w}{\gamma_{Mw}}$$

Shear stress:

$$\tau \leq 0{,}6 \cdot \frac{f_w}{\gamma_{Mw}}$$

Combined normal and shear stress:

$$\sqrt{\sigma_{\perp}^2 + 3 \cdot \tau^2} \leq \frac{f_w}{\gamma_{Mw}}$$

7.3.3. Fillet weld

A fillet weld is defined with the throat thickness "a" given in mm. The Figure VI.4 shows how to measure the throat thickness.
The effective length should be taken as the total length of the weld if:

• the length of the weld is at least 8 times the throat thickness
• the length of the weld does not exceed 100 times the throat thickness with a non-uniform stress distribution
• the stress distribution along the length of the weld is constant

FIGURE VI.4

FILLED WELD

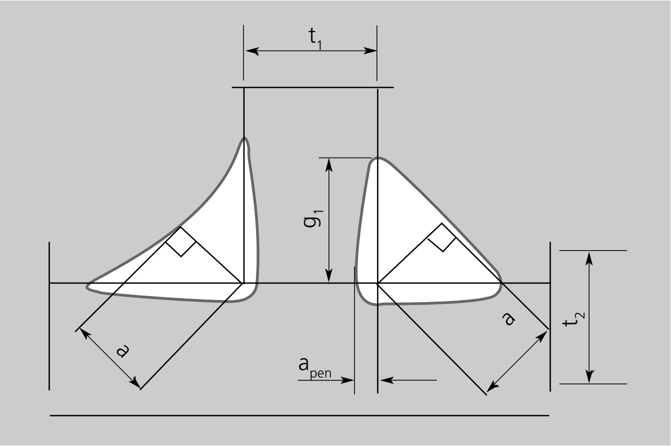


FIGURE VI.5

EXAMPLE OF UNIFORM STRESS DISTRIBUTION

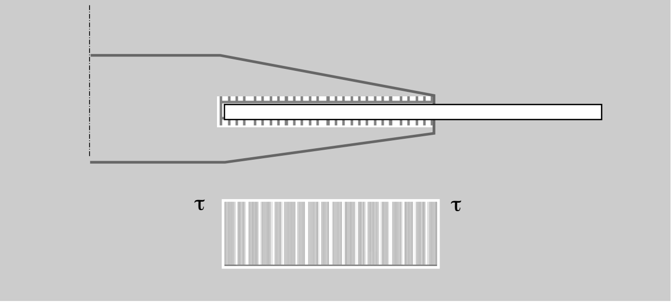
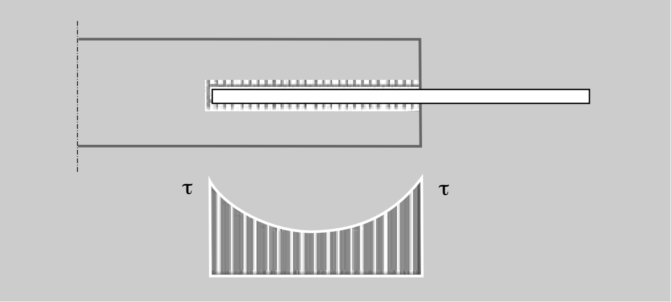


FIGURE VI.6

EXAMPLE OF NON UNIFORM STRESS DISTRIBUTION



The forces acting on a fillet weld shall be resolved into stress components with respect to the throat section (see Figure VI.7). These components are:

$\sigma_{\perp}$: normal stress perpendicular to the throat section

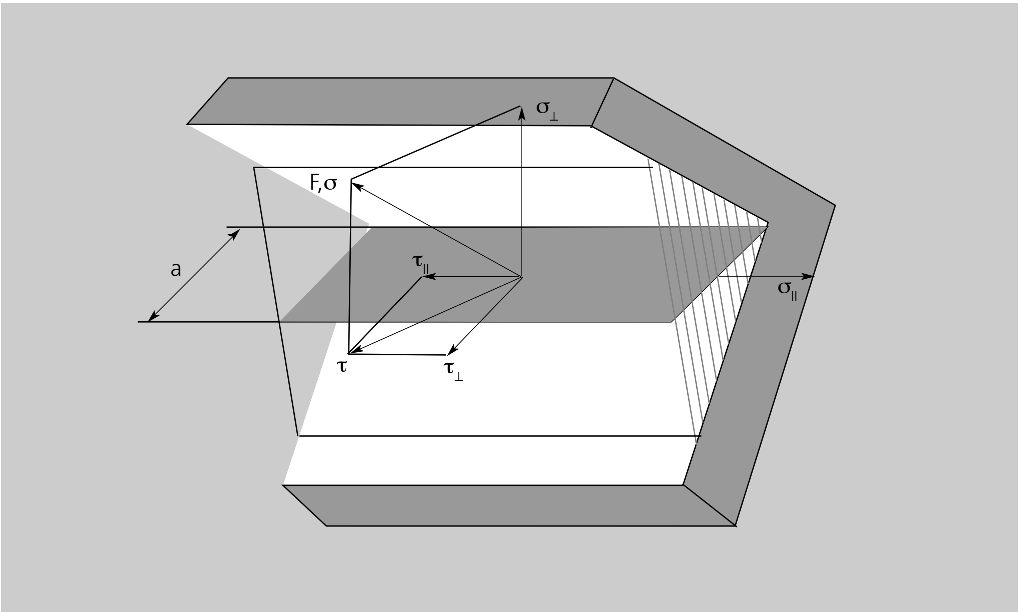
$\sigma_{||}$: normal stress parallel to the weld axis

$\tau_{\perp}$: shear stress acting on the throat section perpendicular to the weld axis

$\tau_{||}$: shear stress acting on the throat section parallel to the weld axis

FIGURE VI.7

FORCES ACTING ON A FILLET WELD



Design formula for fillet weld:

$$\sqrt{\sigma_{\perp}^2 + 3 \cdot \left(\tau_{\perp}^2 + \tau_{||}^2\right)} \leq \frac{f_w}{\gamma_{Mw}}$$

7.3.4. Heat affected zone

The stress in the heat affected zone has to be checked. The stress is calculated for the smallest failure plane for both butt welds and fillet welds. The sketches below (ref. BS 8118) indicate the failure plane for some welds (Figures VI.8, VI.9, VI.10, VI.11):

W: weld metal, check of weld
F: heat affected zone, check of fusion boundary
T: heat affected zone, check of cross section

FIGURE VI.8
BUTT WELD

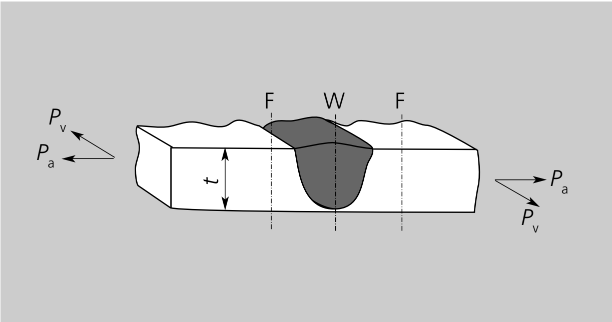


FIGURE VI.9
FILLET WELD

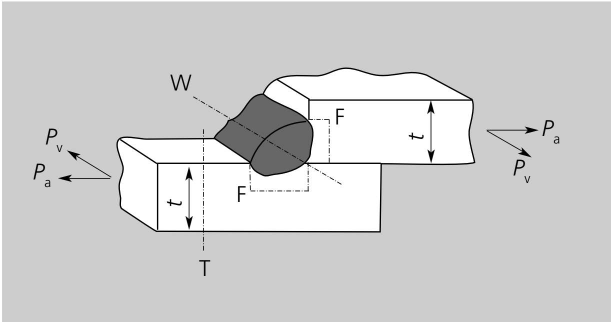


FIGURE VI.10
T BUTT WELD

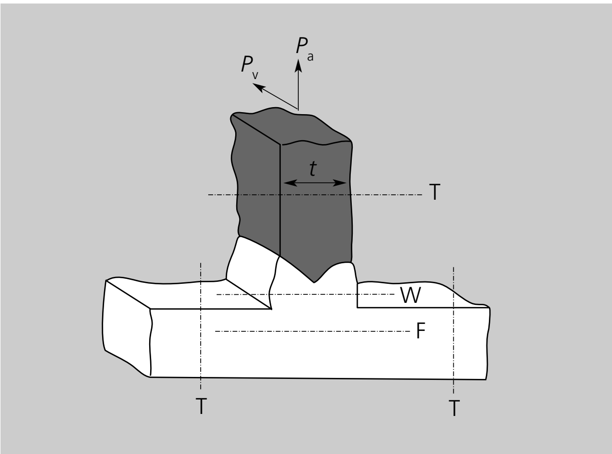
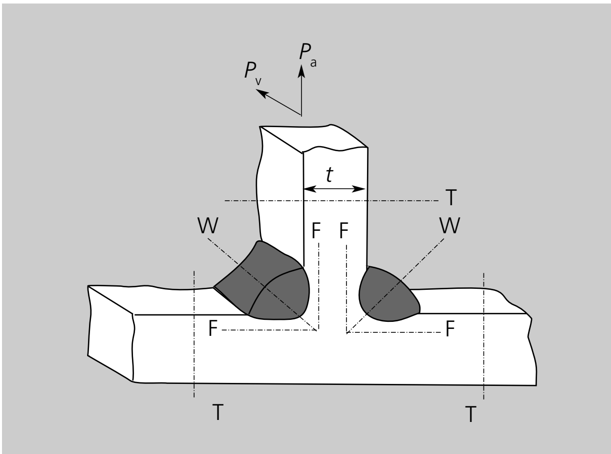


FIGURE VI.11
T FILLET WELD

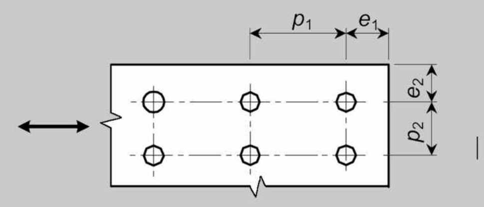
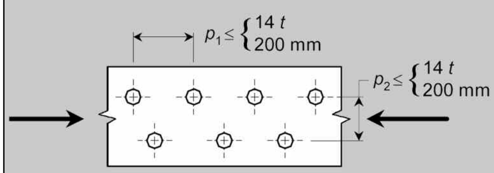
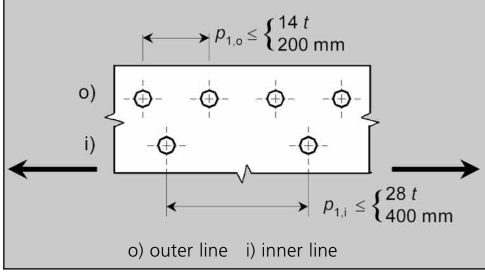


7.4. Bolted connections

The rules for bolted connections are given in EN 1999-1-1, clause 8.5.

Minimum, regular and maximum spacing, end and edge distances for bolts are given in the Table VI.4.

TABLE VI.4

<table>
<tr><th></th><th>Minimum</th><th>Regular</th><th>Maximum</th></tr>
<tr><td></td><td>$e_1 = 1.2 \cdot d_0$
$e_2 = 1.2 \cdot d_0$
$p_1 = 2.2 \cdot d_0$
$p_2 = 2.2 \cdot d_0$</td><td>$e_1 = 2.0 \cdot d_0$
$e_2 = 1.5 \cdot d_0$
$p_1 = 2.5 \cdot d_0$
$p_2 = 3.0 \cdot d_0$</td><td>$e_1 = 4 \cdot t + 40mm$
$e_2 = 4 \cdot t + 40mm$
$p_1 \leq \begin{cases} 14 \cdot t \\ 200mm \end{cases}$
$p_2 \leq \begin{cases} 14 \cdot t \\ 200mm \end{cases}$</td></tr>
<tr><td></td><td>$p_1 = 2.2 \cdot d_0$
$p_2 = 2.4 \cdot d_0$</td><td>$p_1 = 2.5 \cdot d_0$
$p_2 = 3.0 \cdot d_0$</td><td>$p_1 \leq \begin{cases} 14 \cdot t \\ 200mm \end{cases}$
$p_2 \leq \begin{cases} 14 \cdot t \\ 200mm \end{cases}$</td></tr>
<tr><td></td><td>$p_1 = 2.2 \cdot d_0$</td><td>$p_1 = 2.5 \cdot d_0$</td><td>Outer lines:
$p_1 \leq \begin{cases} 14 \cdot t \\ 200mm \end{cases}$
Inner lines:
$p_1 \leq \begin{cases} 28 \cdot t \\ 400mm \end{cases}$</td></tr>
</table>

d_0 is the diameter of the hole and t = thickness of the plate

The maximum clearance for fitted bolts is 0.3 mm and for non-fitted bolts 1.0 mm.

Failure modes for bolted connections may be:

- block tearing, failure in shear in a row of bolts along the shear face of a bolt group and tension failure along the tension face of the bolt group
- shear failure in the bolt
- bearing failure of the bolt hole
- tension failure of the bolt
- punching shear around the bolt head or nut
- combined shear and tension failure

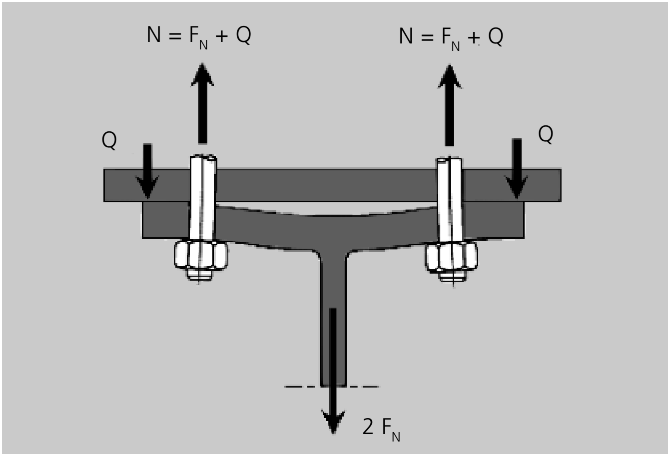
TABLE VI.5

Failure mode	Formula	Parameters
Shear resistance per shear plane	$F_{v,Rd} = \dfrac{\alpha_v \,.\, f_{ub} \,.\, A}{\gamma_{M2}}$	α_v = 0.6 for steel bolts, 4.6, 5.6 and 8.8 α_v = 0.5 for steel bolts, 4.8, 5.8, 6.8 and 10.9 α_v = 0.5 for stainless steel and aluminium bolts A is the cross-section of the bolt at the shear plane
Bearing resistance	$F_{b,Rd} = \dfrac{k_1 \,.\, \alpha_b \,.\, f_u \,.\, d \,.\, t}{\gamma_{M2}}$	$k_1 = \textit{smallest of} \begin{cases} 2.8 \dfrac{e_2}{d_0} - 1.7 \\ 2.5 \end{cases}$ for edge bolts $k_1 = \textit{smallest of} \begin{cases} 1.4 \dfrac{p_2}{d_0} - 1.7 \\ 2.5 \end{cases}$ for inner bolts $\alpha_b = \textit{smallest of} \begin{cases} \alpha_d \\ \dfrac{f_{ub}}{f_u} \\ 1.0 \end{cases}$ $\alpha_d = \dfrac{e_1}{3 \,.\, d_0}$ for end bolts $\alpha_d = \dfrac{p_1}{3 \,.\, d_0} - \dfrac{1}{4}$ for inner bolts
Tension resistance	$F_{t,Rd} = \dfrac{k_2 \,.\, f_{ub} \,.\, A_s}{\gamma_{M2}}$	k_2 = 0.9 for steel bolts k_2 = 0.5 for aluminium bolts k_2 = 0.63 for countersunk steel bolts A_s is the tensile stress area of the bolt
Punching shear resistance	$B_{p,Rd} = \dfrac{0,6 \,.\, \pi \,.\, d_m \,.\, t_p \,.\, f_u}{\gamma_{M2}}$	d_m is the mean of across points and across flats of a bolt head or the nut or the outer diameter of the washer t_p is the thickness of the plate under the bolt head or the nut
Combined shear and tension	$\dfrac{F_{v,Ed}}{F_{v,Rd}} + \dfrac{F_{t,Ed}}{1.4 \cdot F_{t,Ed}} \leq 1.0$	$F_{v,Ed}$ is the load effect of shear $F_{t,Ed}$ is the load effect of tension

Connection details that carry tensile forces, and where the tensile forces don't go directly through the bolts, additional forces in the bolts have to be accounted for. These forces are called prying forces (Q) and they can be considerable large. See the figure VI.12.

FIGURE VI.12

PRYING FORCES




Truck bodies for beverage transport

8. Fatigue

8.1. Theory

Structures with repeating loads may be susceptible to fatigue when the number of load cycles is high, even when the loads give low stresses in the structure. Fatigue failure starts with development of a crack at a point with stress concentrations. With continuous repeating loads the crack will grow, this will be shown as one striation in the failure surface for each load cycles. The distance between the striations is depending on the stress range and that is giving the growing speed. The stress range is defined as the algebraic difference between the stress peak and the stress valley in a stress cycle. At low stress ranges the crack grows slowly and with high stress range it grows fast. (Figure VI.13)

Trailer fatigue testing in laboratory (Benalu)

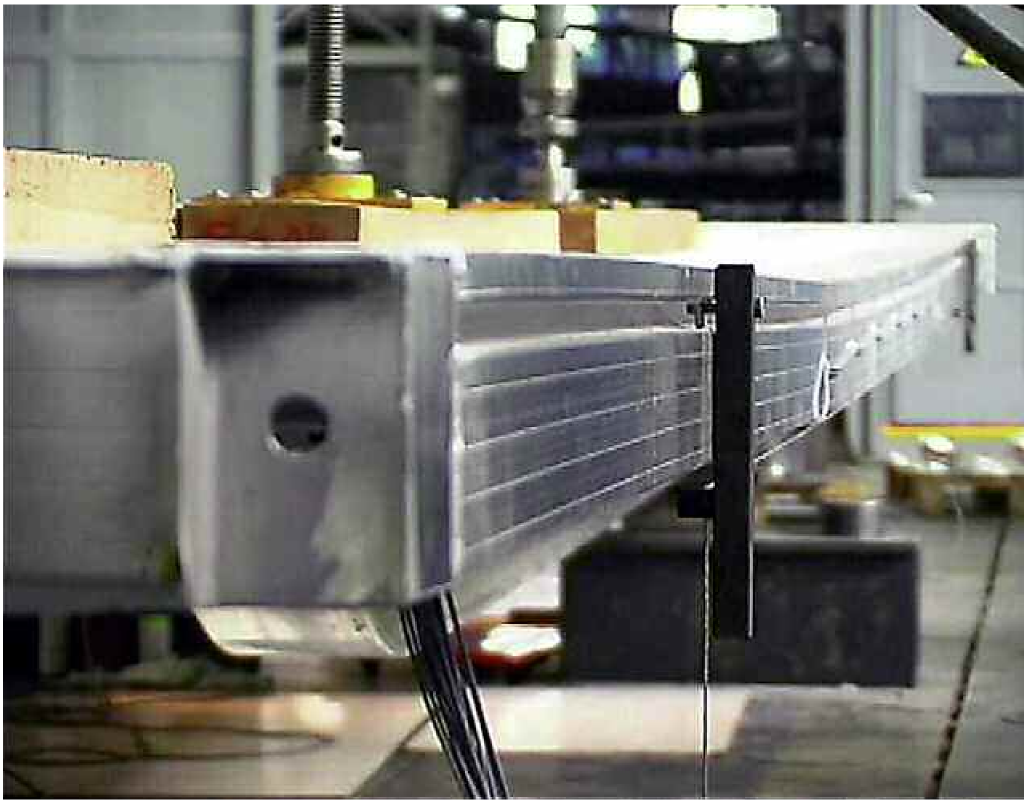
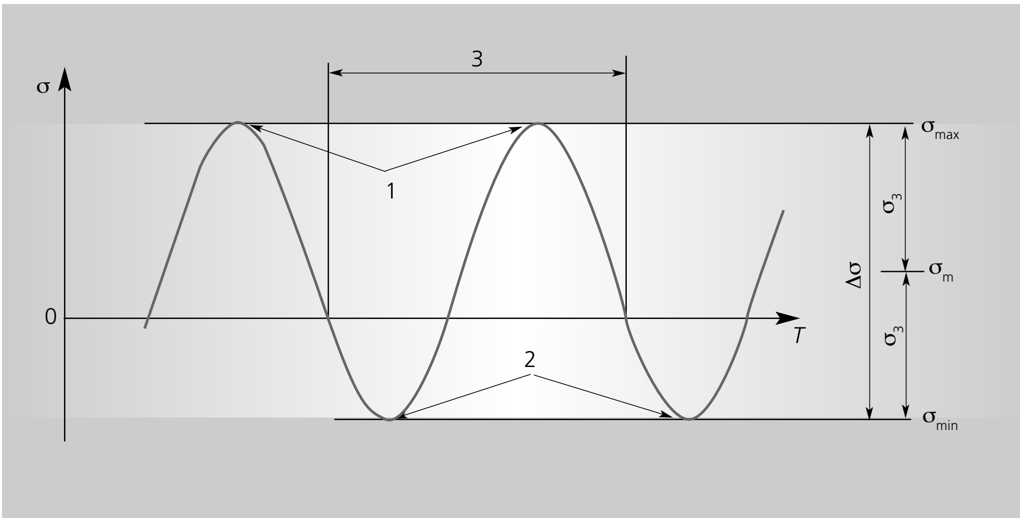


FIGURE VI.13



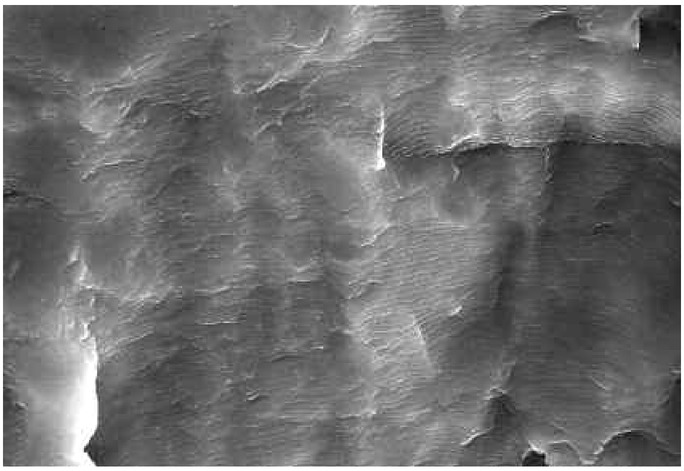
1. Stress peak
2. Stress valley
3. Stress cycle

$\Delta\sigma$ Stress range
σ_3 Stress amplitude

Rules for fatigue design are given in EN 1999-1-3. The rules are based on quality levels given in EN 1999-1-3 and EN 1090-3.

