TALAT Lecture 4300

Beam Welding Processes of Aluminium

14 pages, 14 figures

Basic Level

prepared by Ulrich Krüger, Schweißtechnische Lehr- und Versuchsanstalt Berlin

Objectives:

- to give a brief introduction to beam welding and cutting techniques of aluminium
- to describe the process principle of electron and laser beam welding and cutting of aluminium
- to give some information about the choice of welding and cutting parameters
- to give information about the weldability of aluminium alloys with electron beam welding

Prerequisites:

- General mechanical engineering background
- basic knowledge of electron and laser beam physics

Date of Issue: 1994

4300 Beam Welding Processes of Aluminium

Table of Contents

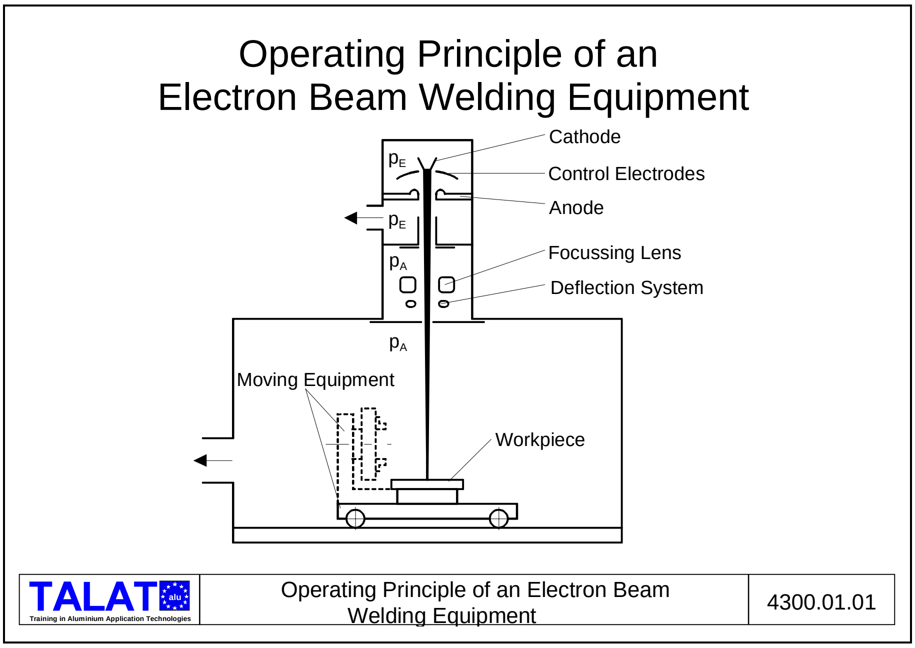
4300.01 Electron Beam Welding

- Operating principle of an electron beam welding equipment
- Process steps of the deep welding process
- Electron beam welding of butt joints
- Terms used for describing a weld
- Electron beam weldability of aluminium alloys
- Electron beam welds in aluminium alloys
- Rate of vaporisation during electron beam welding of 7050 (AlZnMgCu)
- Tensile strength of electron beam welded 7050 (AlZnMgCu)

Operating Principle of an Electron Beam Welding Equipment

The electron beam welding is associated with energy densities of > 10^8 W/cm^2. A vaporisation of the metal occurs above 10^6. The electrons emitted from an incandescent electrode and accelerated in an electron gun are focussed to bombard the work placed in a vacuum chamber. An arrangement of deflecting systems is used to make the beam move. The work can also be moved along different axes, so that the welding location is accessible (**Figure 4300.01.01**).

