TALAT Lecture 4202

Weldability

13 pages, 14 figures

Basic Level

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Objectives:

– describing the important factors governing weldability of aluminium, such as influence of alloying elements, combinations of base material and filler materials and edge preparation for welding

Prerequisites:

– basic knowledge in metallurgy of aluminium

Date of Issue: 1994

4202 Weldability

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Weldability of Aluminium and its Alloys

The weldability of aluminum parts covers the aspects of suitability of welding with respect to the material properties, reliability of design and the manufacturing possibilities (**Figure 4202.01.01**).

Weldability of Aluminium and its Alloys

The Weldability of Aluminium Parts Depends on:

* the Welding Properties of the Alloy
  Chemical Composition
  Metallurgical Properties
  Physical Properties

* the Design and Service Requirements
  Design
  Loading Condition

* the Welding Conditions
  Preparation for Welding
  Welding Operations
  Post-Welding Treatments

TALAT Training in Aluminium Application Technologies | Weldability of Aluminium and its Alloys | 4202.01.01

The weldability of aluminium and its alloys depends mainly on the alloy composition, the welding technology and on the notch sensitivity determined by the design (stiffness, residual stress). Some aluminium alloys are susceptible to hot cracking above the solidus line.

Pure aluminium and Al-Mn alloys are very suitable for welding.

Increasing amounts of magnesium in Al-Mg alloys increase the oxidation tendency, making such alloys more difficult to weld. The Mg burn-off is compensated for by using filler metals with higher magnesium contents.

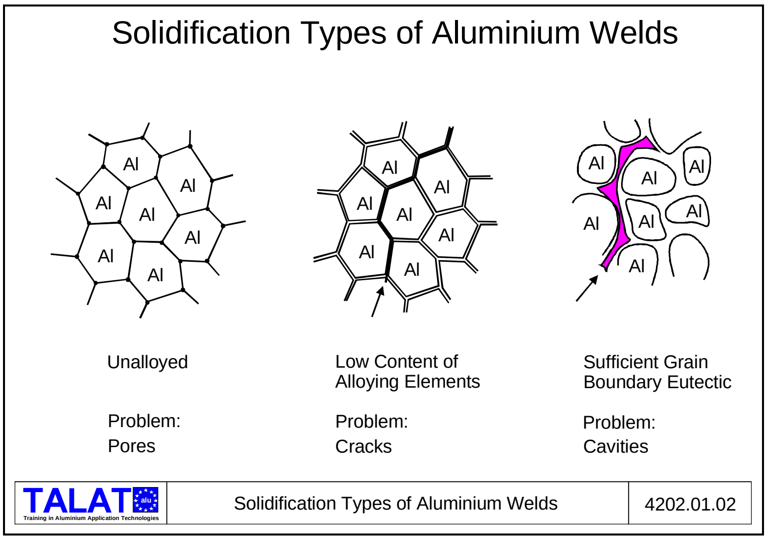
Compared to the non-heat-treatable alloys, the heat-treatable alloys (AlMgSi, AlZnMg) have a lower weldability. It is also not possible to use filler metals of the same composition as the base material (increased risk of cracking). Consequently, non-heat-treatable filler metals (e.g., S-AlMg4,5Mn, S-AlSi5) are used for welding heat-treatable alloys.

The presence of copper in the alloy beyond 0.25 % reduces the weldability.

Solidification Types of Aluminium Welds

Because of the rapid cooling of the molten weld pool, the filler metal used must be able to guarantee the strength and formability as well as to be able to counteract the risk of cracking due to shrinkage.Three solidification mechanisms are known:

- pure metal, no critical temperature interval
- little eutectic at the grain boundaries, critical temperature interval
- sufficient eutectic at the grain boundaries, no critical temperature

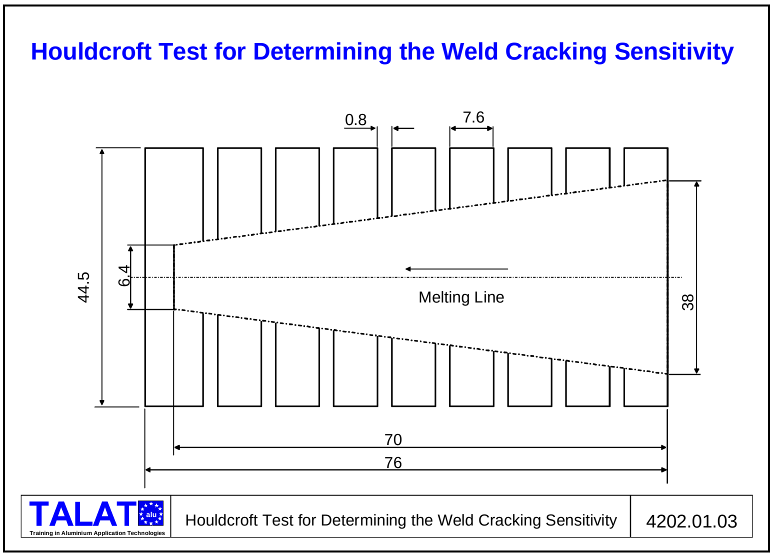


The filler metal must be chosen to ensure a sufficiently large amount of eutectic. Grain boundary movement leads to deformation and material separation. If enough eutectic is available, this can flow in and counteract these defects (**Figure 4202.01.02**).