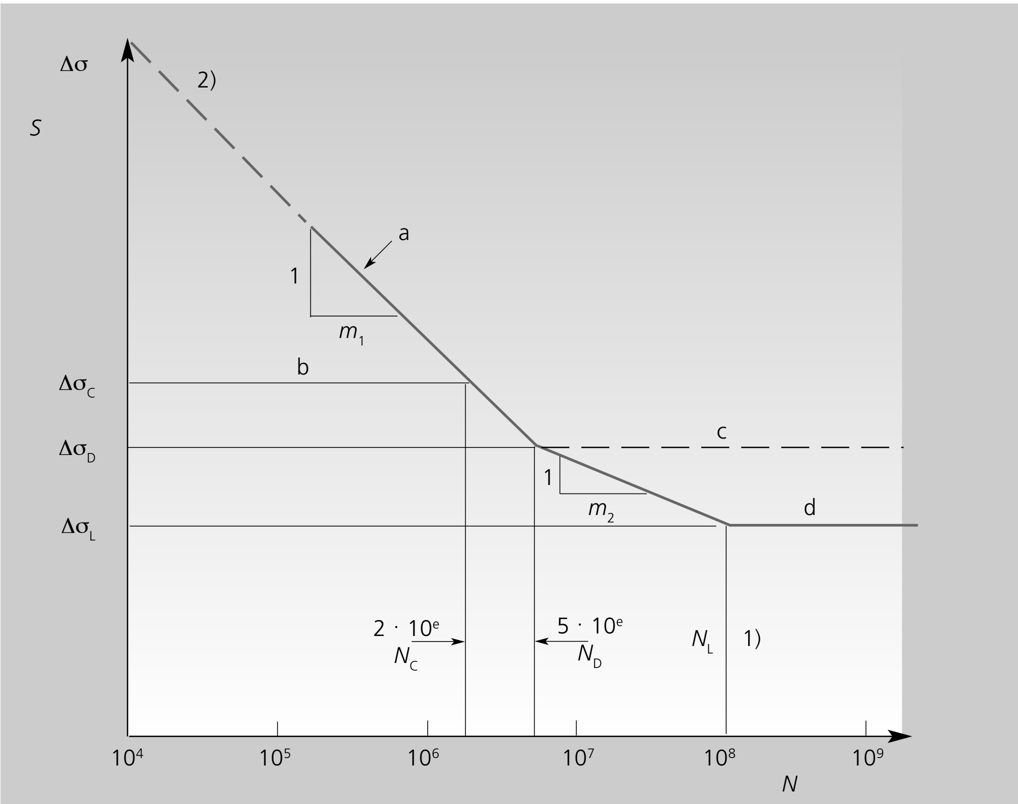
- The fatigue strength depends on:
- type of detail (design)
- stress range
- number of cycles
- stress ratio
- quality of manufacturing

The picture is showing the striations in a fatigue failure surface of an aluminium tube.



The properties of the parent material have very little influence on the fatigue strength in practical structures and components. For connections the properties of the parent material have no influence at all. For a plate or extrusion with no manufacturing or only holes and notches the standard deviate between EN AW 7020 and all other structural alloys. The fatigue strength is given as SN curves for the different details. All detail categories given in EN 1999-1-3 have their own SN curve. A typical SN curve is shown on the Figure VI.14.

FIGURE VI.14



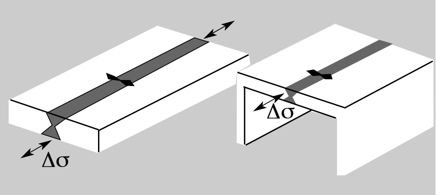
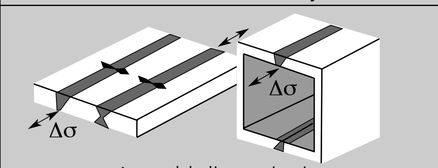
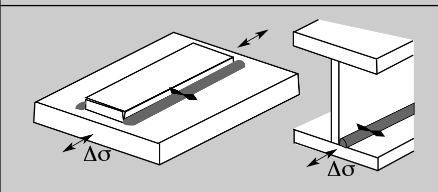
a. Fatigue strength curve b. Reference fatigue strength c. Constant amplitude fatigue limit d. Cut-off limit

1) Number of cycles (10^8) at which the cut-off limit is defined
2) For low cycles fatigue, this part of the curve may not be correct, other calculation methods are recommended (Annex F of EN 1999-1-3). It shall be checked that the maximum design stress range don't result in a tensile stress exceeding the design stress in ultimate limit state.

The stress ratio, R, is the minimum stress divided by the maximum stress in a constant amplitude stress history or a cycle derived from a variable amplitude stress history. Favourable stress ratio will enhance the fatigue strength for some cases compared with the values given in the standard. For initiation sites in base material away from connections, there will be an increase in the fatigue strength for R < +0.5. For initiation site at welded or mechanical fastened connections in simple structural elements, where the residual stresses has been established, taking into account any preaction or lack of fit, there will be an increase in the fatigue strength for R < -0.25. For other cases there will be no change from the values in the standard.

Some typical details categories are shown in the Table VI.6. The first row in the table gives the detail type number, the second row gives the detail category, the third gives a sketch of the detail and also showing the initiation site and the direction of the stress, the fourth gives the weld type, the fifth gives the stress parameter, the sixth gives the welding characteristics, the seventh gives the quality level for the internal imperfections and the eight gives the quality level for the surface and geometrical imperfections. The requirements for the quality levels are found in EN ISO 10042 and additional requirements are given in EN 1090-3.

TABLE VI.6

5.1	63-4,3	 At weld discontinuity	Full penetration butt weld Weld caps ground flush	Nominal stress at initiation site	Continuous automatic welding	B	C
5.2	56-4,3					C	C
5.3	45-4,3	 At weld discontinuity	Full penetration butt weld		Any backing bars to be continuous	C	D
5.4	45-4,3	 At weld discontinuity	Continuous fillet weld			B	C
5.5	40-4,3					C	D

Detail types 5.4 and 5.5 are an example where the same detail has different fatigue strength depending on the quality of the weld.

The SN curves that correspond to these detail categories are shown on Figure VI.15.

The numerical values for the same curves are shown in the Table VI.7.

FIGURE VI.15

INFLUENCE OF WELD QUALITY ON FATIGUE STRENGTH

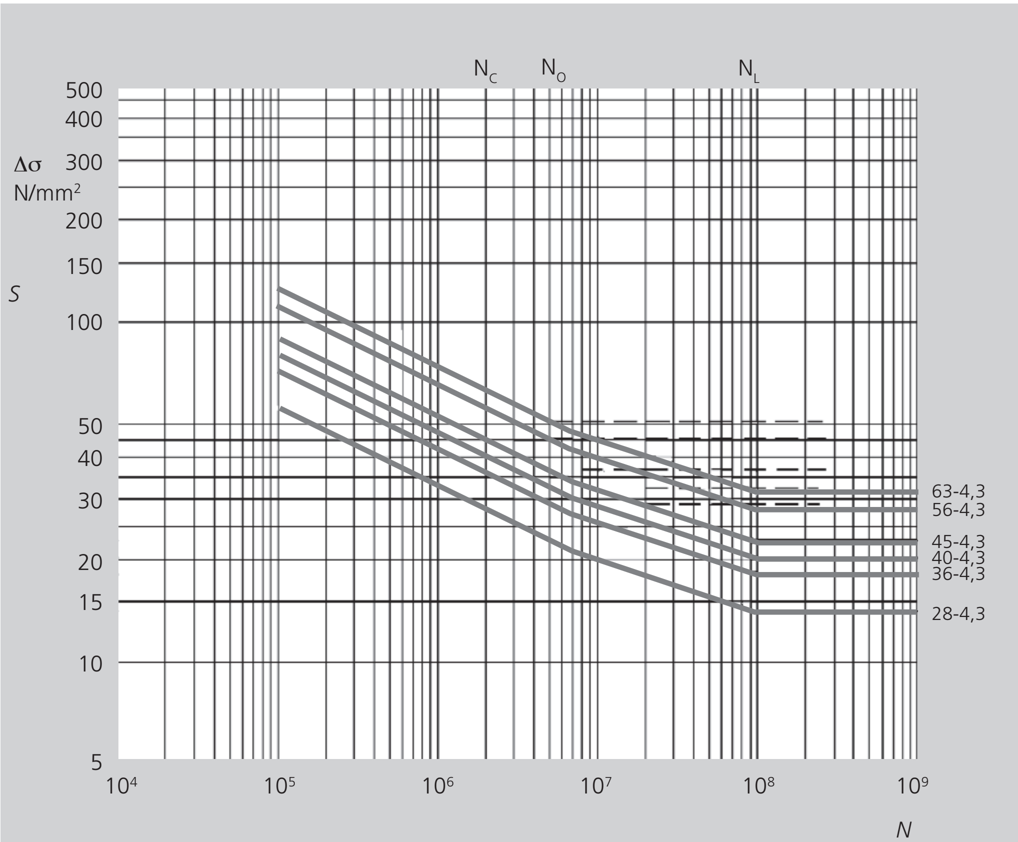


TABLE VI.7

SLOPE		Cycles *N*						
m_1	m_2	1E+05	1E-06	2E+06	5E+06	1E+07	1E+08	1E+09
4.3	6.3	126.4	74.0	63.0	50.9	45.6	31.6	31.6
4.3	6.3	112.4	65.8	56.0	45.3	40.5	28.1	28.1
4.3	6.3	90.3	52.9	45.0	36.4	32.6	22.6	22.6
4.3	6.3	80.3	47.0	40.0	32.3	29.0	20.1	20.1
4.3	6.3	72.3	42.3	36.0	29.1	26.1	18.1	18.1
4.3	6.3	56.2	32.9	28.0	22.6	20.3	14.1	14.1

Fatigue field test (Benalu)

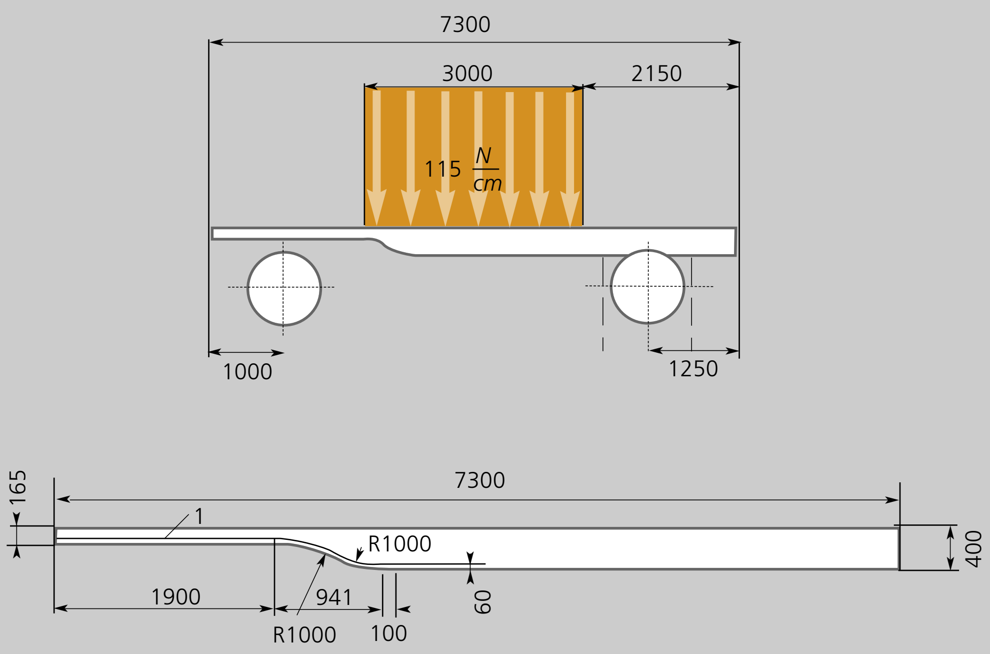
8.2. Practice: comparison between good and bad chassis solutions

The following sections shows good and bad design solutions for aluminium trailer chassis.

They all refer to the load case described in Figure VI.16.

FIGURE VI.16

BOUNDARY CONDITIONS AND BEAM GEOMETRY AS A BASIS FOR THE FINITE ELEMENT ANALYSIS



Load case with 0,5x115 N/cm is used (dashed rectangle).
Cross section of the beam is a simple symmetrical H-section with a flange-width of 150 mm, flange-thickness of 12 mm and web-thickness 8 mm.
(1: To achieve the gooseneck, a part of the web has been cut off and re-joined by welding at a distance of 60 mm from the lower flange.)

8.2.1. Gooseneck

The Gooseneck area of the chassis beam will be the most stressed part and has to be very carefully treated to avoid problems. Generally good precautions will be:

- It is of utmost importance to avoid all welding or heat treatment on, or near, the flanges.
- No welded or bolted attachments to, or near, the flanges in this area.
- No joining of the beams and/or reinforcement of the beams in this area.
- No sudden variation of material thickness or properties in this area.

It is obviously mandatory to follow the fabrication or shop drawings, design manuals, welding procedures, QA-manuals and the designer's guidance throughout the whole fabrication process.

Figures VI.17, VI.18 and VI.19 present a few lifespan examples depending on the geometry of the Gooseneck (i.e. curvature radius).

One can see the increase in stress level is approximately 70% and the increased deflection (δ) approximately 23%. The consequence will be a relative lifespan decrease of 50 % from the nor-

FIGURE VI.17

PLAIN CHASSIS BEAM, R = 1000 mm (σ_{max} = 43 MPa, δ= 5.3 mm)

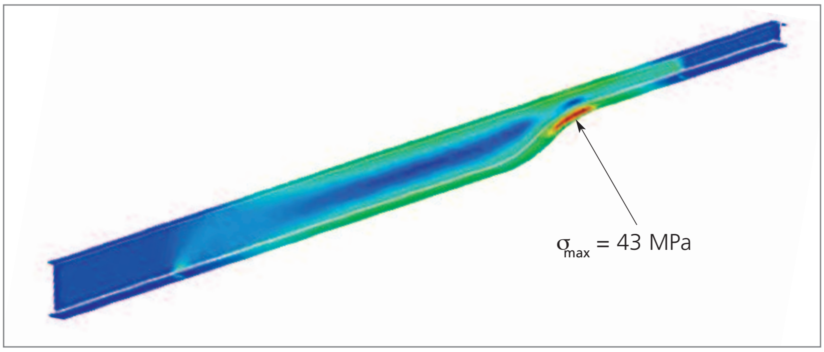


FIGURE VI.18

PLAIN CHASSIS BEAM, R = 450 mm (σ_{max} = 73 MPa, δ= 6.9 mm)

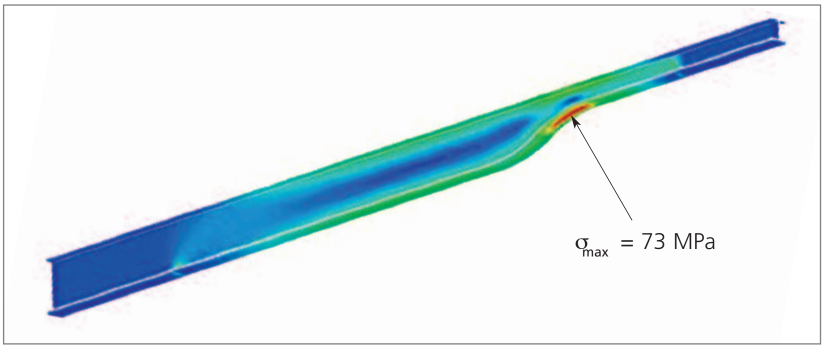
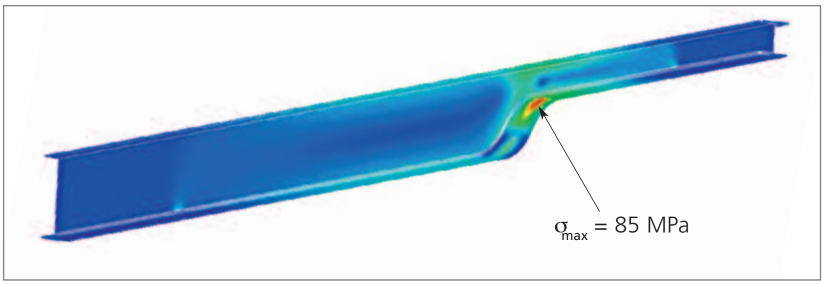


FIGURE VI.19

PLAIN CHASSIS BEAM, R = 300 mm (σ_{max} = 85 MPa, δ= 7.5 mm)



mal radius of 450 mm to 350 mm. As illustrated, an increased radius of 1000 mm will offer very low stresses and demonstrates simply the importance of smooth transitions.

8.2.2. Perforation

The fixture of the supporting legs to the chassis beam will normally be located at the highest stressed area of the chassis beam, i.e. in the gooseneck area. Hence a perforation of the bottom flange by boltholes must be avoided as well as any welding on or near the flange.
Figures VI.20 and VI.21 show the consequence of perforating the flange compared to the web in this area.

The reduced relative lifespan will be as much as >80% due to the effect of stress concentration in the perforated area of the flange. For the situation with the perforation through the web, the lifespan will not be reduced. Both examples show the importance of a location away from the most stressed area of the beam. If a perforation through the flange is inevitable, the location should be as close as possible to the edge of the flange (as far from the web as possible). Note that

FIGURE VI.20

HOLE IN CHASSIS BEAM FLANGE, (Ø = 20 mm): σ_{max} = 102 MPa

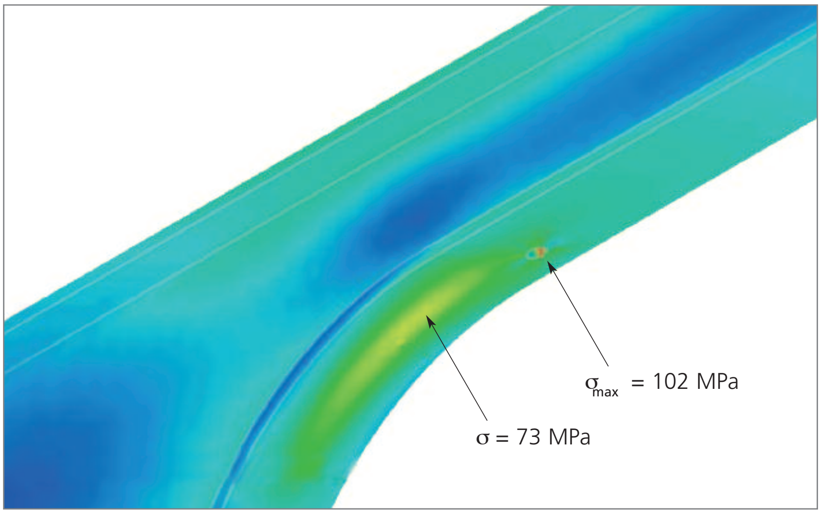
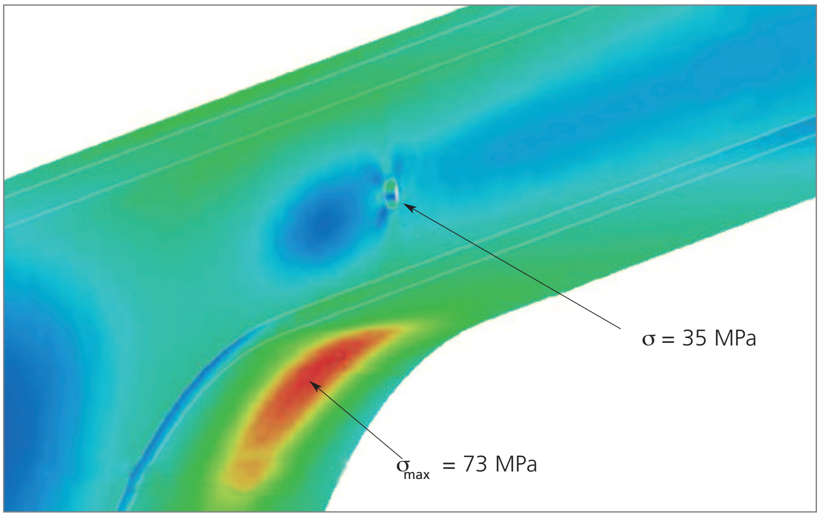


FIGURE VI.21

HOLE IN CHASSIS BEAM FLANGE, (Ø = 20 mm): σ_{max} = 73 MPa (on flange)



required minimum distance from the edge should be according to actual standards, normally 1,5ø – 2,0ø depending on direction of load, etc. Also note that local bending capacity of flange must be checked according to actual location.

8.2.3 Welding

A fixture by welding in the web area of the beam is a much-used alternative to bolting, and will be fully acceptable as long as welding is avoided in or near the flange (i.e. in the most stressed area of the beam). Figures VI.22 and VI.23 illustrate the consequence of welding on the flange and on the web.

The lifespan reduction will be as much as >90% in the case of the fixture by welding on flange, due to the effect of stress concentration in the welded area of the flange and the decreased material properties due to heating.

The fixture by welding in the web area will be of no effect to lifespan. In both cases a geometrically perfect weld is assumed. In real life, imperfections are common and therefore good workmanship and after treatment of welds must be considered.