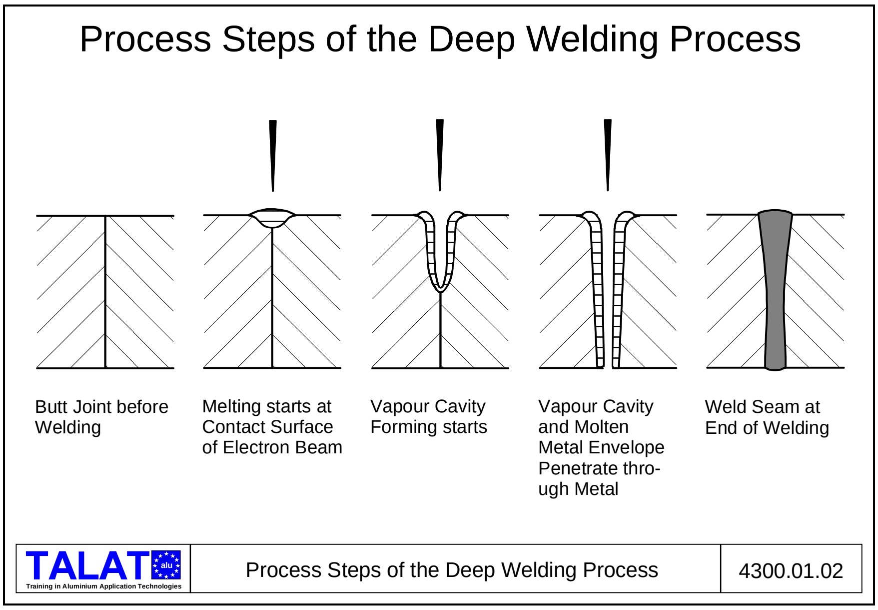
Welding can be carried out with or without a filler metal .



Process Steps of the Deep Welding Process

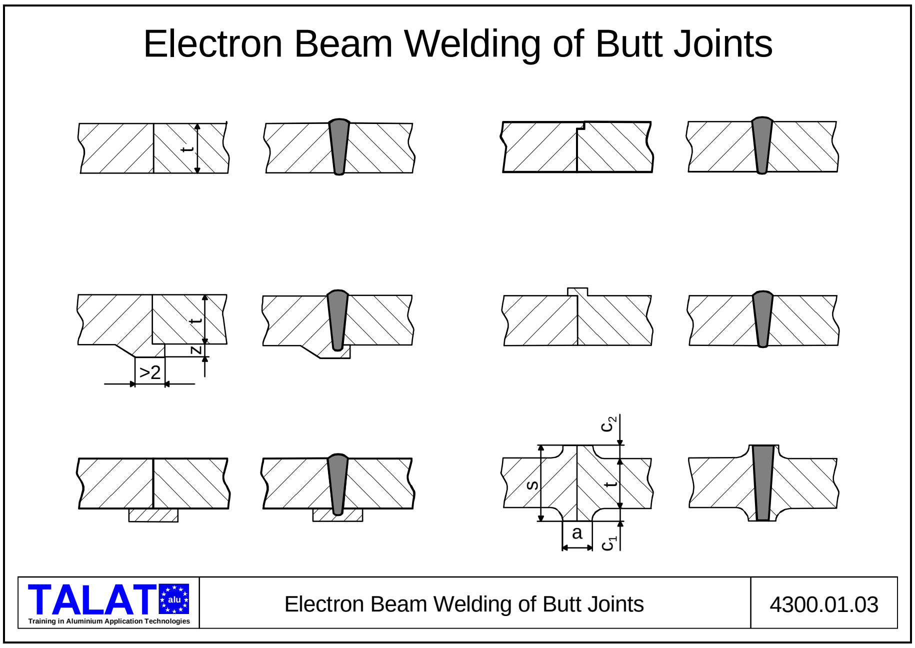
The formation of a vapour cavity or deep-weld effect is typical for beam welding processes. A cavity consisting of a vapour core surrounded by molten metal is created. The beam can thus penetrate through the whole thickness of the metal. Vapour pressure and surface tension have a two-fold effect: they keep the cavity open towards the top and thus allow an unhindered beam penetration and at the same time allow the weld pool to flow together or allow a crystallisation in the beam vicinity (**Figure 4300.01.02**).

Care must be taken to ensure that the vapour cavity exists long enough for degassing to occur so that the weld porosity is eliminated or kept to a minimum.