For this reason, AlSi filler materials have a lower risk of cracking than the AlMgMn fillers, but with reduced strength.

Houldcroft Test for Determining the Weld Cracking Sensitivity

Numerous tests have been developed to determine the weld cracking sensitivity of aluminium alloys. The best-known test for sheets is the Houldcroft ("fish bone") test. This can be conducted with or without filler metals. The specimen consists of a rectangular plate with eight grooves cut to different depths on both sides (**Figure 4202.01.03**).



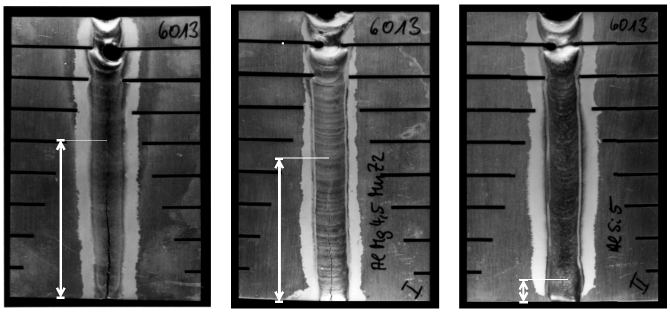
The specimen dimensions, distance between grooves as well as groove width and depth depend on the sheet thickness. At the starting end of the weld in the middle of one side, cracks can form and grow due to the somewhat higher stress existing here. The grooves reduce the stress in steps so that the crack stops growing. The length of the crack formed is an indication of the crack sensitivity of the aluminium alloy tested.

Houldcroft Test with Alloy 6013 T6 (AlMgSiCu)

The Houldcroft test is a simple and reliable test method for determining the hot cracking sensitivity of TIG welded aluminium alloys. When the Houldcroft test is applied to alloy 6013 it turns out to be extremely sensitive to hot cracking, see example in **Figure 4202.01.04**.

This alloy has a cracking sensitivity factor of A = 55 % during welding without filler metal. The upper limit for economical welding as determined using the Houldcroft test is normally about A = 35 %.
It is well known that using a filler metal with a suitable composition can help reduce hot cracking. The alloy 6013 shown in **Figure 4202.01.04** was welded both without a filler metal as well as with the filler metals S-AlMg4,5MnZr and S-AlSi5. The test showed that the filler metal S-AlMg4,5MnZr is not suitable for the alloy 6013 (A ≈ 46 %). With filler metal S-AlSi5 it was possible to attain a safe value of A = 9 %, so that this filler metal is recommended for the alloy 6013.

Houldcroft -Test with 6013 T 6 (AlMgSiCu)
2.5 mm Thick



Welding without Filler | Welding with Filler S-AlMg4,5MnZr | Welding with Filler S-AlSi 5

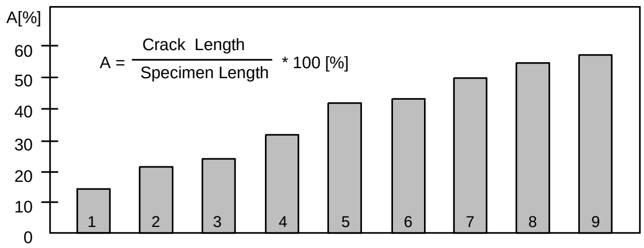
Source: SLV, Berlin

TALAT Training in Aluminium Application Technologies | Houldcroft - Test with Alloy 6013 T6 (AlMgSiCu) | 4202.01.04

Results of the Houldcroft Test for various Al Alloys

Nine aluminium alloys were tested and compared using the Houldcroft ("fish bone") specimen. The factor A (in %) is a measure for the hot cracking sensitivity, with the quotient A being equivalent to the ratio of the measured crack length to the total length of the specimen. A = 100 % means that the crack runs along the whole length of the weld. As can be seen in **Figure 4202.01.05**, the Al-Mg types of alloys have a low hot cracking sensitivity (A ≈ 15 %) and the Al-Cu-Zn-Mg alloys build the other extreme with high cracking sensitivities of A ≈ 80 % and higher.