FIGURE VI.22

FIXTURE BY WELDING ON FLANGE: σ_{max} = 97 MPa

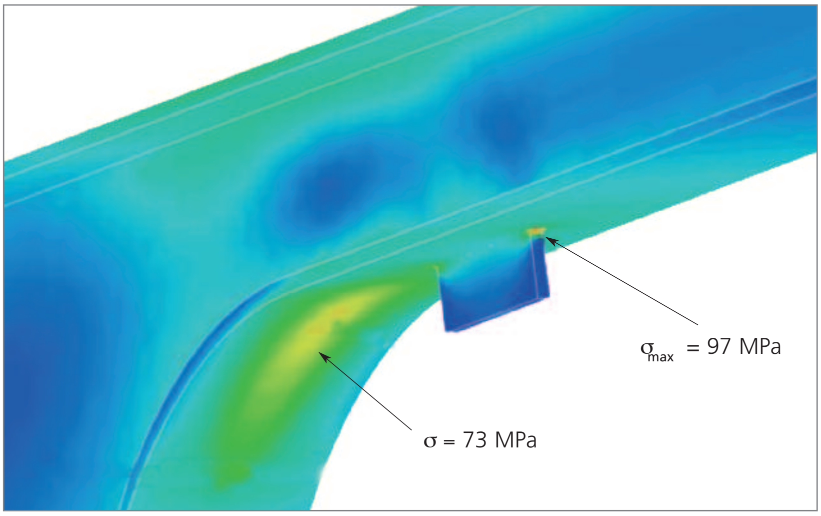
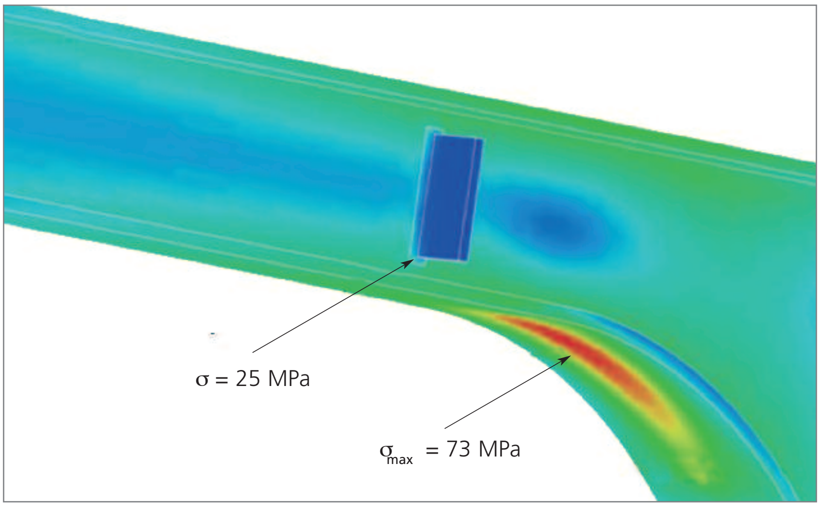


FIGURE VI.23

FIXTURE BY WELDING ON WEB: σ_{max} = 73 MPa (on flange)



Aluminium road tankers (Schrader)

9. Special design issues

9.1. Tanks for the transport of dangerous goods - ADR

Tanks for the transport of dangerous goods have to be built according to the rules defined in the following agreement and standards:

- ADR: Agreement for the transport of Dangerous goods by Road[1]
- EN 13094 "Tanks for the transport of dangerous goods - Metallic tanks with a working pressure not exceeding 0.5 bar - Design and construction"
- EN 14025 "Tanks for the transport of dangerous goods - Metallic pressure tanks - Design and construction"

In particular, tank shell thickness (e) is determined by the following equivalence formula, where e_0 is the minimum shell thickness for mild steel and R_m and A, the tensile strength and elongation of the metal chosen.

$$e = \frac{e_0 \times 464}{\sqrt[3]{(R_m \times A)^2}}$$

For tanks protected against damage:

- For shells with circular cross-section ≤ 1.80 m:
  $e_0 = 3$ mm
  e cannot be lower than 4,00 mm for aluminium alloys[2]
- For shells with circular cross-section > 1.80 m
  $e_0 = 4$ mm
  e cannot be lower than 5,00 mm for aluminium alloys

For other tanks:

$e_0 = 5$ mm for shells with circular cross-section ≤ 1.80 m
$e_0 = 6$ mm for shells with circular cross-section > 1.80 m

Furthermore, absolute minimum shell thicknesses are fixed depending on the type of tank, the shell dimension and the material used.

1. See ADR - Annex A – Part 6 – Chapter 6.8: http://www.unece.org/trans/danger/danger.htm
2. Whatever the result of the equivalence formula is.

Suitable aluminium alloys for that application are listed in standard EN 14286 "Aluminium and aluminium alloys - weldable rolled products for tanks for the storage and transportation of dangerous goods". See also Chapter V, section 6.4 in this manual.

For tanks protected against damage, several alloys listed in EN 14286 allow manufacturing tank shells with e = 5.3 mm (corresponding to R_m x A = 6600) and even e = 5.0 mm (for those with R_m x A ≥ 7152).

9.2. Tippers

9.2.1. Construction

Tipper body trailers (or "dump bodies") are constructed in two different versions:

- Combination of plates and extrusions (more frequently used version)
- Extrusion intensive construction, where all sides of the trailer are made of clamped and / or welded extrusion profiles

Another version which came up in the last few years is a material – mix version with a steel bottom plate and aluminium side- walls (bolted to the steel plate).

Two main tipper types can be differentiated:

- Rectangular trailer
- Half – pipe trailer

Independent from the type of tipper, all extrusion cross – sections and the thickness of the plates are calculated with respect to:

Aluminium tipper bodies (Stas)

Production of aluminium tipper bodies (Schmitz)

- Actual load (compression / tension)
- Bending forces (static and during tipping operation)
- Other forces like shear stress, deflection, buckling

In addition, the type of products to be transported has to be taken into consideration during design of the tipper. This is due to the fact, that the load can be just concentrated locally and on a very small area or it can be divided quite uniform across the whole bottom of the tipper body.

9.2.2. Wear

Wear (or abrasion- resistance) is the most discussed issue when it comes to the construction of an aluminium tipper. A lot of uncertainties about the abrasion – resistance of the aluminium as well as the totally different type of loads makes it nearly impossible to find a perfect solution for each transport problem.

Wear is not only taken into account for the calculation of the actual plate or extrusion thickness, especially of the bottom plate, but also for the type of aluminium to be chosen.

9.2.2.1. Defintion of Wear

The mechanism of wear is quite complex. Wear generally occurs when one surface (usually harder than the other) cuts off material from the second. The area of contact between the two surfaces is thereby very small and concentrated on surface asperities. The shear forces are transferred through these points and so the local forces can be very high.

Abrasives can act like in a grinding process where the abrasive is fixed relative to one surface or in a lapping process, where the abrasive tumbles, producing a series of indentations.

9.2.2.2. Factors influencing the wear

The wear condition can vary extremely from one load to another. Therefore it is not always possible to link the actual hardness of a work-hardened alloy to the wear resistance[3]. It was found out that for a very large extent, the type of load is a decisive factor.

Soft goods like potatoes, fruits, sugar beets or other agricultural products are much less abrasive than mineral goods. In case of mineral goods like stones, powders, cement, chalk etc. the size, form (sharpness) and hardness of the material is by far the most critical factor regarding abrasion (in laboratory tests even the change of a type of sand increased the wear by 35%).

3. *Abrasive wear of aluminium alloys rubbed against sand*, K. Elleuch, S. Mezlini, N. Guermazi, Ph. Kapsa, Wear 261 (2006) 1316–1321

Even the wear debris acts thereby as an additional source for abrasion.

Also the number of tipping operations is to be considered. The more often the trailer is tilted, the more often abrasion occurs. The number of cycles has a linear function when set into relation to the mass lost of the aluminium plate.

Very often, tippers are used by the transport companies for other products than they are originally made for and so a reliable calculation of the lifetime of an aluminium bottom plate cannot be determined.

9.2.3. Material selection

The choice of material for the bottom plate of tipping trailers is nowadays often a question of specific experience, material availabilty and manufacturer s specific production methods.

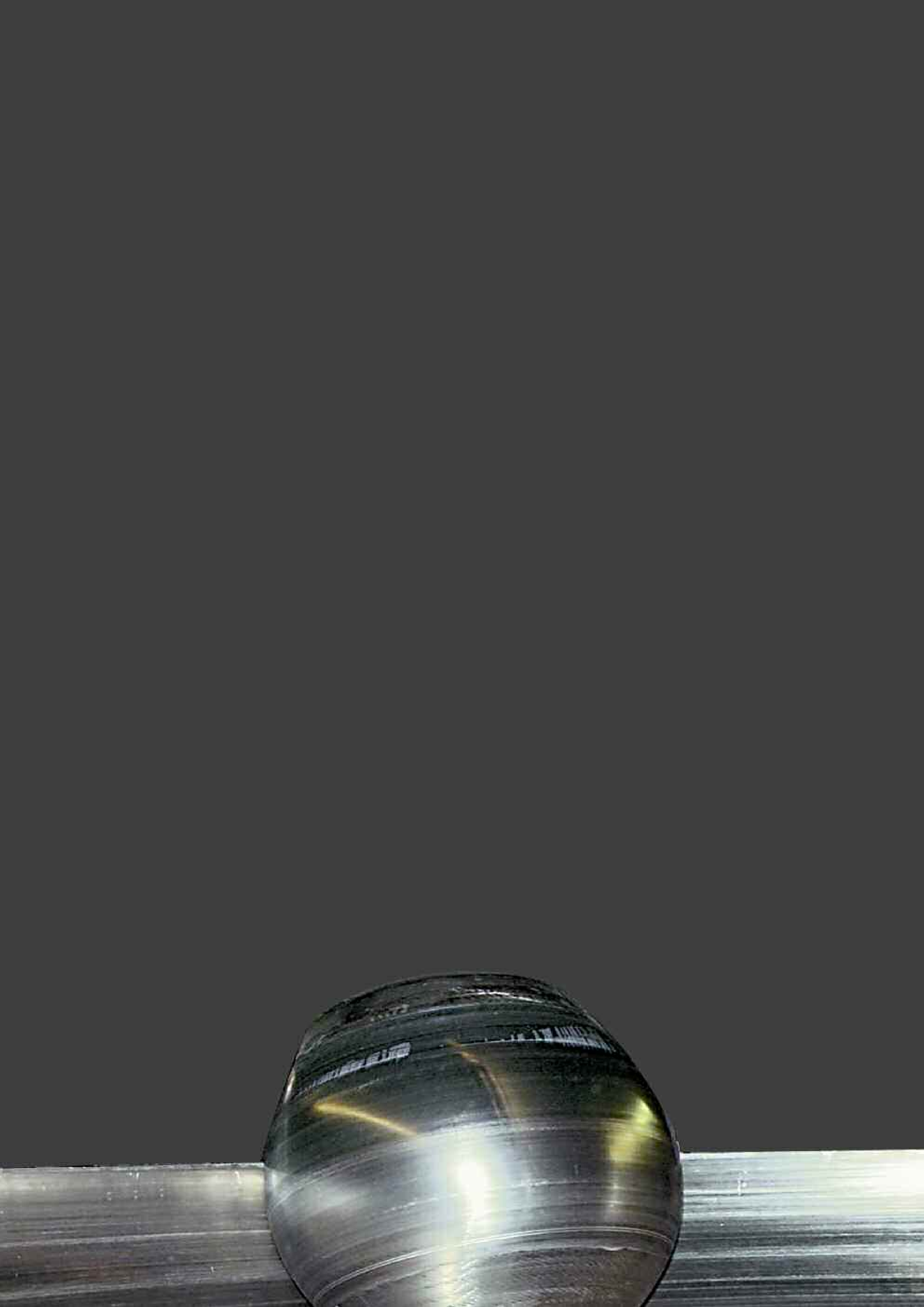
Typical bottom plate material is:
- 5083 H32, H321, H34
- 5086 H24
- 5383 H34
- 5454 H22, H24
- 5456 H34

or other, mill-specific alloy types.

Full aluminium tipper (Menci)

10. References

- EN 1999-1-1 Eurocode 9 Design of aluminium structures, Part 1-1 General structural rules.
- EN 1999-1-3 Eurocode 9 Design of aluminium structures, Part 1-3 Structures susceptible to fatigue.
- EN 1090-3 Execution of steel structures and aluminium structures, Part 3 Technical requirements for aluminium structures
- EN-ISO 10042 Arc-welded joints in aluminium and its weldable alloys – Guidance on quality levels for imperfections.
- BS 8118 Structural use of aluminium, Part 1 Code of practice for design.
- ADR: Agreement for the transport of Dangerous goods by Road.
- EN 13094 Tanks for the transport of dangerous goods - Metallic tanks with a working pressure not exceeding 0.5 bar - Design and construction.
- EN 14025 Tanks for the transport of dangerous goods - Metallic pressure tanks - Design and construction.
- EN 14286 Aluminium and aluminium alloys - weldable rolled products for tanks for the storage and transportation of dangerous goods.



CHAPTER VII

FABRICATION

1. Introduction

The forming operations used in the commercial vehicle industry are many and various. The manufacturer will cut, fold, roll and bend semi-finished sheets and extrusions to produce a vehicle or an accessory.

These operations, some of which such as cutting and drilling can now be programmed and automated, are carried out according to rules which we have summarized in this chapter. In certain cases and in some countries they are also standardized, and the relevant standards are referred to where they exist.

In any case, it is very important to use equipments dedicated to aluminium.

Most aluminium alloys used in commercial vehicles belong to the family of aluminium-magnesium alloys (5000 series) for rolled products or to the aluminium-silicon-magnesium family (6000 series) for extruded products.

1.1. 5000 series alloys

In soft conditions, 5000 series alloys have excellent forming properties as suggested by the difference between proof stress and ultimate tensile strength and by the level of elongation[1].

As metals are hardened by mechanical cold working, it may be necessary to improve ductility so as to continue forming by machine or by hand. This is done by annealing[2], a process that is easy to accomplish either in a furnace or with a welding torch, using tallow as a temperature indicator which turns a light brown colour at 340 °C. Heat indicator crayons or even a stick pyrometer may also be used.

If necessary, inter-stage annealing can be repeated between shaping operations, however there is one golden rule: only anneal the metal if it becomes difficult to work, in other words when the work-hardening rate is greater than or at least equal to the so-called critical work-hardening rate.

1.2. 6000 series alloys

These are used mainly as extruded sections. The main alloy elements are magnesium and silicon.
These are heat treatable alloys supplied in the T6 or T5 condition and, less commonly, in the T4 or T1 condition[3].

Generally speaking the shaping properties of this family of alloys in the fully heat-treated condition are limited. Nevertheless shaping should be performed cold as heating will considerably reduce mechanical properties (approx. 40 %).
More complex shaping of the extrusions may be done in the T1 or T4 condition, before ageing to full hardness in T5 or T6. In this case it is beneficial to do the forming within a short time window of a few days after the solution heat-treatment to T1 or T4,

1. Please refer to EN 485-2.

2. For 5000 alloys with Mg content above 3%, this must be done very carefully to prevent sensitization to intergranular corrosion. See also Chapter XI, section 2.2.6.

3. Please refer to Chapter V section 5, for an explanation of these tempers.

i.e. before that the material gets hardened by cold-ageing.
If very extensive shaping is to be done, you should do this in a time-span of a few minutes after the treatment to T1 or T4.

1.3. 7000 series alloys

These extrusions are used in some high-strength applications within transportation, automotive and sports equipment. The main alloy elements are zinc and magnesium.
The extrusions are used in the T5, T6 or a T7 over-aged condition.
The shaping may take place in the T1 or T4 condition, before the material is artificially aged. More complex forming is done in the T4 condition, shortly after the solution heat treatment, before ageing to T6 or T7.
Before using 7000 alloys, prior consultation with the supplier is strongly recommended.

2. Fabrication of products from plate

The general methods of aluminium alloy fabrication and the machines used are not very different from those used for steel. Aluminium alloys are easy to fabricate.

However, their relative softness must be taken into account and it is essential to use special tools to avoid damaging aluminium surfaces. Risks of contamination from traces of ferrous and cuprous metals must also be avoided as these can cause localized corrosion. It is essential to work in an environment where such risks are minimized.

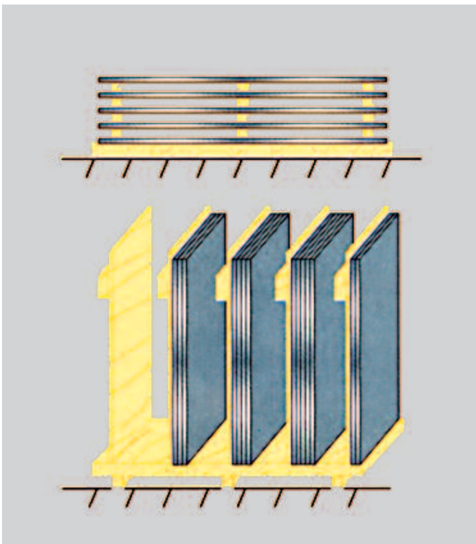
2.1. Storage

Aluminium sheets are classified by family of alloy and stored upright when more than 0.8 mm thick (Figure VII.1). Thin sheets (less than 0.8 mm) should be stored flat.

Aluminium sheets should never be placed directly on the ground, even if concreted, and should be kept away from splash water, condensation and hostile environments.

They are best stored under cover in a ventilated area and separated by timber blocks to prevent condensation stains.

FIGURE VII.1
STORAGE



2.2. Marking out

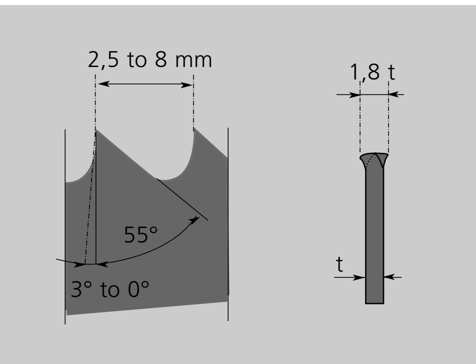
Scribing tools should not be used, since any tracing marks which might be left on the finished component can become crack starters under high loads.

This precaution is not necessary where the scribe indicates a cutting line.

As a general rule it is advisable to trace using a hard pencil (e.g. 5H) which is easier to see and easy to erase in case of error.

FIGURE VII.2

BANDSAW



2.3. Cutting to shape

Plate or crocodile shears can be used to make straight cuts. The rating of the shear should be more or less the same as for cutting non-alloyed steel with low carbon content and the same thickness.

Sawing is a common cutting process which is very economical for aluminium alloys.

2.3.1. Band saw

The most common type of saw is the band saw. This can be a simple timber band saw but with a blade of specially designed profile to break and dislodge the aluminium chips from between the saw teeth.

This is achieved by the alternation or pitch of the teeth and by the clearance angle defined Figure VII.2.

THE CHARACTERISTICS OF A BAND SAW FOR ALUMINIUM ARE AS FOLLOWS:

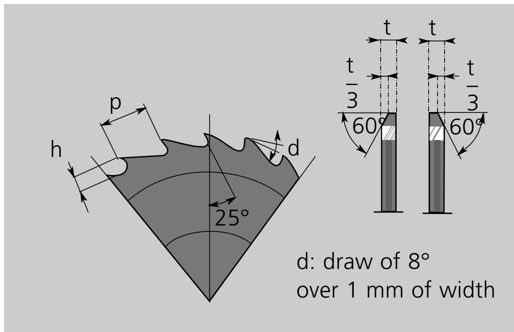
- E (thickness) = $\frac{\text{Diameter of flywheel}}{1000}$
- Width = 10 to 30 mm
- Tooth pitch = 2.5 to 8 mm; two teeth must always be in action
- Lubricant = tallow or soluble oil.

2.3.2. Circular saw

As with the band saw, the saw pitch varies with the thickness or section to be sawn but the process of cutting, which is a function of the machine characteristics, makes it similar to milling (Figure VII.3).

FIGURE VII.3

SAW - MILLING OR CIRCULAR



With the band saw and circular saw, the cutting speeds for 3000, 5000 and 6000 series alloys are as follows:

- HSS blade: 600 to 1000 m/min.
- Carbide blade: 800 to 1500 m/min.

The portable milling saw is a tool that can be used to straight cut products up to 20 mm thick and with good rates of advance.

It may be preferable to use a jigsaw for thicknesses of 6 mm or less. The jigsaw is highly manoeuvrable and can be used to cut complex curves.

Water jet cutting (SAG)

2.3.3. Fluid jet

Metals, including aluminium alloys, can be cut using water jets bearing abrasive particles (PASER process) at high pressures (3000 bars and over). Granules of garnet, corundum or other very hard minerals are used.

The advantage of this process is that it does not affect the metallurgical condition of the product and is very versatile.

Its performance is also excellent, and in aluminium, thicknesses between 1 and 100 mm can be cut at rates of 3500 mm/min down to 30 mm/min for the larger thickness.

2.3.4. Plasma

There are two plasma cutting techniques (Figure VII.4):

- traditional plasma, with a draft of some 6°,
- water VORTEX plasma, with a very small cutting draft, of the order of 2°.

Compared to traditional plasma, water VORTEX plasmas facilitate greatly increased cutting speeds and reduce nuisance factors such as smoke, noise, ozone discharge. The process requires substantial amounts of power however.

The plasma is formed in a special torch, and an inert gas (usually argon or nitrogen) moving at great speed is dissociated under the effect of an electric arc to attain the plasma state.

Owing to its high cutting speed (several metres per minute), its quality and precision of cut and suitability for automation, a plasma cutting machine can be a highly profitable investment, even for short production runs.

FIGURE VII.4
PLASMA TECHNIQUES

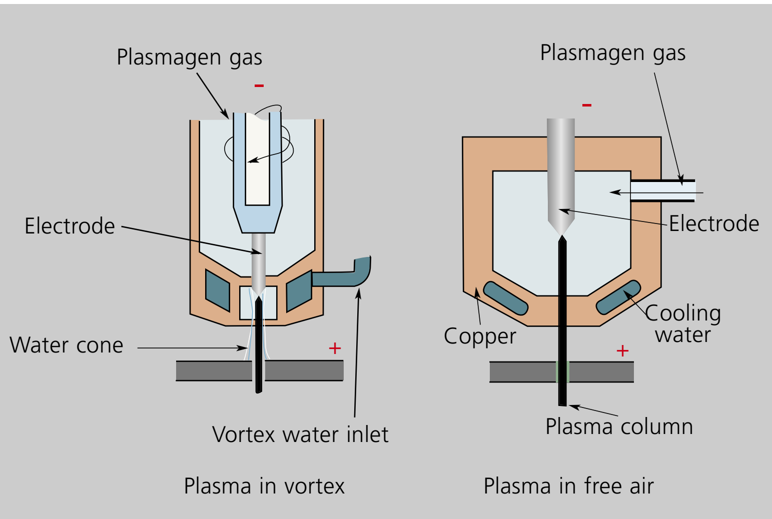
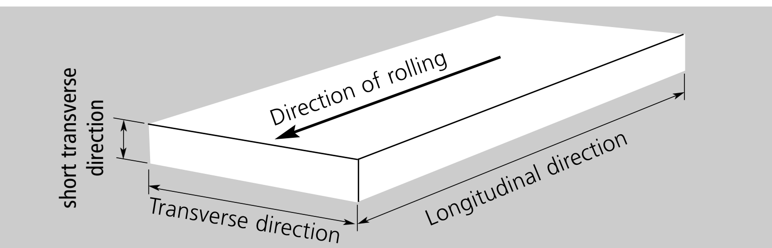


FIGURE VII.5
FIBRE ORIENTATION



2.3.5. Laser cutting

This process is mainly used in the automotive industry.
More information can be found in the Aluminium Automotive Manual (www.eaa.net/aam).

Note:
The width of the heat affected zone is less than 1 mm whatever the alloy and for all thicknesses. However cracking is sometimes observed in the short transverse dimension (Figure VII.5) that can attain a depth of some 2 mm. Whatever the thickness of the product, machining off 2 mm of material will restore the metal's original qualities.
This is obviously unnecessary if the cut pieces are intended for use as welding blanks.