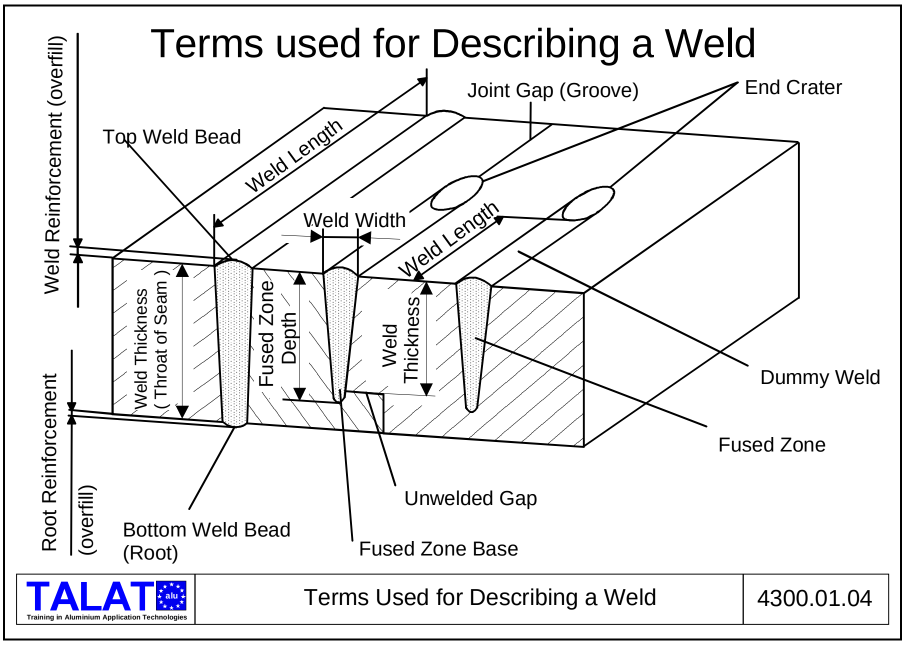
Electron Beam Welding of Butt Joints

The surfaces to be joint are mechanically worked or, as in the case of extrusions, have especially formed lips which help to position the parts to be welded and serve as weld pool supports. Weld pool supports in the form of grooved sections are usually not used, since the high energy beam reaches right through to the bottom of the joint. This would lead to an undesired welding. The remaining weld-pool supports tend to reduce the dynamical strength. For this purpose, joint forms and machining allowances are designed (**Figure 4300.01.03**).



Terms Used for Describing a Weld

Joints made by the electron beam welding process are characteristically extremely narrow and deep. The ratio of weld thickness (throat of seam) to weld width lies between 5:1 to 25:1. Thus it is possible to weld even thick sheets with a square butt joint with the electron beam welding process where the other welding processes would require large V-angles and filler metal (**Figure 4300.01.04**).



Besides the terms normally used for describing weld joints, one also uses terms like fused zone base and weld thickness or throat of seam, which are specific for electron beam welding. Besides welding, it is also possible to use a reduced beam power for surface treatments like remelting, hardening, engraving etc.

Electron Beam Weldability of Aluminium Alloys

Generally, aluminium and its alloys can be welded easily with the electron beam welding process.

Among the non-heat-treatable alloys, the hot-cracking tendency increases with increasing magnesium content. At the same time, the high vapour pressure of magnesium increases the danger of porosity in welds. Similar to the metallurgical conditions for fusion welding processes (TIG, MIG), the cracking tendency depends on the contents of magnesium and silicon. As far as possible, the alloy $AlMg_3$ should be avoided.

The heat-treatable alloys have only a limited suitability. The high vapour pressure of zinc leads unavoidably to weld porosity. Due to the reduced heat input, the alloys containing copper can be easily welded (the weldability of copper-containing alloys with other welding processes is poor).

Alloys which can be naturally aged exhibit an increase in hardness after welding, without, however, attaining the original hardness fully (**Figure 4300.01.05**).