2.4. Edge rolling

This shaping technique requires no special equipment for aluminium. The rollers must of course be clean and have smooth surfaces.

Plasma cutting (Benalu)

2.5. Bending

For multiple folds, holes should be used to mark the crossover points of the fold lines to avoid causing cracks when the folds are made.

Aluminium does not require any special bending tools, and conventional table bending machines or presses are perfectly adequate provided the working parts of the tooling are free from unacceptable irregularities.

The bending radii to be observed as a function of the thickness are given in standard EN485-2.

2.6. Non-machinable faces

As with bending, one worthwhile precaution is to remove all score marks from the edges caused by cutting so as to prevent the formation of cracks at points of deep deformation.

Shaping is carried out on the 5754, 5086 and 5083 grades (and on other alloys in the same family) in the annealed or H111 condition. In some cases shaping may call for inter-stage annealing[4], and this can be done as described before using an annealing torch and tallow as temperature indicator.
Inter-stage annealing can be carried out several times in the course of the shaping operation; however care should be taken to avoid annealing a metal that is only slightly work-hardened to prevent the risk of grain enlargement.

4. For 5000 alloys with Mg content above 3%, this must be done very carefully to prevent sensitization to intergranular corrosion. See also Chapter XI, section 2.2.6.

3. Fabrication of products from extrusions

Extrusions are usually individually protected in packing cases to prevent problems such as fretting in transit.

3.1. Storage

Extrusions are best left in their original packing cases until required. As with aluminium sheets, they should never be set down directly on the ground, even if concreted, and should be kept away from splash water, condensation and hostile environments to prevent possible corrosion during storage.

3.2. Cutting

The processes of sawing described above are also suitable for cutting aluminium extrusions
.

3.3. Bending

The bending of extrusions on an industrial scale may be carried out with different methods and means.

3-point press bending (Benalu)

3.3.1. Bending by 3-point press-bending

This may be done when the bend radius is small compared to the height of the extrusion section, and when the accuracy (spring-back) of the bend as well as the optics are not so important. It is typically performed in a simple tool in a (mostly) hydraulic press.

3.3.2. Bending by 3-point press-bending with rotating dies

This process is typically using a tool in a press or a bending machine. The rollers may be kinder to the extrusion work piece than by the method in 3.3.1 due to less abrasive sliding action between tools and work piece.

3.3.3. Bending by compression bending

A sliding tool forces the extrusion to follow a circular die. The extrusion is not moving length-wise relative to the die.

Bending over rotating tools

3.3.4. Bending by compression roll-forming

It is identical with 3.3.3, but with a rotating wheel instead of the sliding tool. Very severe reforming may be made. It is usually performed in roll-forming machines with purpose-built tools.

3.3.5. Bending by rotary draw bending

It is mostly performed in standard tube-bending machines.

3.3.6. Stretch-bending over a fixed tool ("swing arm stretch-bending")

The ends of the profile are gripped to stretch-bend the profile against a fixed last which has the form of the finished product. In many cases this form may be a bending sweep built-up by compounded radii. Nearly all of the cross section of the extrusion will be subjected to tensile stress above the yield stress limit, and this applies to the full length of the work piece. This means that the spring-back effect on global shape will be little, constant and predictable. When a closed extrusion is formed in this way, the outer wall may be subjected to sagging. This may be countered by using a basic extrusion with an outer wall which is barrel-shaped outward or by inserting a suitable elastic material (e.g. rubber). The operation may be performed by a dedicated tool in a press or in a stretch-bending machine.

3.3.7. Stretch bending by rotating dies (rotary stretch bending)

By this method the extrusion is gripped at its ends and bent over one ore two (normally two) rotating dies having a contour corresponding to the final product shape. The stretching comes as a result of the rotation and may effectively be controlled by the location of the rotary axes.
As opposed to the situation in conventional stretch bending method (3.3.6), the bending starts at the end and propagates towards the centre of the extrusion. The primary bending moment is generated by the rotating dies, and is typically constant along the workpiece. The process is characterized by very low transversal (shear) forces and thus also low contact forces between extrusion and dies. Rotary stretch bending can be implemented in a dedicated press tool or in a stand-alone bending machine.

3.3.8. Three-dimensional stretch-bending

Over fixed or rotating dies (lasts), the extrusion is gripped at its ends, and stretched into a three-dimensional shape ("out of the plane"). This may be done with tools where the movements are defined mechanically, or in programmable tools or machines.

3.3.9. Manipulation of the cross section

This is usually performed by indenting or pressing in a dedicated tool in a press.

3.3.10. Mechanical calibration of parts of the extrusion

This is usually performed by compression-stretching or expansion-stretching in a dedicated tool in a press.

3.3.11. Achievable bending radius

The achievable radii for bent extrusions are highly dependent on the geometry of the profiles and are difficult to predict. Therefore it is advisable to carry out tests on specimen. Table VII.1 gives guidance for bending of hollow circular tubes. If smaller radii are needed, filling of the tubes with sand before bending is helpful.

TABLE VII.1

BENDING HOLLOW TUBES (D ≤ 90mm): BENDING RADIUS AS A FUNCTION OF RATIO D/t

Alloy	Temper	Ratio D/t					
		5	10	15	20	25	30
5754	H111	1 to 1.5 D	2.5 to 3 D	3.5 to 4 D	4.5 to 5 D	6 to 7 D	8 to 9 D
6060	O	1 to 1.5 D	2.5 to 3 D	3.5 to 4 D	4.5 to 5 D	5 to 6 D	7 to 9 D
	T5	2 to 2.5 D	3 to 4 D	4 to 5 D	6 to 7 D	8 to 10 D	12 to 15 D

D: Outside diameter *t: Thickness*

4. Drilling

Drilling aluminium alloys is a simple operation but calls for careful sharpening and polishing of the drills given the relative softness of the aluminium alloys used in the manufacture of commercial vehicles. If inadequate sharpening causes the drill to bend or buckle, it will tear the metal around the part of the hole that is already drilled.

The following types of drill can be used for drilling aluminium alloys[5]:

- the standard twist drill - the most common type,
- the straight flute drill,
- the gun drill,
- the half-round or three quarter round drill.

4.1. Twist drill

To have a substantial sharpening gradient, the helix angle must be 40° while the point angle varies from 120° to 140° according to the shape of the neck, with a clearance angle of 8°. The other characteristics of the twist drill are as follows:

- cutting speed 30 to 80 m/min depending on rating and the desired quality - for very accurate holes the ideal speed is 30 m/min,
- penetration rate determined by the drill diameter: 0.05 mm/rev for a 2 mm diameter drill, to 0.3 mm/rev for a 30 mm diameter drill,
- soluble oil cooling,
- point height : this must exceed the thickness of the drilled material.

4.2. Straight flute drill

This drill facilitates rapid chip removal and is more efficient for aluminium alloys of medium hardness than the twist drill. The four cylindrical witnesses also prevent "triangulation" of the hole and provide drill guidance.

4.3. Gun drill

This type of drill is excellent for large diameter holes of 20 mm and over, also for drilling stacked sheets. The drilling conditions are the same as for the standard twist drill.

4.4. Half-round or three quarter round drill

These drills are used mainly in boring operations. The accuracy of the bore diameter achieved with these tools is of the order of 0.02 mm:

- cutting speeds are between 10 and 15 m/min,
- rate of advance is 0.05 mm/rev,
- cooling is with cutting oil.

5. Steel twist drills can be used for small runs with mainly manual tools.

5. Tapping

Threads in aluminium may be made, when other joining techniques are not applicable[6].

6. In a connection, where continuous joining methods such as welding or bonding are used, no additional fasteners should be applied.

Threaded holes in aluminium should only be used where no other possibility exists and the yield strength of the metal exceeds 200 N/mm2. The bearing length of the bolt should be 1,5 x diameter of the bolt. If the bolts must be used for repeated loosening and tightening, inserts should be applied e.g. Helicoils.

If threads are made in aluminium, care should be taken to ensure that the thread length is sufficient for the purpose. The thread length may be between 1 and 2 times the major diameter of the threads, and must depend on the application, the alloy as well as the temper of the material. For example, the necessary thread length of a high strength 6000 alloy in T6 may be 1.2 times the major thread diameter. Conversely a softer alloy demands a longer thread length.

There are two methods of tapping:
- by chip removal,
- by upsetting.

TABLE VII.2

DIAMETER OF PILOT HOLES FOR THREAD TAPPING

∅ nominal	4	5	6	8	10	12	14	16	18	20
Pitch	0.70	0.80	1	1.25	1.50	1.75	2	2	2.5	2.5
Diameter	3.2	4.2	4.9	6.6	8.3	10	11.7	13.7	15	17

5.1. Chip removal

Only taps with straight threads should be used to avoid seizing the metal at the flanks. Table VII.2 gives diameters for pilot holes for tapping aluminium alloys in the 5000 and 6000 series. Pilot holes for these alloys in the annealed condition must be some 3-5% bigger than in Table VII.2 and for castings with 12 and more % silicon content some 2% smaller.

The cutting speed varies from 10 to 50 m/min depending on the machine and method of clamping the tap, whether floating or in a chuck. Cooling is done with cutting oil.

5.2. Upsetting

The thread is achieved by plastic deformation of the metal using a tap with- a rounded polygon section that has no cutting wedge.

The diameter of the pilot hole will depend on the desired thread depth, and must be drilled accurately. Upsetting speeds can attain 50 m/min, cooling is done with cutting oil.

Tapping by upsetting offers a number of advantages with aluminium alloys:

- the tap has a long life,
- it increases the hardness of the thread, its tearing resistance and fatigue strength,
- no chips.

5.3. Threaded inserts

It is usual to use threaded inserts – available in diameters M2 to M68 (Figure VII.9) – when screwed aluminium alloy assemblies are required to be frequently dismantled. The inserts are in the form of a spring made from rolled wire or are a diamond section made of stainless steel.

Captive threads can also be used. These have one or two flights that grip the flanks of the screw thread and counteract the loosening effects of dynamic stresses, vibrations or thermal shock. Boring is done using a standard twist drill, but tapping must be done with a special tap. All chips and cutting fluid must be removed from the bore before the insert is fitted.

Threaded inserts are fitted with pneumatic hand tools which hold them by a driver at the top end of the thread. This can then be broken off after fitting.

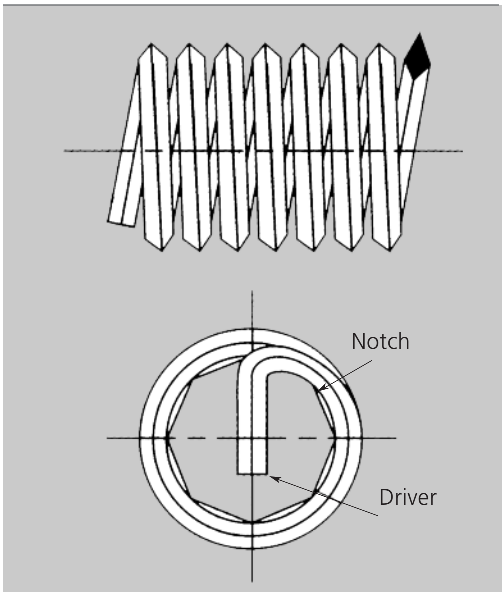
Threaded inserts can also be used to repair a tap in aluminium that is worn or has been rejected during manufacture.

6. Deep drawing

Deep drawing is mainly used in the automotive sector.
For more information on that technique, please refer to the Aluminium Automotive Manual: http://www.eaa.net/aam/

FIGURE VII.9

HELI-COIL INSERTED THREAD



Spinning
of an aluminium tank-end
(König)

7. Spinning

Spinning is a forming technique used in the commercial vehicle industry to make some components such as tank-ends.

7.1. Advantages of spinning

The tools used in spinning are very simple, being basically the internal shape of the required form. However production times can be up to 20 longer than for deep drawing.

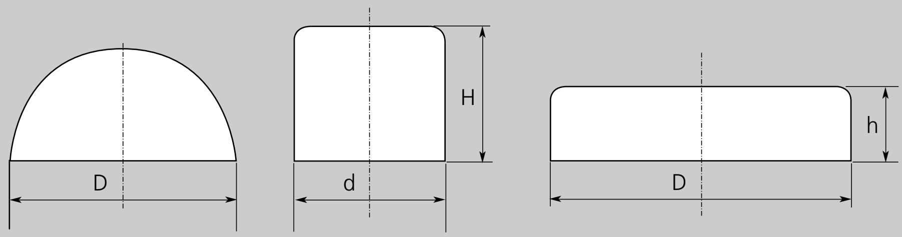
Calculations combining the cost of tooling and production costs show that spinning is competitive for short runs.

7.2. Diameter of spinning blanks

Three formulae are used to quickly determine the diameter of blanks for the most common shapes (Figure VII.10). In spinning, the diameter of the blank is less critical for the success of a part than it is in deep drawing, and it is only the cost of the material that dictates shape optimization. A simplified calculation is adequate for prototypes.

FIGURE VII.10

DIAMETER OF SPINNING BLANKS



$\varnothing$ blank $= \frac{D \times \pi}{2}$ $\varnothing$ blank $= H + d$ $\varnothing$ blank $= \frac{4}{3} h + D$

CHAPTER VIII

WELDING

Welder (STAS)

1. Foreword

Welding is the most common method of joining used in the manufacture of commercial vehicles and their bodies e.g. tanks, tippers, dumpers, chassis etc.
The different physical, chemical and mechanical properties of aluminium compared with those of steel lead to the specific behaviour of aluminium during welding. In an atmosphere containing oxygen, a well anchored oxide layer builds up on aluminium. This layer has a melting point of some 2000°C against the melting interval of 630-660°C for the metal underneath. For quality welds this layer must be removed or at least broken up.
Despite the fact that the melting interval of aluminium is by far lower than that of steel, the high thermal conductivity and the high melting energy make that, for arc welding, aluminium requires about the same amount of energy as steel.

The thermal elongation of aluminium is twice that of steel and the loss in volume of the weld pool during solidification is important, causing distortion of the joint, if no remedial measures are taken. One method of minimizing distortion is to select a process with small energy input.

TIG and MIG arc welding are the two processes most commonly used in the commercial vehicle industry. The technical progress made by other techniques such as plasma, laser, resistance or friction stir welding and the ever growing diversity of semi-finished products will encourage the application of such welding methods which have up to now been little used in the commercial vehicle industry.

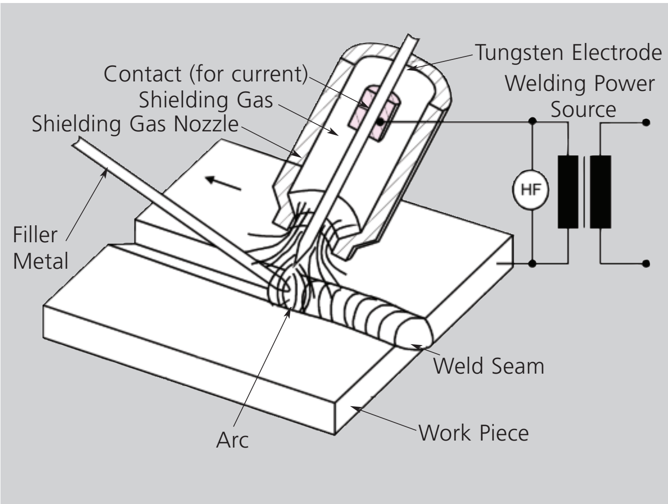
2. TIG welding (Tungsten Inert Gas)

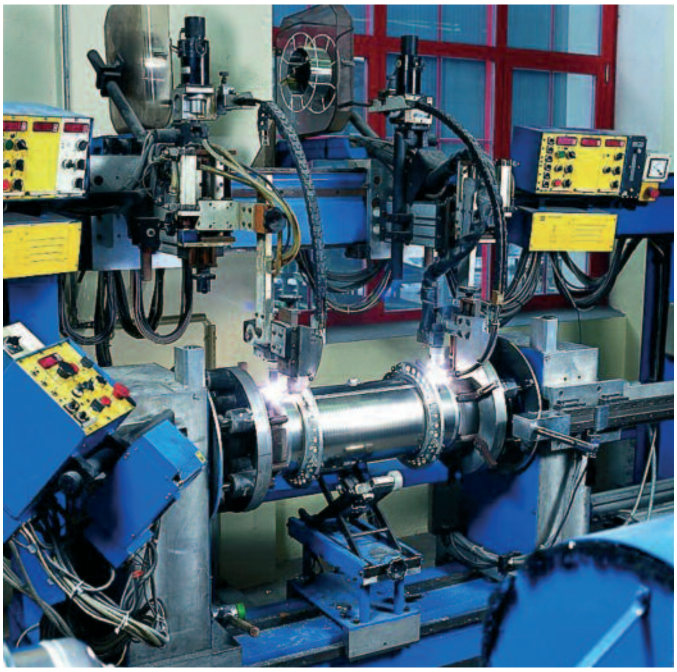
In this process, an electric arc is struck between a refractory electrode made of tungsten and the workpiece, while a shroud of inert gas, usually argon, shields the electrode and protects the molten pool against oxidation. This process uses a high-frequency stabilized AC power source. The oxide film is removed during the negative phase, while the positive phase ensures penetration and cooling of the electrode. TIG welding is suitable for metal thicknesses between 1 and 6 mm.

There is a TIG version where helium is used as the shielding gas. This helps achieving a high temperature in the arc but requires direct current with straight polarity. The effect of oxide film removal is weaker but the welding power is higher and products 10 to 12 mm thick can be welded with a single pass. However this process is strictly for automatic welding only owing to the difficulty of keeping the arc at a constant controlled height within 0.5 mm.

FIGURE VIII.1

PRINCIPLE OF TIG WELDING





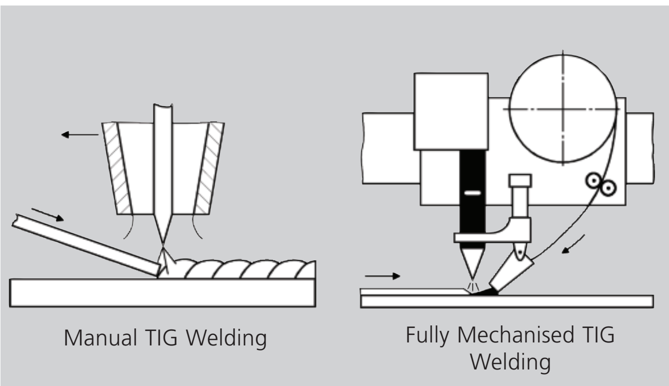
TIG welding of an air pressure vessel (SAG)

2.1. Manual TIG welding

For manual TIG welding, the filler material is a hand-held rod fed into the weld pool. The manual process is used mainly for small welds, circular welds and relatively thin components.

FIGURE VIII. 2

MANUAL AND MECHANISED TIG WELDING



2.2. Automatic TIG welding

Here, the welding torch is automatically guided and, if filler is used, it is fed automatically from a reel.

Automatic TIG welding is an attractive proposition for welding large production runs, especially when there is no access to the back of the weld.

The fabrication of compressed air reservoirs is a good example of the use of automatic TIG welding. These reservoirs consist of a sheet rolled and welded to form the straight cylindrical centre section to which two deep-drawn ends are welded. If the ends are butt joined to the centre without any backing to prevent the problems associated with moisture retention, automatic TIG welding can be used to make an easy connection. It is also possible to support the weld pool by supplying the argon from inside the reservoir.

2.3. TIG welding with AC

It is especially well suited for butt and corner welds on pieces in the thickness range 1-6 mm. Full penetration welds can be made without backing bar. Tack welds must not be removed before executing the seam weld. Changes in weld direction are easy to follow with the torch and do not require any dressing. The process can also be used to smooth the surface of a MIG weld.

The welding speed is lower than for MIG weld and, for work pieces thicker than 6 mm, preheating is required. The slow welding speed is also responsible for a wider heat affected zone and greater distortion of the assemblies.

For fillet welds extreme care is needed to achieve full penetration without lack of fusion at the root.

In the tank and silo production, double side TIG welding of butt welds in vertical upwards position leads to excellent quality, provided the two operators control the process well.

2.4. TIG welding with DC, reverse polarity

In this process the arc length is below 1 mm, ideally 0.5 mm, which means that it is mainly used for machine welding. For manual operation only short lengths can be executed in practice. One such application is stitch welding of assemblies before the seam welding. The small cross section of these stitches is such that they are completely molten up while laying the first pass of MIG weld over it and don’t need to be reduced in cross section by mechanical means.

The oxide film removal is weaker with this process so it is necessary to reduce the oxide layer by mechanical means before welding.

2.5. Edge preparation for TIG welding

In EN ISO 9692-3 this information is given comprehensively, so that we just indicate a few examples for typical joints in vehicle manufacturing (Table VIII.1, p. 115).

To avoid sharp notches, especially at the root of the weld, all edges must be carefully deburred before welding. Instead of grinding discs, milling tools should be used, because residues of the disc on the surface can cause porosity in the weld.

2.6. Choice of filler wire or rod

See section 3.8

2.7. Selection of Welding process

See section 3.9

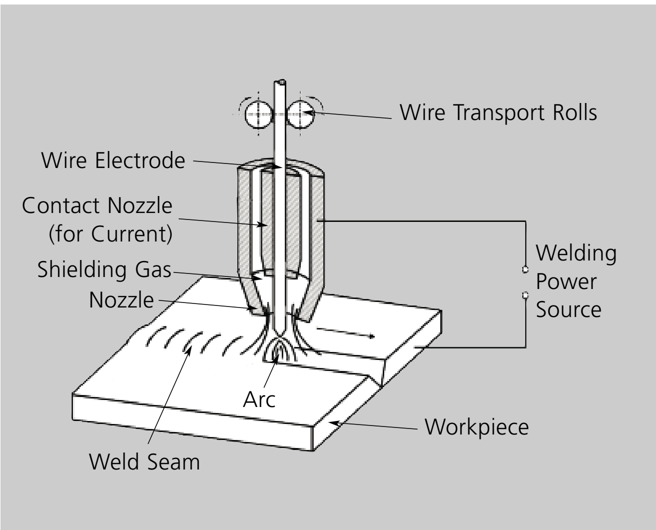
3. MIG welding (Metal Inert Gas)

With MIG welding the aluminium alloy wire is both the electrode and the filler material. It uncoils automatically from a reel to the welding tool (gun or torch) as it is used up. The welding energy is supplied by a DC power source (smoothed current). Connection is made with reverse polarity (i.e. minus to the workpiece) to ensure removal of the oxide film and the fusion of the wire electrode at the same time.

Several MIG processes do exist...

FIGURE VIII.3

PRINCIPLE OF MIG WELDING



3.1. Manual MIG welding

In its manual version, MIG is certainly the most common welding process used in the commercial vehicle industry, producing high quality welds at an attractive quality/cost ratio.

As the filler wire, that is the consumable electrode, is always automatically fed from a reel, the manual MIG welding is also known as "semi-automatic MIG welding".

Manual MIG welding is used for all welds of a complex nature where the dimensions and thickness of the products are compatible with the MIG process and when automation is not considered to be profitable.

If we consider the example of a tank consisting in sheets rolled and welded to form cylindrical sections, we can see that the longitudinal weld can be made by automatic MIG while the circular welds which join the sections to one another are usually made manually on a turntable in two opposing passes. The choice between manual or automatic MIG will depend largely on accessibility.

3.2. Automatic MIG welding

Here, the welding torch is automatically guided.
This is normally used for very long straight welds where an automatic system is profitable. A good example is fabrication of chassis side members consisting of two "T" sections welded to either edge of a central plate which forms the web of the built-up beam. The two welds would normally be made automatically and at the same time to avoid problems of deformation.
Automatic welding is also preferred where an attractive appearance is desirable, e.g. for stiffening channel welded to the side panels of vehicle bodies. Here the appearance and size of the weld bead can be repeated to achieve the impression of consistency.
Finally, automatic welding - both TIG and MIG - provides a repeatable welding quality provided of course that the welding parameters are fully defined to begin with.

3.3. Smooth current MIG Welding

This fast and economical process allows depositing a great quantity of filler metal per unit of time. The energy input is such that butt welds can only be produced with the use of a backing bar, either integrated into the shape of the extrusion or as temporary removable feature in stainless steel, copper or even aluminium. Due to the relatively high welding speed, the heat affected zone[1] is narrower than with TIG welding and thus the distortion of the assemblies is less.

1. The extent of the heat affected zone and the strength in the heat affected zone are given in EN 1999-1-1.

Thin gauge material below 3 mm is difficult to weld with this process because of the high energy of the arc. If no other equipment is available, then a thin gauge filler wire may be used with reduced energy input, but then the wire feed can cause instability of the process even if a push-pull equipment is used.
If the preassembly of structures is carried out with stitches in the MIG process, these short runs must have a similar cross section as the first weld pass and be some 100 mm long to be sound. Before production welding, these stitches must be reduced in cross section by mechanical means (no disc grinders), so that they can be molten up with the weld pass and do not leave imperfections near the root.

Welding of side panels for tippers (Menci)

Welding
of a truck door

3.4. Pulsed current MIG welding

An improvement of the MIG process has been achieved by superimposing a pulsed current over the main current, the object being to maintain a low average current level without sacrificing arc stability.
The filler metal is transferred to the weld pool every time the current is high (i.e. one drop of metal per pulse). The "cold times" when the current is low ensure that arc stability is maintained.

There are three operating modes:
• **synergetic mode**: only the rate of uncoiling has to be regulated. The voltage and frequency are regulated by electronic logic circuits;
• **manual mode**: all the welding parameters are adjustable;
• **programme mode**: each parameter can be stored for use according to production requirements.

The pulsed MIG process is limited to thin products of $2 < t \leq 5$ mm and to vertical fillet welds.
This process makes it possible to weld thin gauge material with standard filler wire. As the weld pool can be better controlled, butt welds up to 5 mm thickness can be executed without backing bar. Furthermore it is very helpful for welding in the vertical and the over head position. The optimal machine setting is more demanding than for standard MIG because there are much more parameters to be defined.
The width of the heat affected zone is analogue to the one for standard MIG as is also the amount of distortion of the work pieces.
For welding over stitches see remark under 3.3 above.

3.5. Wire pulsation

For gauges between 1 and 3 mm, a complementary option “the wire pulsation” could be added to the previously described “current pulsation” in order to improve the arc stability. This “wire pulsation” induces a double pulsation to current signal and consequently to the heat input. For T-joint of dissimilar gauges, the heat input distribution is difficult to maintain constant with classical pulsed current. This double pulsation of current insures the concentration of heat input at the exact location of the joint.

3.6. CMT – Cold Metal Transfer

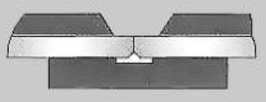
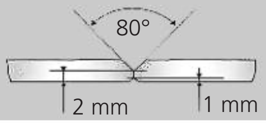
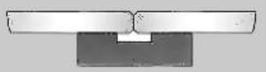
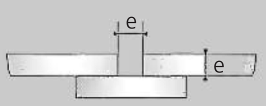
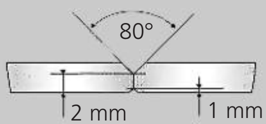
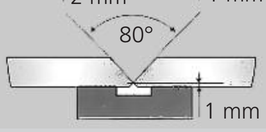
For MIG welding gauges lower than 1 mm, the CMT process (Cold Metal Transfer) could be used. When detecting a short-circuit, this process retracts the wire so as to help detach the droplet. The thermal input is immediatly reduced and the short-circuit current is kept small.

3.7. Edge preparation for MIG welding

Just the most frequent examples are given in the Table VIII.1

For more details please consult EN ISO 9692-3.

TABLE VIII.1
EDGE PREPARATION

Process	Welding position	Weld bead	Thickness	Preparation	Remarks
TIG	All positions	One side only	0.8 < t <1.5		A slight peak formed by the edges limits deformation
TIG	Horizontal	One side only	0.8 < t < 5		Chamfered card, stainless steel support, clamped weld
TIG	All positions	One side only back-weld possible	1.5 < t < 5		Tack-welded free edges
TIG	All positions	One side only	4 < t < 6		Tack-welded free edges. Angle same principle but with offset bevel
MIG	All positions	One side only with back-weld	2.5 < t < 6		Back-weld necessary after gouging to base of first pass
MIG	All positions	One side only	2.5 < t < 6		Stainless steel support
MIG	All positions	One side only	2.5 < t < 6		
MIG	Horizontal and overhead*	One side only with back-weld	6 < t < 25		Back-weld necessary after gouging to base of first pass. Clearance: 1.5 mm max.
MIG	Horizontal and vertical*	One side only	4 < t < 25		Ribbed stainless steel support

* X-shaped bevels are preferred for components 6 mm < t < 25 mm to restrict deformation due to welding.

TABLE VIII.2

CHOICE OF FILLER METALS AS A FUNCTION OF THE ALLOY COMBINATION

Each combination has three possible choices - indicated where the lines intersect - depending on the selected criterion: Optimum mechanical properties: top line – Optimum resistance to corrosion: middle line – Optimum weldability: bottom line

The filler metal indicated is: 4 : series 4xxx → 4043A, 4045, 4047A – 5 : series 5xxx → 5356, 5183, 5556A

Alloy A					
Wrought 5000 Series Mg < 3%	5 5 (a) 4 - 5 (b)				
Wrought 5000 Series Mg > 3% (a)	5 5 5	5 5 5			
Wrought 6000 Series	5 - 4 5 4	5 - 4 5 4	5 - 4 5 4		
Wrought 7000 Series without copper	5 - 4 5 4	5 - 4 5 4	5 - 4 5 4	5 - 4	
Cast Si > 7% (c)	4 (e) 4 4	5 - 4 (e) 5 4	4 4 4	4	4 (d) 4 4
Alloy B	Wrought 5000 Series Mg < 3%	Wrought 5000 Series Mg > 3%	Wrought 6000 Series	Wrought 7000 Series without copper	Cast Si > 7% (c)

(a) 5000 series alloys with more than 3.5% Mg are sensitive to intergranular corrosion when exposed to temperatures over 65°C and when used in certain aggressive environments (see section 2.2.6 in Chapter XI).

(b) 5000 series alloys with less than 3% Mg and 3000 series alloys that contain magnesium may be sensitive to hot cracking.

(c) The mechanical performance of the weld depends on the internal soundness of the castings. Gassed materials and injection mouldings are considered to be non-weldable.

(d) The percentage of silicon in the filler wire must be as near as possible to that in the casting.

(e) The welding of aluminium-silicon castings (40000 series) to 5000 series alloys should be avoided where possible as Mg_2Si intermetallics form in the weldment and weaken the joint.

3.8. Choice of filler wire or rod

Most of the alloys listed in Chapter V are weldable and also combinations of these alloys are possible. Welding consumables are not available in exactly the same chemical composition as the base metal to be joined. There are wires and rods in the 4XXX and 5XXX series, namely 4043A, 4045, 4047A, 5183, 5356 and 5556A in the market (see also ISO 18273). In the Table VIII.2 , with the recommendation of the best suited weld consumable, we distinguish between different requirements for the weld: optimal strength, good corrosion resistance and weldability. A choice must be made according to the relative importance of these three requirements.

The weld consumables should be stored in their sealed package and once a package is open, it should be kept in a dry atmosphere, because humidity on the surface of the wire or rod causes porosity in the weld. If open reels of filler wire are exposed to ambient climatic conditions for a longer period (months), it is recommended to dry them in a warming box at approx. 80° C for one night before use.

3.9. Selection of welding process

TABLE VIII.3

SELECTION OF WELDING PROCESS

Process	TIG		MIG			
Atmosphere	Inert		Inert			
Electrode	Refractory		Consumable			
Current	A.C.	D.C.	Smooth	Pulsed	Pulsed	Pulsed
Special effect					Wire pulsation	Cold Metal Transfer
Suitability						
Thickness range (mm)	0.8 ≤ t ≤ 5	0.2 ≤ t ≤ 10	3 ≤ t	2 ≤ t	1 ≤ t ≤ 5	t ≤ 1
Manual	yes	no	yes	yes	difficult	no
Automatic	yes	yes	yes	yes	yes	yes
Industrial robot	no	no	yes	yes	yes	yes

4. Plasma MIG welding

This process combines the high melting capacity of the MIG process with the nearly ideal shape of the plasma arc and its very good gas shield for the welding pool. The result is an extremely good quality of welds, especially the absence of porosity. The plasma arc is maintained between the plasma ring nozzle of the torch and the work piece, the MIG arc is in the centre of the plasma arc. Both arcs have the same polarity where the high kinetic energy of the plasma arc destroys the oxide layer on the work piece. Mechanical removal of the oxide layer can be dispensed with.

The process is well suited for applications with high requirements for tightness and surface aspect. It is possible to carry out butt welds of up to 10 mm thickness in one pass with the edge preparation in V. The welding speed is higher than for MIG welding.

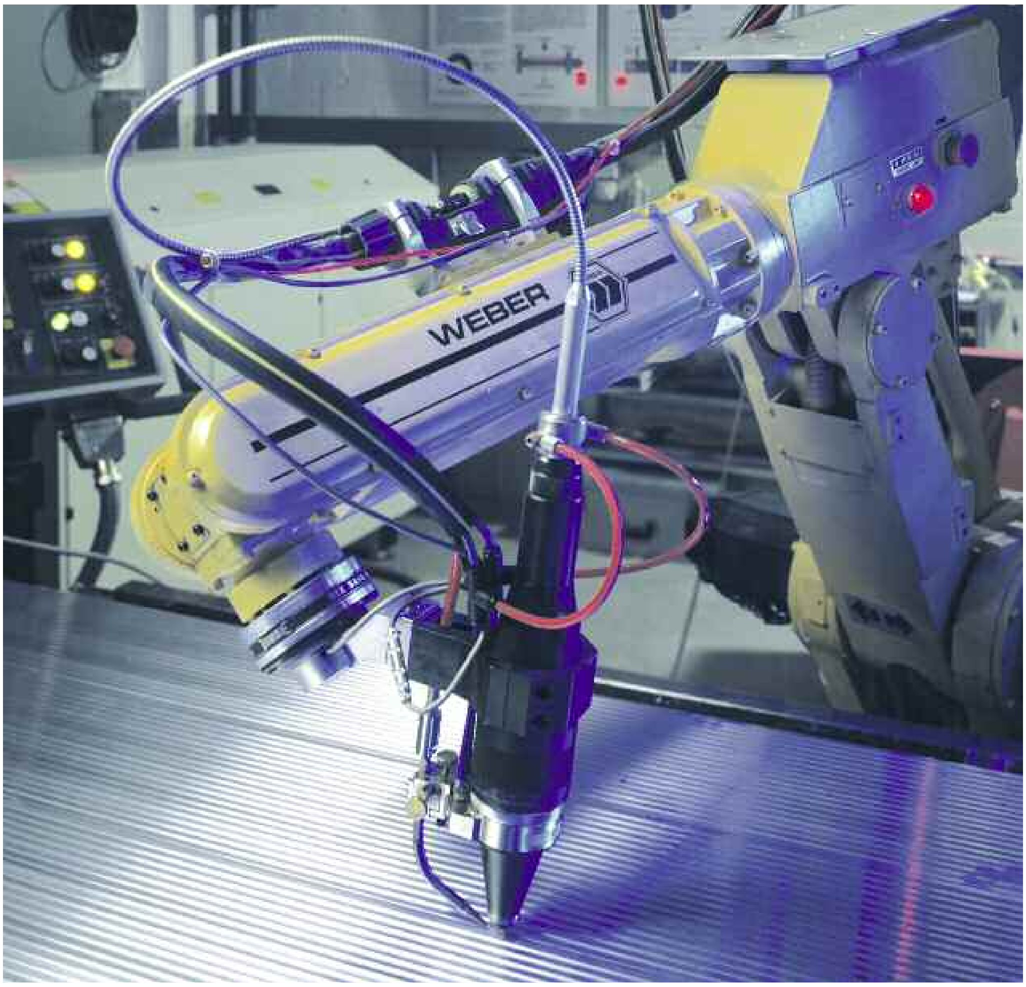
5. Laser welding

Laser welding of aluminium alloys is developing rapidly parallel with the development of ever growing power of laser sources. There are on one side CO_2 lasers of up to 20 KW and more and Nd:YAG lasers of 6 KW and more. With the CO_2 laser, the orientation of the beam is limited, whereas with the Nd:YAG laser optical fibres allow to bring the laser beam directly to the weld zone. This gives high flexibility especially for robot welding. The high reflectivity of aluminium makes it necessary to install the laser equipment in a separate room, where during operation of the equipment, nobody without adequate eye protection has access. The sensor which emits the signals necessary for the motion control of the laser beam must be very effective for not being disturbed by reflections.

The process is mainly used for thin gauge materials (1 – 4 mm) and the pieces to be joined must fit perfectly as is the case e.g. in the production of tailored blanks for the car industry.

The achievable welding speeds are up to 12m/min with thickness of around 1mm and still 1-3 m/min with thicknesses between 1.5 and 3 mm. Compared with standard arc welding, laser welding allows the production of components with reduced geometrical distortions and residual stresses, as well as narrower heat affected zone, a direct consequence of the high work speed and thus the low heat input.

The laser welding process is preferably used with filler wire for aluminium alloys.



Laser welding

6. Laser MIG welding

The combination of a standard arc welding process with the laser welding process allows to benefit from the advantages of both processes, which are good process stability, high welding speed and enhanced bridging capacity.

The laser beam runs ahead of the MIG arc but both focus on the same point of the metal surface. The shielding gas is provided by the MIG torch. Preferably a mixture of helium (70%) and argon (30%) is used. This process is ideal for continuous automatic welds up to 10 mm thickness in one pass, where the requirements for fit up of the pieces to be joined is less stringent than for pure laser welds.

The same safety measures as for laser welding must be applied.

7. Resistance welding

This technique is very common in the automotive industry and not so widespread in the Commercial Vehicles industry.

For this reason, we do not give details here.

Interested readers should refer to the Aluminium Automotive Manual: www.eaa.net/aam

8. FSW - Friction Stir Welding

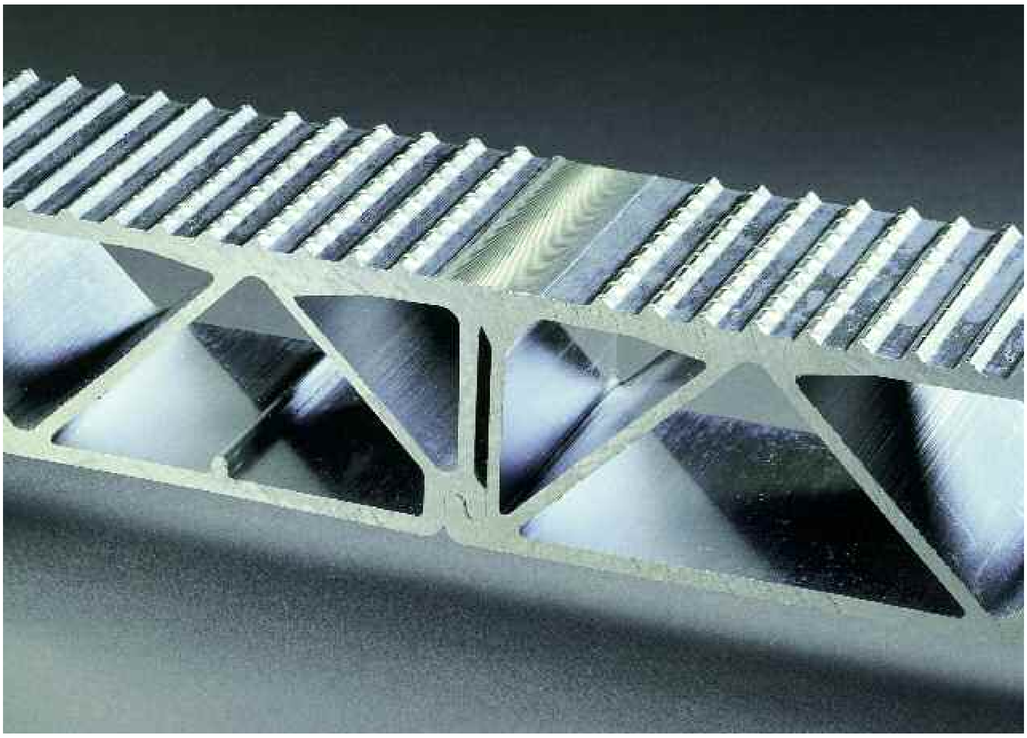
Friction Stir Welding

This is an innovative process which had been developed by TWI Ltd (The Welding Institute) and is protected by patents in Europe, USA and Australia. Anyone using the process needs a license from TWI.

The process operates in the solid phase of the metal below the melting point of the alloy. A tool in the form of a finger with a shoulder is rotated and moved into the metal with a defined rotational speed along the contact line between the two parts to be joined. The friction of the tool in the metal supplies the needed energy to heat the local zone to the desired temperature. Through the rotation and the translation of the tool the material in the weld zone is plastically deformed to create the weld. The process can be used for butt welds, overlap welds, T – sections and corner welds. For each of these joint geometries specific tool designs are necessary. The process can be used in all positions i.e. horizontal, vertical, overhead and orbital.

The process can be used for welds up to 50 mm thickness from one side and up to 100 mm from two sides. Advantages are:

- High productivity, i.e. low cost potential
- Low distortion, even in long welds
- Excellent mechanical properties as proven by fatigue, tensile and bend tests
- No fume
- No porosity
- No spatter
- Low shrinkage
- Can operate in all positions
- Energy efficient
- No consumable tool (one tool typically can be used for up to 1000 m of weld length in 6000 series alloys)
- No filler wire
- No gas shielding
- No welder certification
- Some tolerance to imperfect weld preparations – thin oxide layers can be accepted
- No grinding, brushing or pickling required in mass production



Friction stir welded taillift profiles

The limitations of the FSW process are continuously reduced by intensive research and development.
However, the main limitations of the FSW process are at present:

- The relatively high investment requires a high degree of repeatability in order to materialize the cost saving potential
- Work pieces must be rigidly clamped.
- Backing bar required (except where self-reacting tool or directly opposed tools are used).
- Keyhole at the end of each weld.
- Cannot make joints which require metal deposition (e.g. fillet welds).

Up to now the dimensionally biggest equipment can cope with work pieces up to 20 m long.

9. Surface preparation before welding

For quality welds it is recommended to machine the edges (see section 3.7) of sheet to be welded after water jet, plasma or laser cutting to remove this rough surface with a thick oxide layer and also with micro cracks in order to avoid weld defects such as cracks and oxide inclusions. The same should be done for plate with thickness over 10 mm that has been sheared. There is a great risk of cracks in the short transverse direction, where a removal of 2 mm via milling or routing is adequate.

The metal to be welded must be dry and without contamination of any grease or other products that evaporate under the action of the arc. To achieve this clean surface, the pieces to be welded should be brought into the workshop two days before production. This will allow condensation that might occur when the temperature in the storage area is lower than in the workshop to dry off.

Immediately before welding, the edges to be joined and their surroundings must be properly degreased using a solvent such as acetone or industry alcohol. Avoid trichlorethylen, which transforms under the effect of the arc into the poisonous gas phosgene. When the solvent on the surface has evaporated, a further cleaning with a stainless steel wire brush (hand-operated or rotary) is recommended.

Outdoor welding is not advisable. If it cannot be avoided, the welding environment must be screened off.

Welding of tipper body (SCHMITZ)

10. Quality control

Quality control enables manufacturers to judge the quality of the products they fabricate and more specifically to grade the quality of a welded joint against an acceptable level of defined defects.

The level of acceptable defects is determined by:

- the types and directions of load (static and dynamic),
- the levels and variations in stress,
- possible hazards to personnel,
- the technical and financial impact of the failure of the welded structure,
- the possibility of routine operational inspection and control.

10.1. Approval procedures

The procedures are either contractual between client and supplier or self-regulated by the fabricator. Welders must be certified and qualified in accordance with EN ISO 9606-2. Welding procedure specification must be in accordance with EN ISO 15609-1, EN ISO 15612, EN ISO 15613 and EN ISO15614-2.

Test specimens must be submitted for tensile or bending tests. Bending tests are important because they:

- detect bonding that is hard to identify in non-destructive testing,
- help achieve a good balance of parameters with a view to preventing these defects.

10.2. Inspecting welded joints

The type of inspection carried out on welded joints will naturally depend on the work rate of the weldments.

In the fabrication shop it is possible to perform the following non-destructive tests (NDT) in addition to visual inspection:

- dye penetration tests are valuable for detecting leaks and emergent cracks,
- weld shape tests (geometrical shape),
- radiography, used to detect internal defects (porosity, cracks, inclusions) in butt joints,
- ultrasonic tests

It may also be prudent to perform some destructive tests on reference specimens.

An inspection plan must be made containing:

- extent of inspection before welding
- extent of inspection and NDT
- NDT methods to be used
- acceptance criteria (quality level) in accordance with EN ISO 10042

10.3. Weld defects & approval criteria

Weld defects and quality levels are given in EN ISO 10042. Guidance for choice of quality level is given in EN 1090-3.