Electron Beam Weldability of Aluminium Alloys

Alloy Group	Alloy Example	Weldability
Non-Heat-Treatable Wrought Alloys	Al 99,5	Good
	AlMn 1	Good
	AlMg 3	Hot Cracking Tendency
	AlMg 5	Good, Vaporisation Loss of Mg, Weld Porosity Tendency
Heat-Treatable Wrought Alloys	AlMgSi 1	Good
	AlCuMg 2	Good
	AlZnMgCu	Not Suitable, Vaporisation Loss of Zn and Mg, Porosity, Hot Cracking
Non-Heat-Treatable Casting Alloys	G-AlSi 12	Good
	G-AlSi 9 Cu 3	Good
	G-AlMg 5	Good, Vaporisation Loss of Mg, Weld Porosity Tendency
Heat-Treatable Casting Alloys	G-AlSi 7 Mg	Good
	G-AlMg 5 Si	Good, Vaporisation Loss of Mg, Weld Porosity Tendency
	G-AlCu 4 Ti	Hot Cracking Tendency
	GD-AlSi 8 Cu 3	Weld Porosity

TALAT Training in Aluminium Application Technologies | Electron Beam Weldability of Aluminium Alloys | 4300.01.05

Electron Beam Welds in Aluminium Alloys

Practical experience with electron beam welding exists for a number of aluminium alloys. Materials up to 40 mm in thickness can be welded. Even here, experience shows that $AlMg_3$ alloys can be welded only by adhering to special measures. An explanation for the hot cracking tendency lies in the fact that the beam with its high energy density causes a relatively high amount of magnesium to vaporise so that the remaining content now lies in the range of 1.5 %. It is just this magnesium content which causes a maximum amount of cracking (**Figure 4300.01.06**).

Electron Beam Welds in Aluminium Alloys

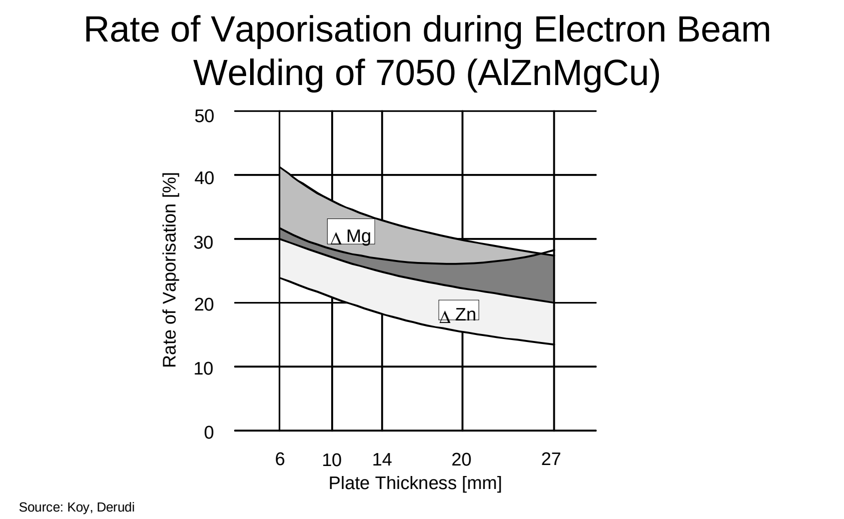
AA Alloy No.	Designation	Suitability	Tested for Max. Weld Thicknesses (mm)
1050A	Al 99,5	A	5
2024	AlCuMg2	A	10
2219	AlCu6	A	7
3103	AlMn1	A	5
5056	AlMg5	A	10
5083	AlMg4,5Mn	A	1.5
5754	AlMg3	B	5
6351	AlMgSi1	A	12
7050	AlZn6CuMg2	A	27
A413	G-AlSi12	A	40

A = Suitable for Welding (No Special Measures Required)
B = Suitable for Welding Only If Special Measures Used

TALAT Training in Aluminium Application Technologies | Electron Beam Welds in Aluminium Alloys | 4300.01.06

Rate of Vaporisation during Electron Beam Welding of 7050 (AlZnMgCu)

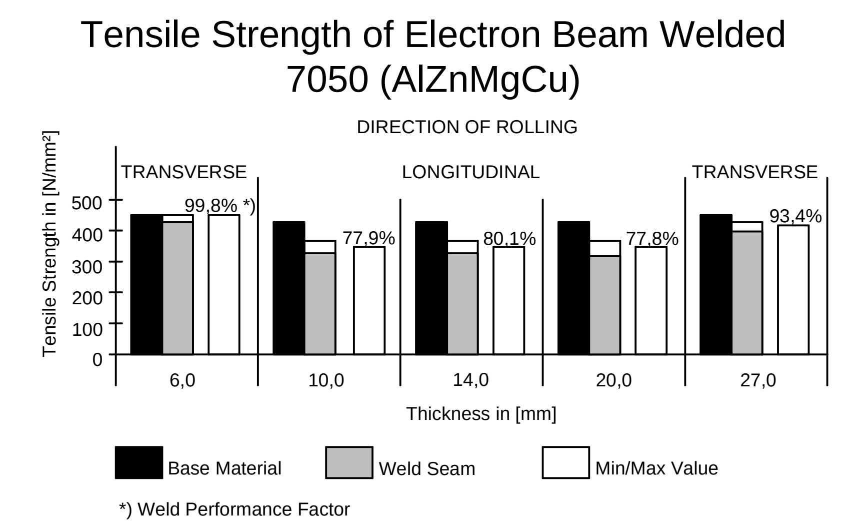
The alloying elements magnesium and zinc, with their low vapour pressures, reduce the suitability of these alloys for welding. This tendency, however, decreases with increasing material thickness, so that problems occur especially during the welding of thin sheets. The reason for this is that thicker sheets conduct heat more rapidly away than thin sheets (**Figure 4300.01.07**).



TALAT	Rate of Vaporisation during Electron Beam Welding of 7050 (AlZnMgCu)	4300.01.07

Tensile Strength of Electron Beam Welded 7050 (AlZnMgCu)

Electron beam welded joints of the alloy 7050 (AlZnMgCu) exhibit weld performance factors which vary with rolling direction and thickness of the material. The unshaded third columns in (**Figure 4300.01.08**) show that the weld performance factors for samples transverse to the rolling direction is almost equal to 1 for the 6 mm and 27 mm thick samples (i.e., the weld joint has a tensile strength almost equal to that of the base material). The weld performance factors of the longitudinal samples is almost independent of the thickness and is about 80 %.



TALAT	Tensile Strength of Electron Beam Welded Alloy 7050	4300.01.08

4300.02 Laser Welding

- Principle of a solid-state laser
- Comparison between electron beam welding and laser welding

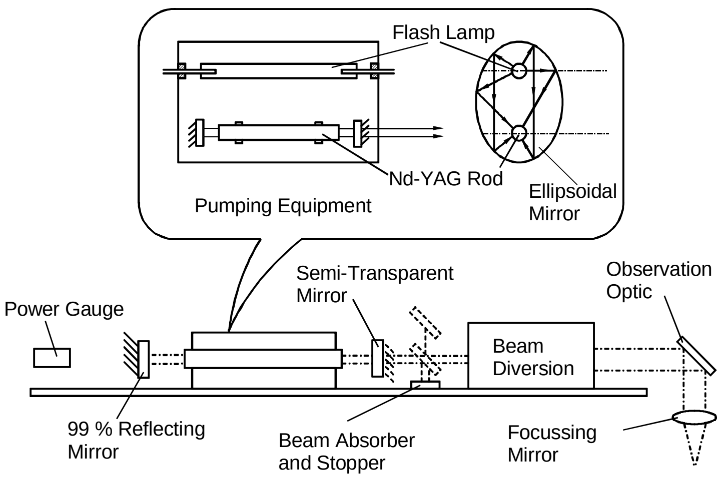
Principle of a Solid-State Laser

Similar to electron beam welding, the laser beam is also a high-energy source (maximum energy 10^9 W/cm^2). For welding purposes, a lower energy is used (between 10^6 to 10^8 W/cm^2) since a higher energy would lead to increased vaporisation of metals causing a weakening of the laser beam. In contrast to the electron beam welding, the laser can be used under normal atmospherical conditions without losing its energy. The laser can be utilised for both, welding and cutting. Two types of lasers are generally used:

- solid-state laser (Nd-YAG laser) (**Figure 4300.02.01**)
- gas-discharge laser (CO_2)

Currently, the maximum energies of the laser types used are 1.0 to 1.5 kW for the solid-state laser, and 20 to 25 kW for the CO_2 laser. Consequently, the solid-state laser is used for thinner sheets and the CO_2 laser for thicker ones. The solid-state laser has a small wavelength (ca. 1.06 µm) making it possible to use flexible light-conducting cables. The solid-state laser can thus be guided much more easily than the CO_2 laser which requires an arrangement of mirrors.