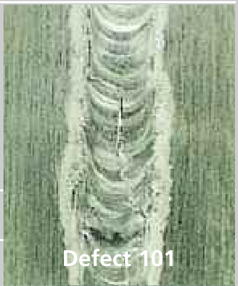
An international nomenclature of defects has been established and is given in EN ISO 6520-1 which lists 6 groups of imperfections:

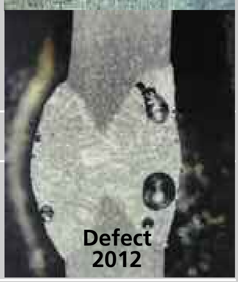
- Group 100: Cracks
- Group 200: Cavities and wormholes
- Group 300: Solid inclusions
- Group 400: Lack of fusion and penetration
- Group 500: Defects of shape
- Group 600: Sundry defects

TABLE VIII.4

LISTS SOME COMMON WELD DEFECTS AND THEIR CAUSES

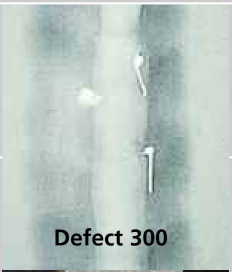
N°	Type of Defect	Likely Cause	Photos of Imperfections
101	Cracks	Base alloy unsuitable Poor choice of filler metal Incorrect welding sequence Excessive clamping Sudden cooling	
104	Crater cracks	Pass finished with sudden arc cutoff	
2012	Irregular wormholes	Work inadequately degreased Work and/or filler wire dirty or wet Insufficient protection by inert gas (low gas flow or leak in the system) Pass begun on cold component High arc voltage Weld cooled too quickly	
2014	Aligned wormholes	Incomplete penetration (double pass) Temperature gradient between backing and work too abrupt Excessive gap between edges of the joint	
300	Solid inclusions	Dirty metal (oxides, brush hairs)	
303	Oxide inclusions	Poor gas shielding Metal stored in poor conditions Castings	

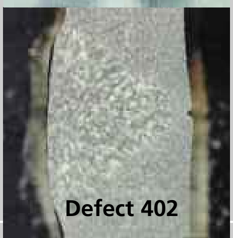




N°	Type of Defect	Likely Cause
3041	Tungsten inclusions (TIG)	Electrode diameter too small Poor handling by welder Excessive current density Poor quality of tungsten electrode
402	Incomplete penetration	Inadequate cleaning (presence of oxide) Incorrect bevel preparation on thick work (too tight, excessive shoulder) Gap between workpieces too small (or incon-sistent) Low current, especially at the start of the seam Welding speed too fast High arc voltage
4011	Lack of fusion on edges	High arc voltage Low current, especially at the start of the seam Work cold (difference in thickness between materials to be welded)
502	Excessive thickness	Poor power control (poor U/I match) Welding speed too slow Poor edge preparation on thick work Insufficient starting current
507	Misalignment	Work positioned incorrectly Incorrect welding sequence
508	Angle defect	Excessive welding power Incorrect welding sequence
509	Collapse	Wire speed too fast Torch speed too slow Poor torch guidance
602	Splatter (or beads)	Incorrect arc control Problem in electrical contact to ground

Photos of Imperfections


Defect 300


Defect 402


Defect 402


Defect 502


Defect 507

11. Design and prevention of deformation

11.1. Causes of deformation

In machine welded structures, deformation can be caused by:

11.1.1. The direction of the welds

It is a well known fact that a bead contracts most at the end of the weld, which is why the greatest deformation occurs in the end zones. So far as possible therefore it is essential to orient the weld towards the outside of the workpiece so as to release as much stress as possible. Otherwise, with the weld facing the middle of the component, the contraction stresses are "trapped" and deformation will be greater as a result. The end of the weld must be finished to prevent any danger of cracking on the end crater.

11.1.2. The effect of punching

This is normally due to design error. If we take the example of a bulkhead inside a tank, it is essential that the bulkhead, which is either deep-drawn or spun, has a down flanging resting flat against the body of the tank and by which the bulkhead is welded to it. This approach should prevent the problem of punching due to the weld contracting and should minimise deformation (Figure VIII.4).

Similarly, where the body of a tank has to be stiffened, it is essential to place a support plate between the stiffener and the skin of the tank to prevent deformation by the effect of punching due to weld contraction (Figure VIII.5). In the absence of a support plate the tank would deform under the effect of subsequent dynamic stresses.

11.2. Solutions

There are a number of solutions to the above problems:

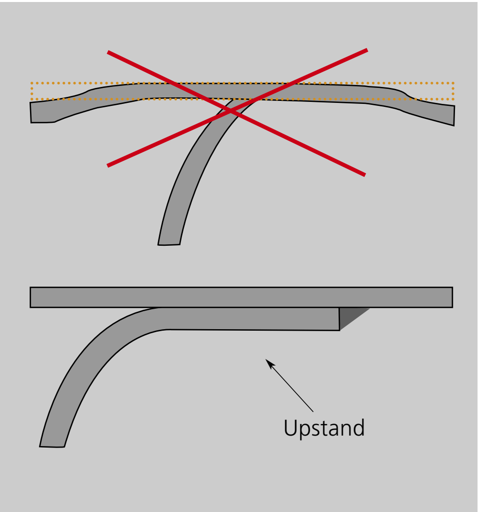
11.2.1. Use of extrusions

It is worthwhile using extrusions in the fabrication of chassis as this can help to:

- position assemblies in less stressed areas,
- make welds that eliminate deformation.

FIGURE VIII.4

UPSTAND WELDING



Chassis side members for instance are usually fabricated from two extrusions forming the two flanges of the member and a sheet for the web.

The assembly shown in Figure VIII.6 can be automatically MIG welded with two welding torches operating simultaneously.

Both methods of butt joining are possible, i.e. with the side member positioned vertically or horizontally. The choice of position will be dictated chiefly by the design of the welding bench. When the side member is horizontal a support will be needed to counteract angular deflection.

11.2.2. End stops

These must be positioned so as to allow free elongation of the assemblies during welding.

"Compressing" a weld, i.e. preventing its elongation, greatly exaggerates contraction and hence subsequent deformation.

11.2.3. Predeforming

Some weld deformations can be offset by predeforming the areas to be welded in such a way that the assembled components "come right" after welding.

If the metal is only predeformed in the elastic zone by clamping, the results can be very erratic, and it is therefore advisable to predeform by bending the metal in the plastic zone. In this way, the results will be predictable and repeatable.

FIGURE VIII.5

WELDING WITH SUPPORT PLATE

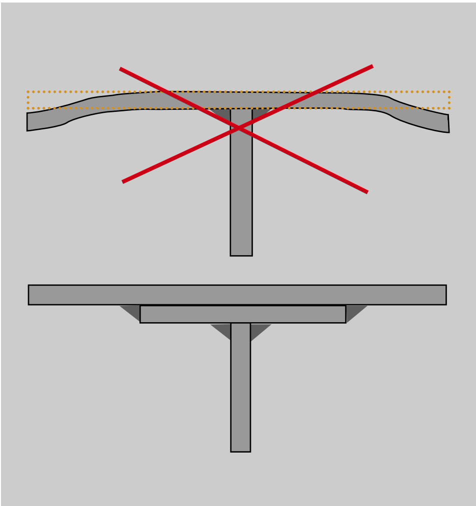
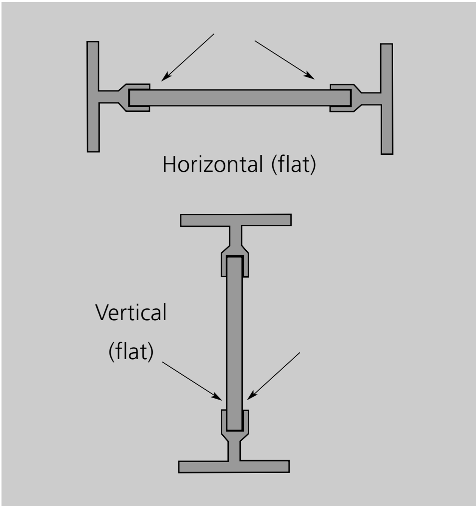
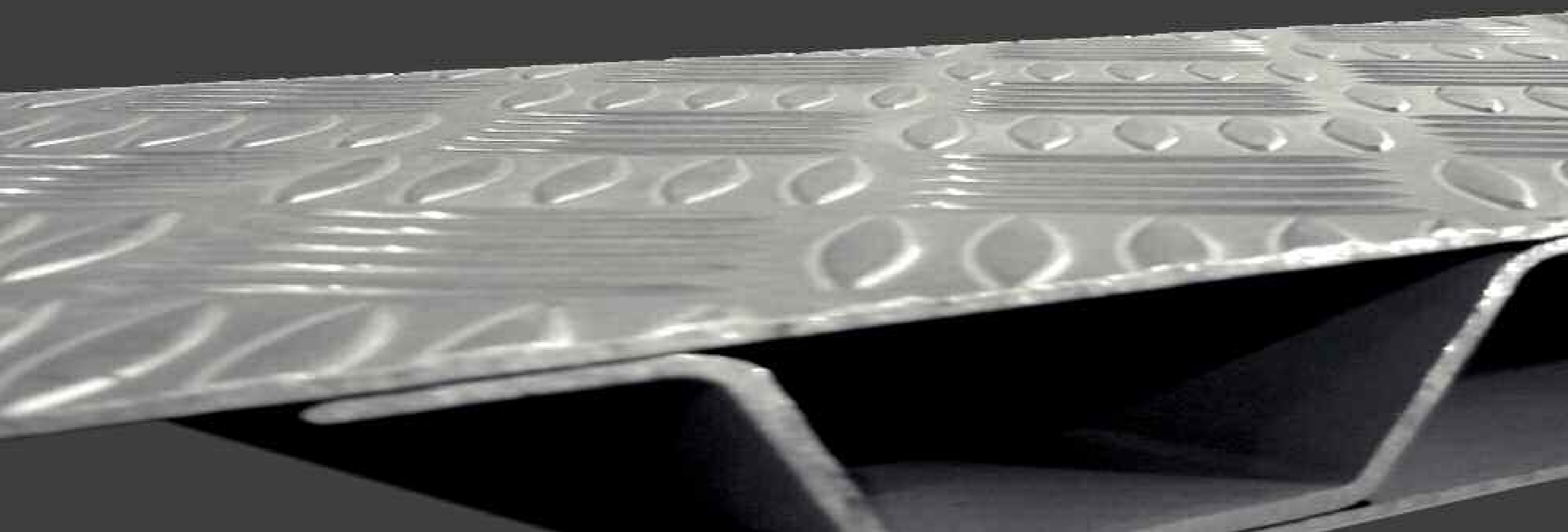


FIGURE VIII.6

FABRICATING A CHASSIS MEMBER





CHAPTER IX

OTHER JOINING TECHNIQUES

1. Adhesive bonding

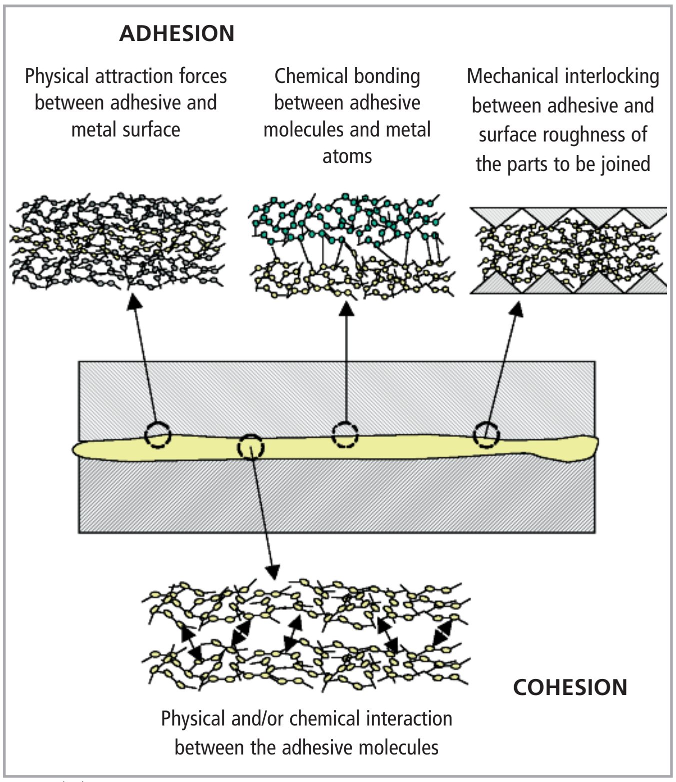
1.1. Definition

Adhesive bonding is defined as a process of joining parts using a non-metallic substance (adhesive) which undergoes a physical or chemical hardening and by thus leading to a joining of the parts through surface forces (adhesion) and internal forces (cohesion).

Adhesion can be physical attraction between the adhesive and the metal surface, real chemical bonding between the adhesive molecules and the metal atoms or mechanical interlocking between the adhesive and the surface roughness of the metal. Cohesion is the inner strength of the adhesive itself as a result of physical and/or chemical forces between the components of the adhesive.

FIGURE IX.1

PRINCIPLE OF ADHESIVE BONDING



Source: Talat lectures

1.2. Advantages and disadvantages

Advantages	Disadvantages
1. Load distributed uniformly at right angle to loading direction	1. Influence of time on process properties
2. Microstructure unaffected	2. Pre-treatment of joined surfaces necessary
3. Distortion-free joining	3. Limited form stability
4. Different materials can be joined	4. Process parameters must be held in narrow ranges
5. Very thin parts can be joined	5. Change of the properties in time (ageing of the adhesive)
6. Weight saving	6. Complicated control of process
7. Heat-sensitive materials can be joined	7. Low peeling strength
8. Metals with different electrochemical potentials can be joined (insulating effect of adhesive)	8. Low adhesive layer strength requires large joining areas
9. High strength joining in combination with other methods (screwing, welding…)	9. Limited repair possibilities
10. High fatigue strength and good vibration damping	10. Difficult strength calculation

Source: Talat lectures

Combination of adhesive bonding and mechanical joining (e.g. riveting or bolting) can eliminate some of the above-listed disadvantages.

1.3. Types of adhesives

Adhesives can be divided into 3 subgroups depending on their forming reaction and polymer structure:

- Polymerisation: An exothermic process in which monomers link together to form macromolecules (polymers). Thermoplastics like methylacrylates, polyvinyl chlorides, polyvinyl acetates and rubber polymers belong to this group
- Polycondensation: Water is produced as a result of the chemical reaction. Thermoplastics like polyamides and polysulfones as well as duromers like phenol formaldehyde resins, urea resins, melamine resins and polymides, are all produced by polycondensation.
- Polyaddition: During this process the hydrogen atoms are rearranged. Very common adhesives for metal bonding like epoxy resins and polyurethanes are produced by polyaddition.

Prototype floor section made of bonded sheets and extruded stiffeners

Patented by Alcan

1.4. Application of adhesives

As adhesive bonding is working by surface forces, prerequisites for a well functioning adhesive joint are
a) the choice of an appropriate adhesive for the materials to be combined
b) the existence of a suitable material surface

A suitable surface means, that the surface area must be large enough to transfer the applied forces and that it is capable to ensure a proper bonding. This can be achieved through a suitable pre-treatment. Any residues of dirt like moisture, oils, dust etc. must be removed prior to application of the adhesive. This can be done by chemical means with the use of detergents, degreasers or etching agents or mechanically by grinding. In any case the surface must be absolutely clean before gluing. It might be favourable to use a primer for better wetting of the metal surface by the adhesive as well.

The joint construction should be related to the adhesion process and its requirements for large bonding areas. Peeling and cleaving forces on adhesive joints must be avoided and bending forces should be reduced to a minimum.
The adhesive can be applied manually (e.g. with the use of cartridges) or for larger areas with automated machines. The bonding should take place in a dry and well ventilated and dust-free workshop.
The work must be done in strict compliance with the manufacturer s rules. The production parameters such as resin/hardener ratio, duration and pressure component fit up during adhesive curing, curing temperature, etc. must be controlled properly.

1.5. Creep and ageing

The durability of adhesive joints depends on factors such as proper pre-treatment, chemical composition of the adhesive and service conditions like stresses, temperature, humidity and exposure to ultraviolet radiation (polymers are sensitive to this kind of radiation and tend to lose their mechanical properties).
The ageing of bonded joints can be caused by creep under stress (creep can be defined as time-dependent increase in the length of visco-elastic substances subject to a constant tensile load).
Adhesive joints should therefore be inspected regularly to prevent damages and to enable repair prior to a possible failure.

2. Screwing and bolt fastening

Bolting creates a joint which can be opened and closed as many times as necessary. It is besides welding the most conventional method for joining metals. In contradiction to welding, different metals can be joined. In commercial vehicles this is most likely the connection between steel and aluminium (e.g. the connection between chassis and tank or tipper body). Special precautions should be taken to avoid galvanic corrosion, please refer to Chapter XI.

The choice of the fastening geometry will depend on the result of the calculation of the applied stresses. In the combination of steel screws with aluminium plates, the risk of galvanic corrosion must be considered: insulating gaskets should be placed around the contact area between both metals.

3. Riveting

Riveting is today a widespread joining method in different sectors of industry, including commercial vehicle construction. As it is a very safe and easy-to-apply technique, riveting has become a very common method for joining assemblies e.g. in the construction of the bodies of refrigerated trailers.

Machine riveting has a lot of advantages:
• High-speed: Machine riveting allows fast operations with the use of pneumatic or hydraulic tools
• Ease of control: the clamping force is always guaranteed by the system as it is less than the force needed to snap the rivet
• Optical appearance: Machine riveting can be combined with a plastic capping of the rivet
• It does not require skilled operators
• Mixed joints are possible: different metals, plastics, sandwich or honeycomb panels

Rivets can be divided into 2 main subcategories: self piercing rivets and conventional rivets which require holes that must be drilled prior to riveting.

Conventional can be sorted into three families:
• **Lockbolts** which visually look like they create the same type of connection as a conventional bolt, but unlike conventional nuts and bolts; they will not work loose, even during extreme vibration. They can only be used when both sides of the joint are accessible. Lockbolts consist of a pin which is inserted in the hole and a collar which is placed on the pin from the opposite end. The tool is placed over the fastener pintail and activated, the pin head pulls against the material, the tool anvil then push's the collar against the joint, at this stage

the initial clamp is generated. The tool then swages the collar into the pin. The pintail then breaks and the installation is complete (Figure IX.2).

Lockbolt strength characteristics

Clamp force or pre-load: during the installation process, as the tool engages and pulls on the pintail, the joint is pulled together before the conical shaped cavity of the nose assembly is forced down the collar, progressively locking (swaging) it into the grooves of the harder pin. The pin and swaged collar together form the installed fastener.

The squeezing action reduces the diameter of the collar, increasing its length, which in turn stretches the pin, generating a clamp force over the joint.

Shear strength of lockbolts varies according to the material strength and minimal diameter of the fastener. By increasing the diameter or the grade of material, the shear strength of the fastener can be increased.

The tensile strength of lockbolts is dependent on the shear resistance of the collar material and the number of grooves it fills.

FIGURE IX.2

LOCKBOLTS

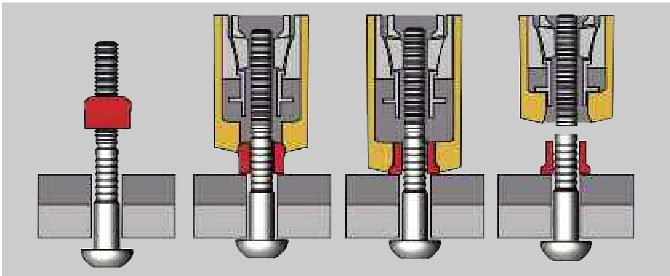


FIGURE IX.3

BLIND RIVET

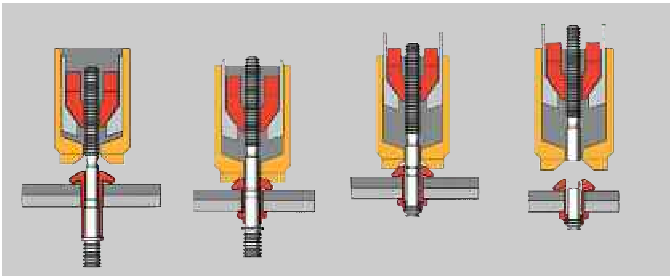
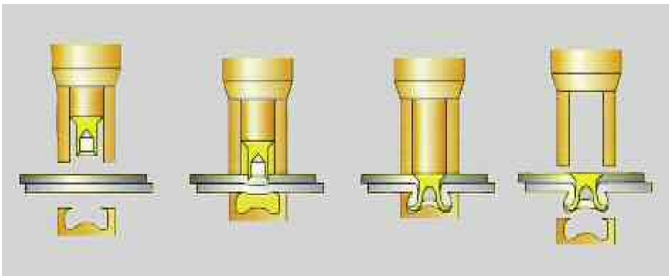


FIGURE IX.4

SELF-PIERCING RIVET



• **Blind rivets**, which are used when only one side is accessible. Blind rivets are characterised by breaking off of the rivet stem after fastening the connection by deformation of the rivet (therefore they are often called "breakstem rivets"). (Figure IX.3)

• **Self piercing rivets** do not require previous drilling. The rivet part of the bolt is pierced through the metal sheet. The further closing motion of the tool, together with the specially shaped counter die causes the rivet head to be formed in such a way that the pierced sheet is covered over in the joining region. (Figure IX.4).

4. Snap-lock & clipping

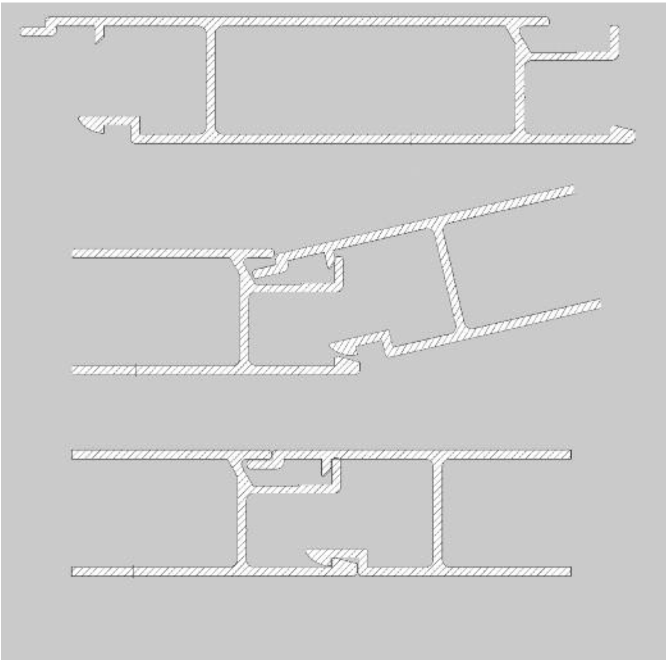
The Snap-Lock is a design which uses serrated components making assembly easy and quick.

The snap-lock design allows siding to be notched and locked into place without face nailing.

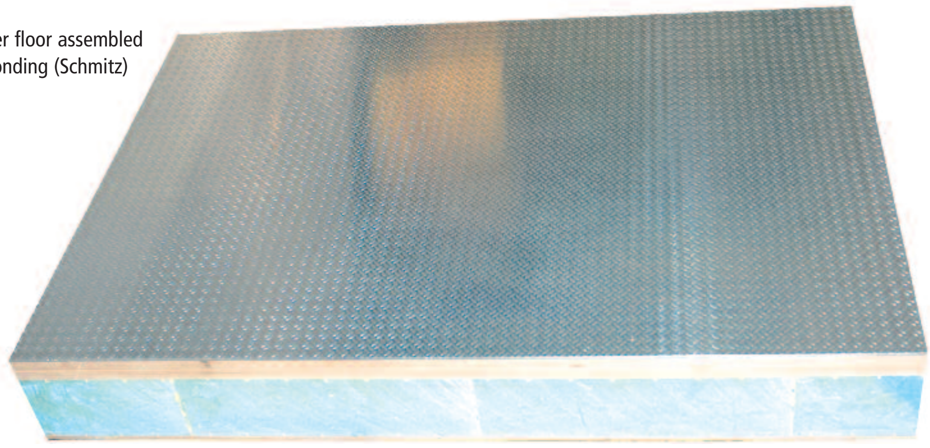
Stresses are distributed over the entire length of the profile and not merely concentrated on the mechanical fixing point (rigidity).

FIGURE IX.5

CLIPPING PRINCIPLE



Reefer floor assembled by bonding (Schmitz)



CHAPTER X

DECORATION AND FINISHING

1. Foreword

Although aluminium can be used without any surface protection and keeps its natural beauty throughout a whole trailer life, it is most likely to use different surface treatment methods to optimise the attractiveness and optical appearance of a trailer, to protect it from severe atmospheric conditions and to give space for company logos or advertisements.

Aluminium tanker (Trailor)

2. Possibilities with aluminium

There are several methods for decoration and finishing of an aluminium surface. Although all of the methods used for other materials are applicable, special attention has to be paid to aluminium s characteristic properties. In each case, especially the softness of the surface and the existence of the oxide layer have to be considered.

There are 2 main methods of decoration and finishing:

- Mechanical finishing
  - Brushing
  - Polishing (or “buffing”)
- Chemical Finishing
  - Anodising
  - Painting

Today, painting is the most common way to decorate trucks and trailers.

3. Mechanical finishing

3.1. Brushing

Brushing is a rather seldomly used method for the decoration of trucks and trailers. It can mostly be seen on tankers for the transport of fluid goods. Like polishing, brushing is based on abrasion effects between the brush surface and the aluminium surface. Due to the brush being the harder part, aluminium is removed from the surface by an abrasive effect. Brushing is done with rotary brushing tools or machines. Normally no additional brushing compounds or chemicals will be used.

Like for every surface treatment of aluminium, the part to be brushed has to be cleaned and degreased properly before applying the brushing process. The cleaning is done to remove any dust, dirt, oil, emulsion or other residues from the rolling process prior to brushing and to prevent particles from being squeezed into the surface during brushing. To secure a uniform surface appearance, it is of great advantage to use an automatic process with several brushes in one single station, which are simultaneously controlled.

3.2. Polishing / Buffing

Polishing or buffing is a quite common method in the North American market to provide a decorative surface finish. 3 main methods can be applied:

- Use of mirror-finished aluminium sheets and plates fabricated in the rolling mill
- Polishing / buffing of mill finish sheets to the desired surface appearance
- Manual polishing

The use of mirror-finished plates or the use of already buffed or polished sheets has the advantage, that the work on site is reduced to the manual polishing of weld seams or places which have been damaged during fabrication. Great care must be taken when handling or working with these sheets, as every little trace of a mechanical defect caused by fabrication must be manually polished.

Mirror finished plates are fabricated in the rolling mill by the use of a special rolling routine with work rolls which have nearly no surface roughness. This makes it a very demanding process and great care must be taken to secure a reliable and constant quality of the sheets.

Buffing or polishing of large plates is done on automatic lines, where the surface is polished with rotary polishers across the whole width of the sheet at the same time. The rotary polishers have special pads on their surface, which polish the aluminium surface under the help of polishing compounds. The polishing compounds works as a slight abrasive and removes the top layer of the aluminium surface in the range of the surface roughness produced by the rolling mill. As the result of polishing is very much depending on the type of alloy and temper, the surface hardness, the type of polishing paste and the machine setting (like rotational speed, pressure and type of pad), this is a method of "trial and error" to find the right setting per specification.

Aluminium tank (LAG)

Aluminium tipper (Benalu)

In any case, before polishing, the aluminium plates should be degreased and cleaned to remove any kind of dust and dirt to prevent abrasive particles from being ground into the aluminium surface.

The same rules apply for manual polishing. This process is difficult to apply and a large and extensive experience is necessary to reach a satisfactory and reproducible result. After removal of surface dirt or oil, the manual process starts with a rotary polisher and the use of quick-cutting abrasive paste. The pad should be a wool compounding type. Speed of the polisher must be limited to prevent burning of the surface. The polisher should be moved back and forth, up and down to ensure a uniform abrasion of the surface. As the pad will suddenly turn black (caused by the polishing residue), great care must be taken to regularly clean or change the pad. After the rough first polish, the type of paste should be changed to one with lower abrasion. Before applying the final polishing step, it is useful to clean the surface again to remove the black residue, which might be trapped into the surface. The final result of manual polishing should be a mirror-like, uniform, swirl-mark, black speck- and bright sparkle-free surface.

To keep the mirror-like surface throughout a long period, it makes sense to apply a clear coat system, as exposure to normal atmosphere would lead to a bleaching of the polished surface.

4. Chemical decoration

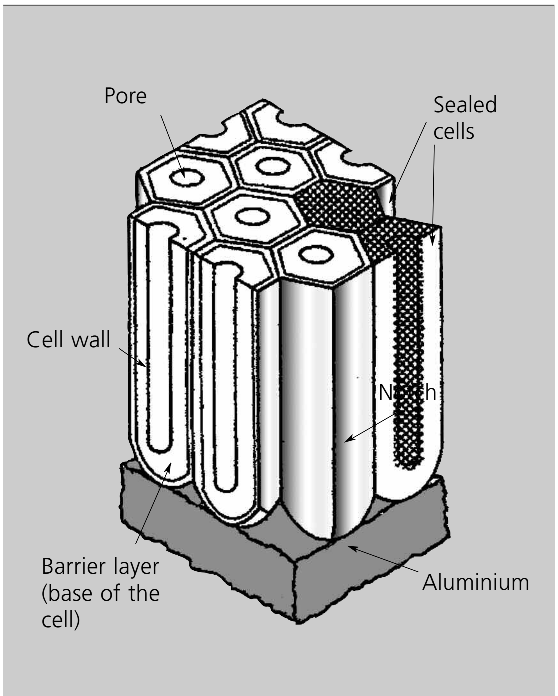
4.1. Anodizing

Anodizing is an electrochemical process to reinforce the natural oxide film on the aluminium surface.

Anodising is done in a sulphuric solution at a certain electric current. The natural oxide film is thereby newly built and the process can be controlled to reach certain thicknesses of the oxide layer (in the range of 1000 times of the natural oxide film). Anodising not only produces most frequently a silver- matt surface, but at the same time enables increasing hardness, corrosion resistance and resistance to abrasion. The process is applied discontinuously on components like castings, extrusions and plates or continuously on coils.

The structure of the anodic film is determined by the process parameters (type of bath, applied current etc.) and consists of hexagonal cells. The center of the cells includes a micro-pore with a diameter of nanometers. These pores have to be sealed to close them and to guarantee an excellent corrosion resistance. This is done in boiling water under the use of sealants. (Figure X.1)

FIGURE X.1
STRUCTURE OF THE ANODISED LAYER



4.2. Painting

4.2.1. Introduction

Painting is the most usual way of decoration for commercial vehicles. Due to the natural oxide film on the aluminium surface, it is of vital importance for a well adherent and durable organic coating to apply an efficient surface preparation.

It is therefore not sufficient to clean the bare aluminium surface and to degrease it prior to paint application. It is essential to remove also the natural oxide layer, because it disturbs adhesion of the paint system.
This can be done in 2 ways:
Chemical pre-treatment by etching (after degreasing or by a combine degreasing/etching process)
Degreasing of aluminium surfaces can be done with fluid degreasing solvents, supplied e.g. by paint producers. The objective of cleaning and degreasing are:
- to remove any kind of fatty or oily residues, or traces of dirt and dust from the surface
- to prevent electrostatic charging.

Cleaning before painting (LAG)

To apply a degreasing solvent properly, it is necessary to wipe the surface with a fresh moistened cloth and then clean it with a new, fresh and dry cloth.

Aluminium has amphoteric properties, which means that it can be dissolved either in an acidic or alkaline environment. Etching of commercial vehicles is normally done by applying the etching agent by spraying. Alkaline etching agents are based on caustic soda, silicates, phosphates, carbonates and sodium hydroxide. The concentration of sodium hydroxide and the temperature of the etching agent have a large influence on the speed and rate of the etching process. Etching can also be done on the base of acidic solutions with phosphoric acid or nitric acid. Etching leaves a rough and very moisture-sensitive surface behind. It is therefore essential to rinse carefully with fresh water after etching (about 20 minutes).

Mechanical treatment by grinding or blasting

Grinding is to be done on a clean and degreased surface to prevent oil being trapped into the aluminium, which could lead to adhesion problems of the paint. The graining of the grinding disk should have a grain size of 120-180.

Blasting allows a more uniform treatment of the vehicle and reaches areas which cannot be reached by a manual grinding machine. It is essential to use iron-free blasting abrasives like non-recycled corundum, as iron can lead to corrosion problems[1]. The rate of abrasion during blasting is very low and well below 0.1 mm and therefore in the same range as etching.

After grinding (which is also used to flatten the welding seams and to plane out scratches) or blasting it is necessary to remove traces of the abrasives by compressed air and then to clean the surface again.

1. The incrustation of iron particles on the aluminium surface is a source of galvanic corrosion that will lead, in the presence of moisture, to superficial micro-pitting.

4.2.2. Application of the primer

The primer should be applied directly after the pre-treatment of the surface to prevent the rebuilding of the oxide film or to prevent any dust being attracted by the vehicle during longer periods of waiting time. Primers (or "wash primers") are used as adhesive agents to maintain the necessary bonding forces between the substrate (aluminium surface) and the paint system. They are also working as corrosion inhibitors, as they prevent water vapour diffusion through the paint system from getting in contact with the aluminium surface. Primers made of epoxy- resins are a well suited material for pre-treating aluminium, but need a thoroughly treated bare metal surface. The primer is normally applied by spray gun and the thickness of the wash primer or reaction primer layer is about 10 µm.

4.2.3. Final coating

The application of the final coating system can be done in different ways, but is anyhow not specific for aluminium. In any case, it is of vital importance to use paint systems with coordinated properties. The technical rules of the paint suppliers have to be strictly obeyed.

The final coating system can be separated into 2- or 3-layer systems with or without the use of fillers and basecoats. Fillers are needed to flatten unevenness and/or to increase thickness of the coating system.

For preparation of the surface, the primer layer has to be ground with a smooth grinding disk (roughness 300-400). Fillers have also to be ground before application of the topcoat system.

The paint is normally applied with spray guns. Drying times and temperatures have to be controlled. It might be necessary to apply an intermediate fine grinding of the single paint layers.

A typical painting procedure of a silo tank trailer could be[2]:

- Etching / degreasing inside and outside by spraying with an inhibited etching agent based on phosphoric acid
- Rinsing with fresh water for about 20 minutes
- Final assembly of the vehicle
- Grinding of the tank surface with a manual grinding machine to remove small surface damages
- Cleaning and degreasing with degreasers or silicone removers
- Application of the wash primer onto the outer tank surface. Layer thickness 8-10 µm.
- Drying of the tank at room temperature (20°C) or at elevated temperatures up to 80°C
- Removal of unevenness with a filler; grinding of the filler layer
- Removal of dirt and dust by wiping with a moisturized cloth
- Application of the 1st paint layer (basecoat or wet-in-wet filler) in 2 steps with a combined layer thickness of 60-70 µm. Special attention should be paid to the area of stone chipping.
- Application of the topcoat (clear-coat) in the desired colour after max. 2 hrs. Final coating thickness 50 – 60 µm.
- Drying of the top layer

Extrusion profile systems used e.g. in tipping trailers can be painted in 2 ways: either the trailer can be painted as a whole or the profiles can be painted individually and then being assembled. The general rules for decoration mentioned above are also valid for these types of constructions.

In any case it is essential for a sufficient and long lasting paint decoration to apply a well conducted preparation of the surface as mentioned before. Problems with the paint decoration often are not related to the paint or the aluminium itself, but more with an insufficient pre-treatment.

2. Koewius, Gross, Angehrn *Aluminium-Konstruktionen des Nutzfahrzeugbaus*, Aluminium Verlag, Düsseldorf, 1990.

CHAPTER XI

CORROSION RESISTANCE

1. Definition of corrosion

Corrosion is a electrochemical interaction between a metal and its environment which results in changes in the properties of the metal and which may often lead to impairment of the function of the metal, the environment, or the technical system of which these form a part (definition as per EN ISO 8044).

Corrosion can occur locally ("pitting"), or it can extend across a wide area to produce general deterioration.

2. Corrosion of aluminium

2.1. The natural oxide layer

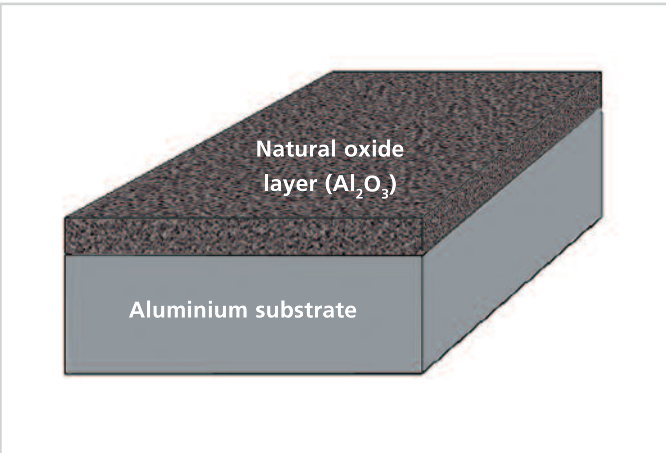
A clean aluminium surface is very reactive and will react spontaneously with air or water to form aluminium oxide. This oxide builds a natural protective layer on each aluminium surface with a thickness of around 1 – 10 nm. The oxide layer is chemically very stable, has a good adhesion to the metal surface, repairs itself and protects the aluminium from further corrosion. (Figure XI.1)

The oxide layer can be destroyed in strong acidic or alkaline environments or where aggressive ions are present. Aggressive ions can destroy the layer locally and lead to local corrosion attack ("pitting"). A typical case for this reaction is the contact between aluminium and chloride ions, which are present in seawater or road salts.

Some alloying elements might increase the corrosion resistance of the oxide layer, while others can weaken it.

Vehicle manufacturers or fleet operators should contact the aluminium supplier in any case of critical working conditions like elevated temperatures or aggressive loads.

FIGURE XI.1



Galvanic corrosion

2.2. Types of aluminium corrosion in commercial vehicles

Although highly resistant to corrosion through its natural oxide film, the following types of corrosion can occur in commercial vehicle construction or operation:
- Galvanic corrosion
- Crevice corrosion
- Pitting corrosion
- Filiform corrosion

2.2.1. Galvanic corrosion

Galvanic or bimetallic corrosion can occur when two different metals (or electroconductive non-metallic materials) are in contact with each other in the presence of an electrolyte. The reason for this type of corrosion is the difference in the electrochemical potential of the two metals. Aluminium is a very electronegative metal and therefore special attention has to be paid when aluminium is used in combination with other metals under the presence of an electrolyte (such as water). In an electrochemical reaction, the aluminium is working as an anode and is dissolving, while the other metal retains its integrity.

In this case, the aluminium ions react with the oxygen of the water to alumina (Al_2O_3), which builds a white layer on the aluminium surface.

There are 3 main prerequisites for galvanic corrosion:

- 2 different metals with different electrochemical potential
- presence of an electrolyte
- contact between the 2 metals

The electrolyte enables the flow of ions between the 2 metals. This can happen if the metals are wetted by the electrolyte (e.g. water containing salt) or emerged in the electrolyte. In commercial vehicles, this type of corrosion can occur where steel and aluminium parts are bolted, riveted or screwed together and where rainwater or road splash water can come in contact with the metal parts. (Figure XI.2)

To avoid direct contact between the 2 metals and to prevent entrapment of water, it is necessary to work with insulating material (such as neoprene or other elastomers) between the metals and to use sealing compounds to close constructive gaps. (Figure XI.3)

FIGURE XI.2

PRINCIPLE OF A GALVANIC CELL BUILT WITH ALUMINIUM AS ANODE

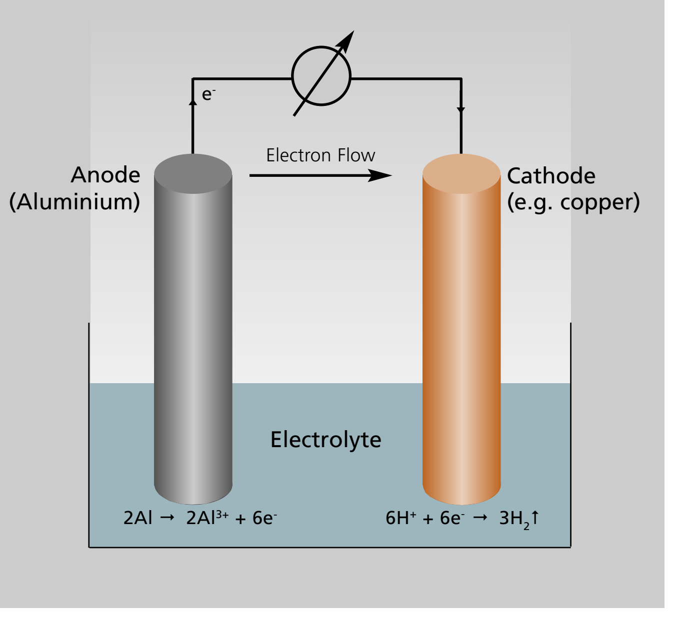


FIGURE XI.3

PREVENTION OF GALVANIC CORROSION

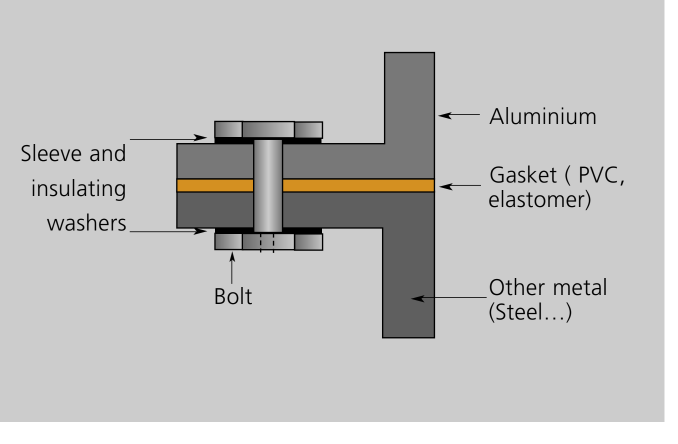


FIGURE XI.4

CRECIVES AND HOW TO PREVENT THEM

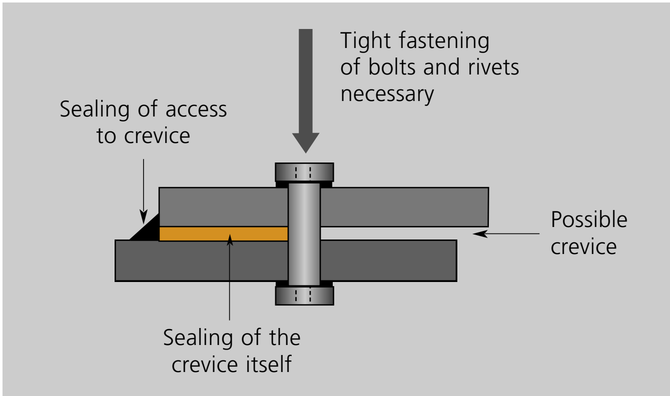
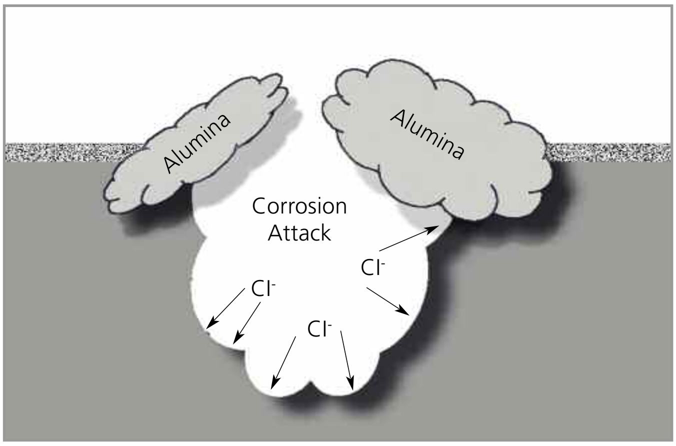


FIGURE XI.5

PITTING CORROSION



2.2.2. Crevice corrosion

Crevice corrosion occurs in small constructive recesses. In a crevice there will be the possibility for accumulation of moisture because of capillary forces and deposits of aggressive media. Therefore, especially in the road water splash zone, constructive gaps should always be closed as far as possible, as the penetrating water might contain aggressive ions (e.g. from road salts). The corrosion rate of crevice corrosion is normally very low due to the corrosion product – alumina – being stable and building a sealing of the crevice. (Figure XI.4)

2.2.3. Pitting corrosion

Pitting corrosion is the most common corrosion form seen on aluminium, characterised by the development of small local pits in the surface. The diameter and the depth of the pits varies and depends on different parameters related to the aluminium itself (type of alloy, rate of cold working, heat treatments) or to its environment (presence of aggressive ions). Pitting corrosion occurs on sites where the natural oxide film is damaged or imperfect due to diverse reasons like manufacturing related circumstances (areas which have been ground, weld discontinuities etc.). The pits are formed with a rapid increase in depth after initiation followed by a slower growth. This is due to the corrosion product - alumina – that is not soluble in water and therefore adheres to the surface of the metal inside the pits. The alumina then obstructs the direct contact between the aluminium surface and the corrosive medium and by this slows down the corrosion speed. (Figure XI.5)

This slowdown in the rate of pitting corrosion explains the fact that aluminium equipment can be used for decades in certain environments (country air, sea air, sea water) without any protection.