Principle of a Solid-State Laser



TALAT	Principle of a Solid-State Laser	4300.02.01

Comparison between Electron Beam Welding and Laser Welding

One of the main advantages of laser welding over electron beam welding is that the handling of the former is technologically simpler and the welding process can be conducted under atmospherical conditions. The laser welding equipment has a relatively simple mechanical construction and a higher welding accessibility making it highly flexible. In this respect, the vacuum chamber required for electron beam welding poses strong limitations on the process.

On the other hand, the vacuum conditions existing in the electron beam welding process inhibit the formation of plasma streams which tend to reduce the welding performance. Thus, much higher weld penetrations can be attained than with laser welding (**Figure 4300.02.02).**

Multistation welding machines can be used for laser welding, thereby increasing productivity and decreasing costs per piece.

Comparison between Electron Welding and Laser Welding

Comparing parameter	CO_2 Laser	EB
Maximum beam energy of equipment usually used in industry	6 kW	60 kW
Maximum fused zone thickness	10 mm	150 mm
Welding atmosphere	air/ shielding gas	vacuum 10^{-2} ; 10^{-4} hPa
Effect of energy absorption	depending on material and beam intensity	depending on material (Z-number) and fused zone thickness
Effect of focus diameter and focus position on beam energy	low	very high
Possibility of welding magnetic materials	yes	no / conditional
Possibility of welding non-ferrous metals	difficult	good
Possibility of welding non-metallic materials	yes	no
Beam deflection/ redirection	electro - mechanical metallic mirrors	electro - magnetic (coils, condenser plates)
Multistation operation (time sharing) possible	yes	no
Adaptability to other	cutting, heat treating, drilling, engraving, marking	drilling, heat treating

TALAT Training in Aluminium Application Technologies	Comparison between Electron Beam Welding and Laser Welding	4300.02.02

4300.03 Laser Cutting

- Principle of laser gas-jet cutting
- Laser cutting diagram for aluminium
- Laser beam cutting of aluminium
- Comparison of laser beam cutting and plasma cutting