In other words, pitting corrosion is quite normal and normaly does not impact the durability of vehicles.

2.2.4. Constructive measures to prevent corrosion

Some general rules shall be applied to prevent corrosion (in most cases to prevent any kind of water trap or areas where condensation can occur):

- Constructive gaps should be avoided or, if not possible, should be sealed. (Figure XI.6)

FIGURE XI.6

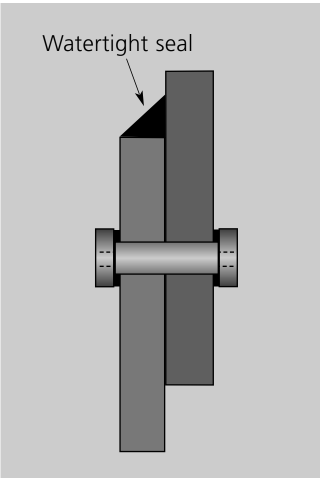
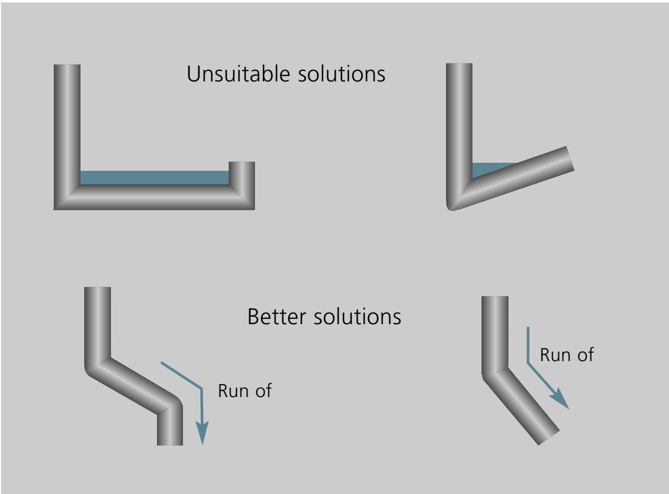
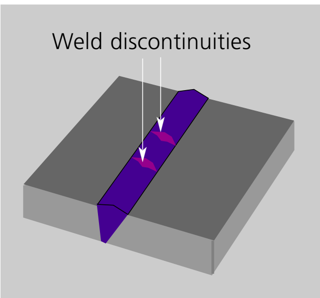


FIGURE XI.7



- Water traps should be avoided. Assemblies should be constructed with the open side downwards. (Figure XI.7)
- Weld discontinuities should, also with regard to other issues like stress, fatigue etc., be strictly avoided. (Figure XI.8)
- Materials having different electrochemical potential have to be separated from each other by coatings or insulating materials.

FIGURE XI.8

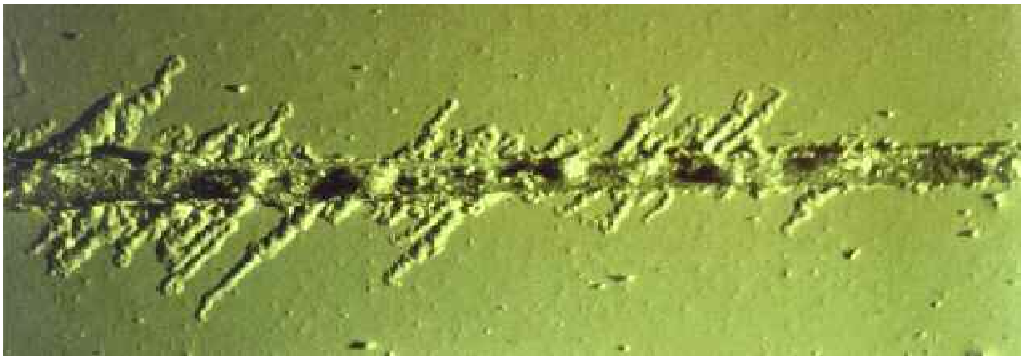


2.2.5. Filiform corrosion

Filiform corrosion (also known as under-film corrosion) occurs under paint or enamel layers. It depends mostly on environmental conditions and the quality of the surface treatment prior to painting. The corrosion filaments have a worm-like appearance and are readily visible. Filiform corrosion does not attack the metal surface, but affects the surface appearance.

The mode of corrosion is quite similar to pitting with the front of the attack being supported by moisture which penetrates the surface layer and leads to oxygen concentrated areas and by thus acting as an anode. Filiform corrosion is mainly an aesthetic effect, but could lead in certain construction parts to delaminating of the surface layer system.

To prevent this type of corrosion it is of vital importance to follow the instructions of the paint supplier, especially with regard to a proper surface treatment under the use of a suitable primer system.



Filiform corrosion coming from default in paint

2.2.6. 5000 series alloys and elevated temperatures

When held for long periods at elevated temperatures (between 65°C and 200°C), aluminium-magnesium alloys containing more than 3% of magnesium undergo metallurgical changes that can lead to intergranular corrosion if the two conditions below are both satisfied:

• Precipitation of a continuous bead of Al_8Mg_5 intermetallic compounds occurs along the grain boundaries (sensitization). These Al_8Mg_5 precipitations are anodic to the bulk material.

• Presence of an aggressive medium, e.g. a saline solution on the bare surface of the material.

This phenomenon has been studied many times with a view to gauging the influence of the following parameters for sensitization:

• The magnesium content and the production process largely determine the kinetics of sensitization of 5000 series material. Proper routes to minimize susceptibility are well established at suppliers.

• Manufacturing processes like forming and thermal joining (welding) might reduce resistance of final product to sensitization.

• The thermal load (i.e. temperature multiplied by time of exposure) is more important than the temperature alone. For example, if 65°C is often given as a limit in catalogues or manuals, it takes two years to sensitize a 5086 alloy at that temperature, while at 100°C, several months are necessary. The fastest sensitizations are generally observed between 130°C and 150°C.

But even if a material is sensitized, corrosion will only happen in aggressive environments, i.e. when a corrosive electrolyte gets in contact with the metal surface. Experience has confirmed this.
There are road tankers for heavy fuel oil, which have seen 20 years and more of service, running 8 to 10 hours a day, which is at least 50,000 hours of cumulative operation at 65-70°C.

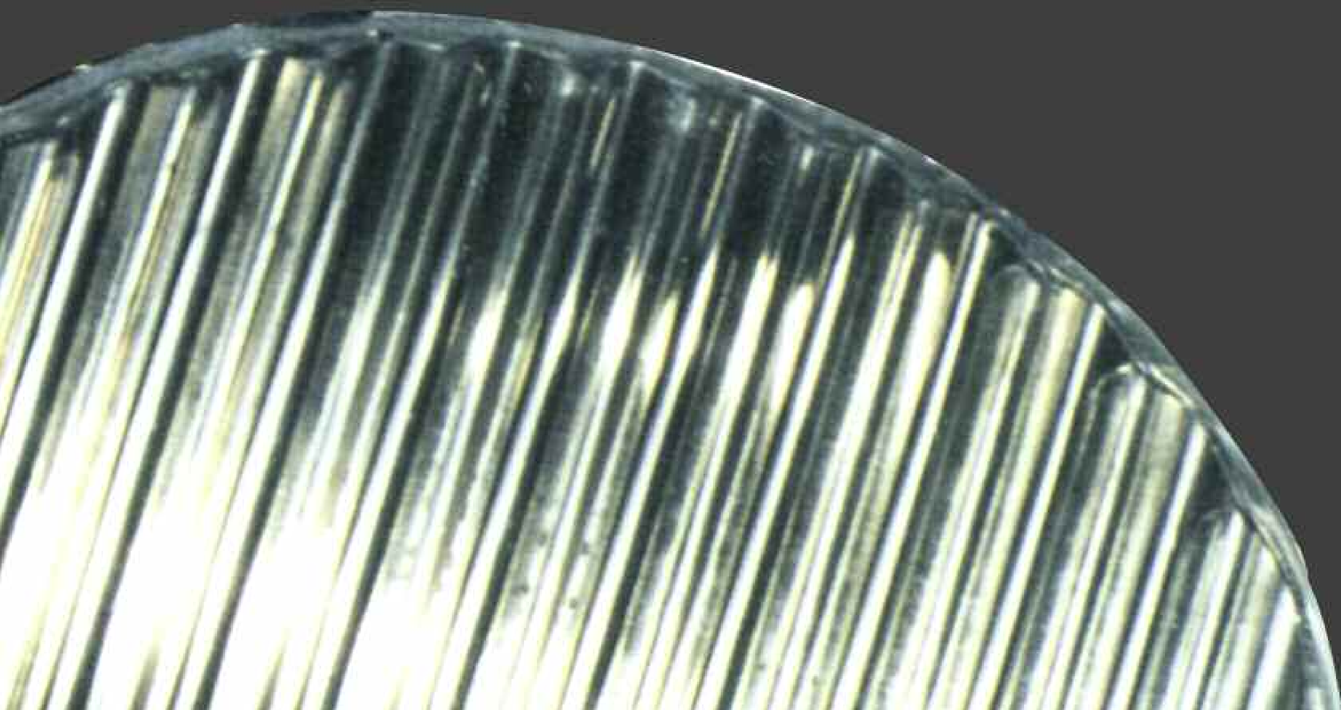
As a general guideline, the use of alloys with a maximum of 3% of magnesium is strongly recommended where exposure for long periods to temperatures in excess of about 75°C occurs. When the use of 5000 alloys with higher Mg content is desired, consultation with the material producer is necessary and their applicability must be evaluated in detail, taking into account the thermal exposure of the part during its total lifetime.

2.2.7. Other forms of corrosion

Other forms of corrosion do exist, but the alloys and tempers most currently used in commercial vehicles are not prone to these types of corrosion.

2.3. Further references

- *Corrosion of aluminium*, C. Vargel, ed. Elsevier
- www.corrosion-aluminium.com



CHAPTER XII

CLEANING OF ALUMINIUM COMMERCIAL VEHICLES

Commercial vehicle cleaning station (Interservice Arras)

1. Introduction

Regular cleaning of a commercial vehicle is a prerequisite to ensure a long lifetime. Any kind of dirt is removed, the optical attractiveness is kept and critical parts like wheels, axles, brakes and hydraulic systems can be better optically controlled. Corrosion is prevented and damages due to mechanical friction between moving parts can be avoided.

In case of tank trailers, there are often strict legal regulations concerning the transport of foodstuff or there are other regulations for strict cleaning when different chemicals are transported which might interfere with the goods transported before. In some cases, aluminium cannot be used as a construction material due to the cleaning instructions, which specify the use of strong aciduous or alkaline chemicals.

In general, cleaning of an aluminium vehicle is not different from cleaning any other vehicle. It can be done on automatic washing lines as well as manually with the use of high pressure spray guns, brushes and cloths.

2. The nature of stains

Stains on commercial vehicles may have the following origins:
- Road caused: dirt, salts, mud, water splash, tyre wear
- Fuel caused: diesel exhaust, soot
- Load caused: cement, asphalt, chalk, residues of agricultural products etc.
- Environmentally caused: effects of air pollution, dust

All these elements, in connection with humidity, can lead to local corrosion and fading or destruction of the paint layer.
In this respect, residues of previously transported goods prior to a new load might also be seen as contamination and require intensive cleaning.

3. The choice of detergent

The detergent used for cleaning an aluminium vehicle must be compatible with aluminium, means it must not be too aggressive.

In general, a detergent has to:
- Have a strong effect on all kinds of dirt
- Allow an efficient removal of aggressive dirt
- Create a bright visual appearance of the surface
- Build up a protective film on top of the paint
- Be in compliance with specific regulations
- Be biologically degradable
- Be harmless to the user

Detergents are a complex mixture of up to 20 ingredients to enable diverse functions at the same time: degreasing, slight etching, washing, conserving etc.

4. Application of the detergent

The cleaning of a vehicle should not take place in direct sunlight. Each detergent should be tested on a raw aluminium surface prior to first use.

The detergent can be used either in automatic washing lines or can be applied manually with the use of high pressure spray guns, brushes, cloths etc. Its main cleaning effects are:
- Chemical

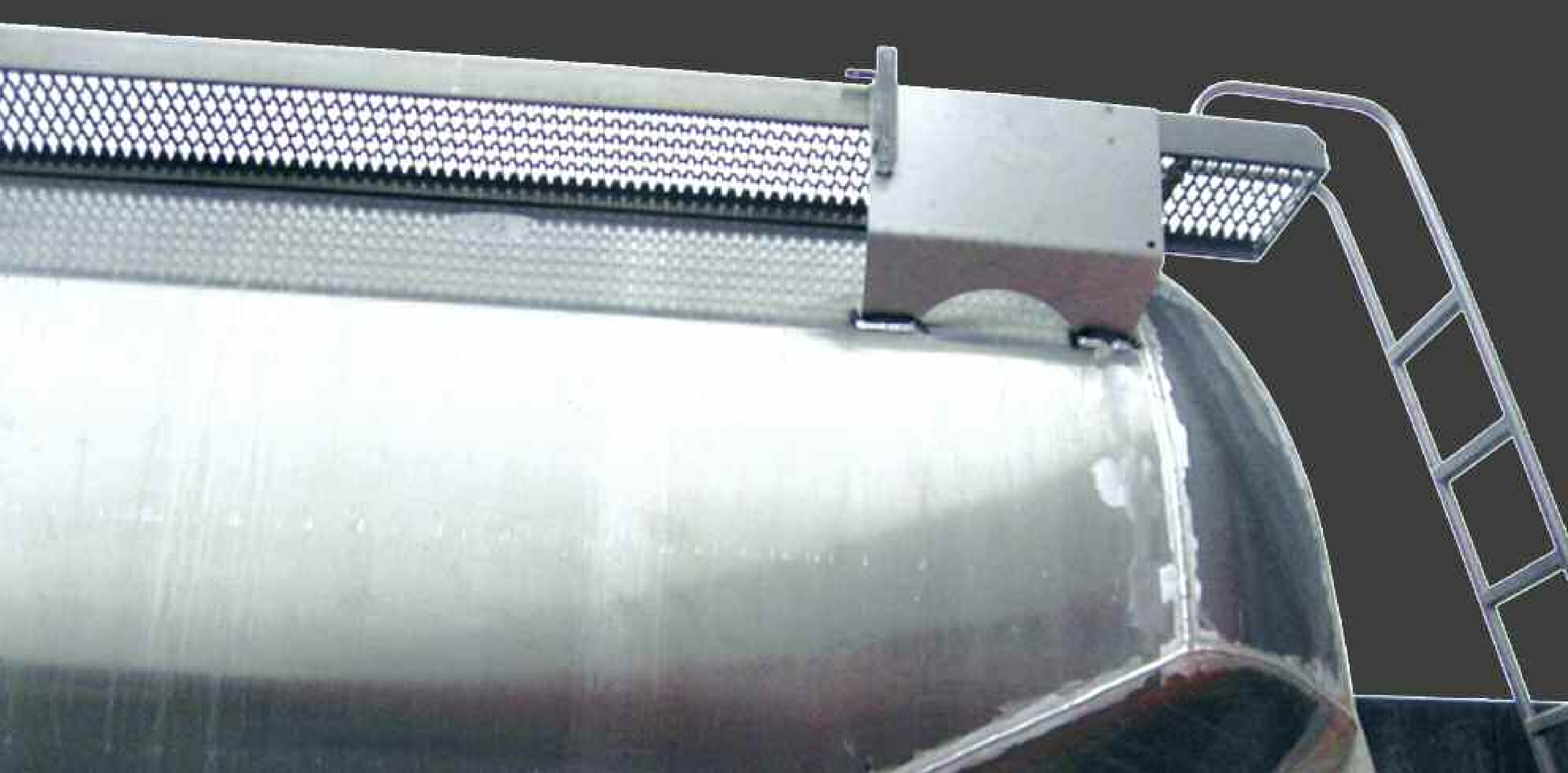
Some elements of the detergent dissolve the dirt or mineral salts without attacking the surface
- Physical

Stains are removed by decreasing the surface tension. Therefore detergents contain wetting elements
- Mechanical

Stains are removed by spraying with pressurised detergent or by abrasion when using brushes
- Temperature

Higher temperatures, or even water steam, increase the cleaning effect by increasing the speed of the chemical reaction between the detergent and the stain.

Spraying should be done from bottom to top of the vehicle to prevent streaking. The residence time should be sufficient to dissolve the stains. The detergent should not dry on the vehicle surface and washing should be followed by intensive rinsing with de-ionized water.



CHAPTER XIII

REPAIR OF ALUMINIUM COMMERCIAL VEHICLES

Inside view of a repaired aluminium tank (Feldbinder)

1. Foreword

Repair of commercial vehicles should be done with the same care as new construction. In general, all rules, materials and methods used for new construction should also be applied for repair causes.
Repair is a case-to-case decision, whether small damaged parts can be repaired without disassembling the structure or whether damaged components (plates, extrusions) must be cut out and replaced completely.
In any case, damages should never just be "over-welded". This method does not reflect a reasonable way of repair. Any parts, which have been cut out due to damages, must always be replaced with the same type of alloy as originally used. This has to be applied to ensure a safe and constant stress deviation across the vehicle and to prevent a weakening of the construction. It has to be taken into consideration, that especially tankers or silo trailers are regarded as pressurized vessels under the European Pressure Vessel Regulation 97/23/EU. This requires additional testing methods for repairs and supervision by certified supervision bodies (like TÜV).
Repair should therefore be carried out by the manufacturer of the original vehicle or in certified repair workshops: qualified welders, working methods according to state-of-the-art technologies, suitable work organisation, etc. are necessary.

Outside view of a repaired aluminium tank (Feldbinder)

2. Execution of repair

A sophisticated repair of an aluminium commercial vehicle should be done according to the following procedures:

- Identification of the damage
  - How much metal has been destructed?
  - Any further damages which could not be seen during first inspection?
- Cut out of damaged components
- Identification of originally used material specification
- Order of replacement material according to detected specification
- Order of suitable welding filler wire (according to norms or specific regulations)
- Pre-cut of replacement part under consideration of the thermal shrinking during welding
- Pre-form replacement material if necessary
- Removal of original coating in the repair zone
- Fixing of the replacement part to the vehicle; if necessary additional forming to the vehicle contour to prevent too much stress during welding
- Joining of the replacement part to the vehicle structure by suitable welding methods.
- Visual control of the weld quality
- If necessary or mandatory (pressure vessels), then non-destructive testing (ultrasonic, x-ray) of the weld seam
- Grinding or flattening of the weld seam
- Repair of the coating
- Final control; it might be required to let all steps of repair be checked by a supervisory organisation.

3. Repair of aluminium chassis

The case of aluminium chassis deserves a particular attention, as a non-professional repair may lead to a deterioration of both the static capacity and fatigue strength.

To avoid this kind of problems, please read Chapter VI, section 8, dedicated to fatigue.

Beginning with fatigue theory, that chapter also illustrates how good practices for perforating and welding can secure long lifespan to vehicle.

Welding of silo body (Feldbinder)

4. MIG and TIG weld repairs

A road vehicle can sustain damage and will need to be repaired. Repairing a commercial vehicle made from aluminium alloys is no more difficult than repairing a steel vehicle, but should be done according to a strict procedure in a properly equipped workshop by skilled operatives under the supervision of an official body and/or classification society if the vehicle's duty calls for this.

No repair work should commence without knowing the type of freight (liquid, powder etc.) which the vehicle has been used to carry and before taking the appropriate safety precautions: cleaning, degassing, with explosimeter checks, dust removal etc. as necessary.

4.1. Choice of alloy

The alloy of the semi-finished products used for the repair work must be the same as (or compatible with) the original alloys as indicated in the manufacturer's manual.

4.2. Preparations

This is the most important phase as it will determine the quality and strength of the repair:

- for cutting out, preference should be given to the plasma torch or a carbide cutting wheel rather than a high speed steel (HSS) wheel or abrasive wheels that might introduce inclusions into the weld seam,
- very carefully grind the area to be welded to remove all traces of paint and various residues,
- carefully degrease with suitable agent

4.3. Welding

The rules for repairing are basically as described in Chapter VII for forming and as described in this chapter for welding. When carrying out repairs it is essential to:

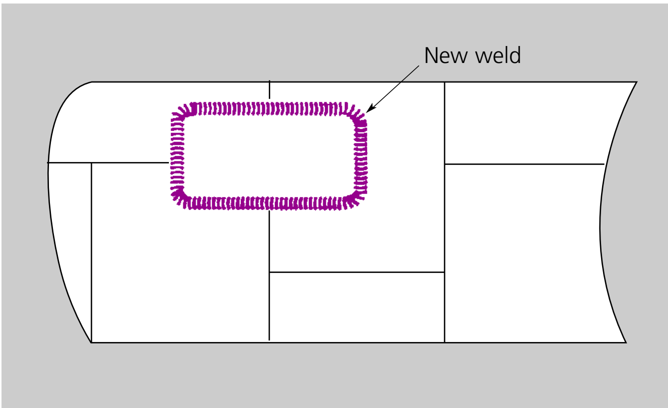
- hold the components, e.g. tank, chassis etc., securely in their relative positions. Clamps should be adjusted to allow expansion however, as too much restriction could aggravate the adverse effects of contraction. It is also useful to mark areas of the structure likely to suffer maximum stress, referring to the manufacturer's design calculations if these are available,
- support built-up parts to control clearances,
- pay particular attention to the weld direction. The purpose of this is to limit deformation and minimize the risk of hot cracking. Volume contraction in the weld bead is approximately 6 % between the fluid state and the solid state at ambient temperature. It is this phenomenon which causes the risk of cracking,
- change the path of welds in order to avoid going back over an original weld (Figure XIII.1),
- perform any necessary tests, e.g. radiography, dye penetration etc.,
- chose the right welding process (TIG or MIG). TIG welding is preferable for minor repairs where access from behind is not possible as it is easier to use and allows better penetration control than MIG welding.

Compact TIG welding machines weighing less than 20 kg are now available on the market capable of delivering a welding current of around 160 A. These machines are easy to carry and are ideal for small, localized repairs.

For minor repairs such as a breach in the skin of a tank, the patch must be perfectly matched to the shape of the breach but should be slightly enlarged by hammering to compensate for contraction following welding. Without this precaution the residual stress might well cause systematic cracking. This phenomenon is more pronounced the smaller the patch.

FIGURE XIII.1

WELD REPAIR



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