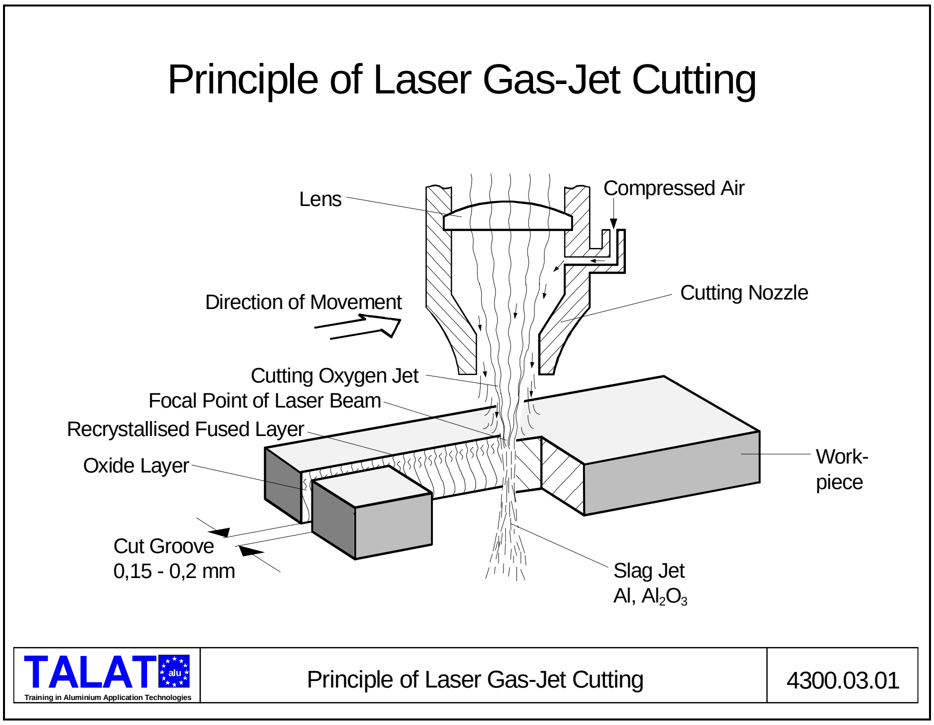
Principle of Laser Gas-Jet Cutting

Three variations of laser cutting are possible:

- laser gas-jet cutting
- laser fusion cutting
- laser sublimation cutting.

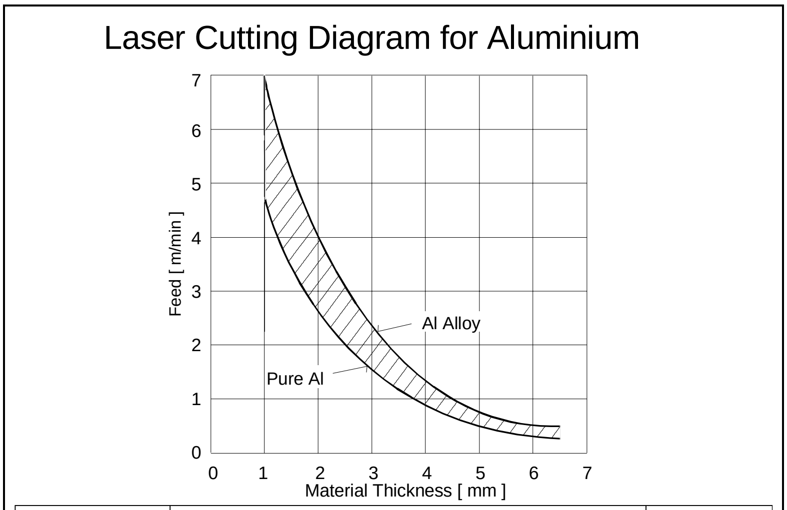
The last mentioned (laser sublimation cutting) cannot be used for aluminium, since the temperature difference between melting and vaporisation is too large. Cuts made using the laser gas-jet cutting process have a high roughness and undesirable burring, so that this process cannot be used for producing high quality cuts.

In laser fusion cutting, a focused laser beam heats the metal to a temperature well above its melting point. Finally, a compressed gas jet (compressed air, nitrogen, argon) blows the liquid metal out of the cutting groove. The cut edges are smooth and without burring (**Figure 4300.03.01**).



Laser Cutting Diagram for Aluminium

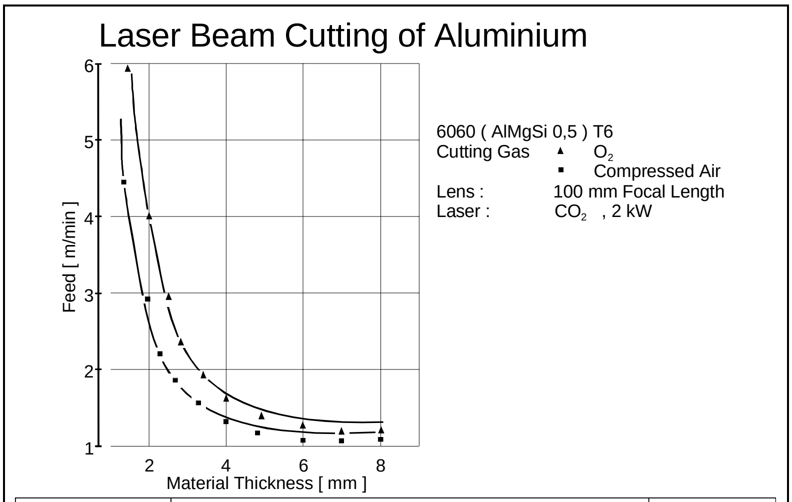
As a general rule, aluminium alloys can be more easily cut than pure aluminium . The reason for this is the higher absorption, i.e., heat losses are lower (**Figure 4300.03.02**).



TALAT | Laser Cutting Diagram for Aluminium | 4300.03.02

Laser Beam Cutting of Aluminium

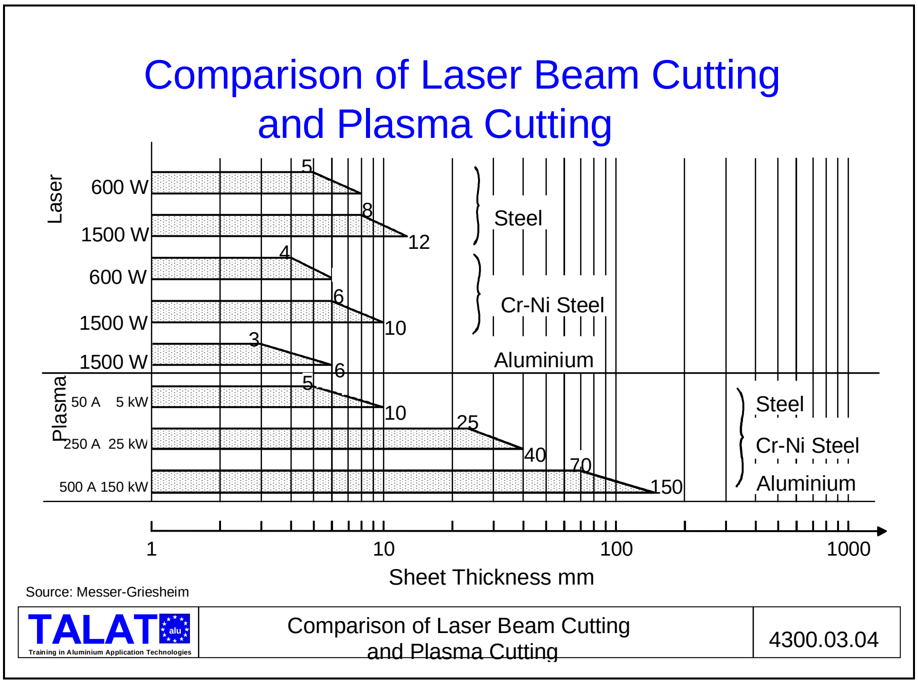
In contrast to steel, the cutting speed of aluminium is vastly reduced with increasing sheet thickness. The reason for this is once again the higher heat conduction loss. Laser gas-jet cutting using oxygen instead of compressed air hardly improves the cutting speed. The reaction energy of oxygen combustion freed during the laser gas-jet cutting process is only partly taken up by the metal. The simultaneously occurring oxidation of the metal surface prevents this. The quality of cut is worse than with compressed air. Undercuttings and burring cannot be avoided (**Figure 4300.03.03**).



TALAT | Laser Beam Cutting of Aluminium | 4300.03.03

Comparison of Laser Beam Cutting and Plasma Cutting

Laser beam cutting is mostly used for thin sheets. The heat input and consequently the distortion is lower than with plasma cutting. Cuts with complicated geometries which require no finishing or supplementary operations can be made with the laser cutting process (**Figure 4300.03.04**).



Plasma cutting is ideal for cases in which high quantities are required. The high energy plasma cutting process allows higher cutting speeds, but with lower cut surface qualities and higher distortions than the laser.

4300.04 Literature/References

- Aluminium-Taschenbuch, 14. Auflage, 1984, Aluminium-Verlag, Düsseldorf

Schulz, H. Elektronenstrahlschweißen. Fachbuchreihe Schweißtechnik Nr. 93, Deutscher Verlag für Schweißtechnik 1989, Düsseldorf

- Laserstrahltechnologien in der Schweißtechnik. Fachbuchreihe Schweißtechnik Nr. 86, Deutscher Verlag für Schweißtechnik 1989, Düsseldorf

4300.05 List of Figures