Results of the Houldcroft Test for Various Alloys



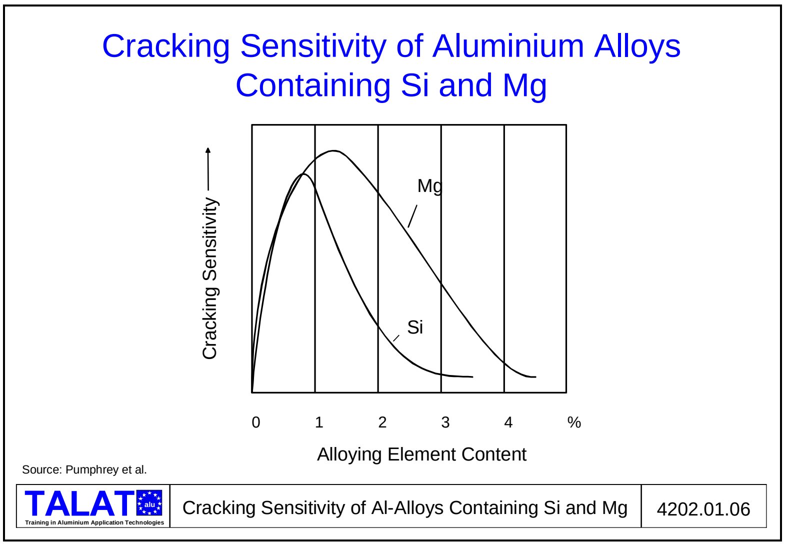
1- 5754 (AlMg)
2- 5056 (AlMg)
3- 5083 (AlMgMn)
4- 2219 (AlCuMn)
5- 6061 (AlMgSiCu)
6- 7020 (AlZnMg)
7- 3103 (AlMn)
8- 7075 (AlZnMgCu)
9- 2024 (AlCuMg)

Source: SLV Berlin

TALAT Training in Aluminium Application Technologies | Results of the Houldcroft Test for Various Alloys | 4202.01.05

Cracking Sensitivities of Aluminium Alloys Containing Si and Mg

The Si and Mg contents have a very pronounced effect on the weld cracking sensitivity. The heat-treatable alloys in particular have compositions which lie in the critical region. Consequently, these alloys are welded using non-heat-treatable filler metal alloys even though this tends to reduce the strength at the joint. The use of heat-treatable filler metal alloys has proved to be unsatisfactory (**Figure 4202.01.06**).



Cracking Sensitivities with Different Alloying Elements

In order to avoid a high cracking susceptibility, the Si content of Al-Si types of alloys should be greater than 2 %.

The corresponding value for Al-Mg types of alloys is about 3.5 % (**Figure 4202.01.07**).

Effects of Alloying Elements on Cracking Sensitivities

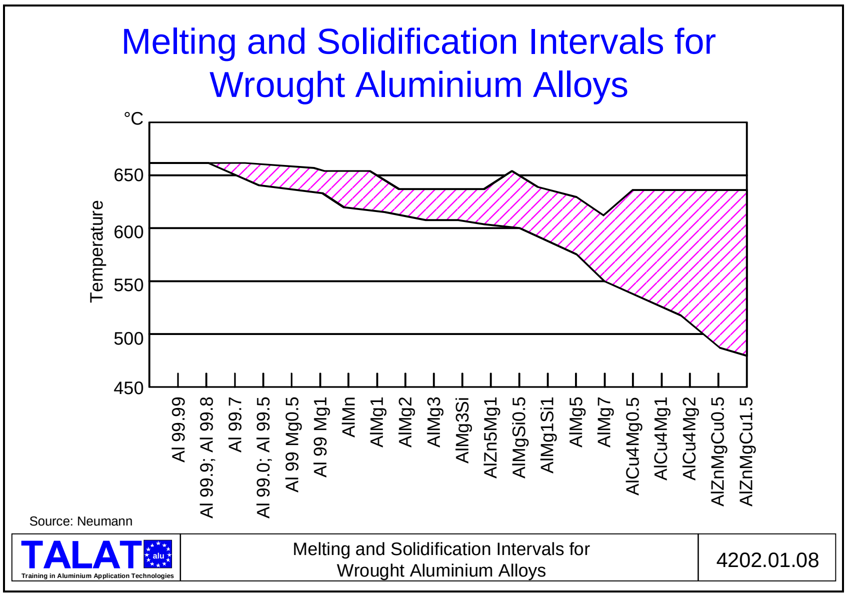
Alloy System	Max. Cracking Sensitivity at	Min. Content for Good Welding Behaviour	Critical Temperature Range
AlSi	0.75 % Si	2 % Si	660 to 577 °C
AlCu	3 % Cu	5 % Cu	660 to 547 °C
AlMg	1.2 % Mg	3.5 % Mg	660 to 449 °C
AlSiMg	0.5 % Si, 0.3 % Mg 0.5 to 0.8 % Si 0.2 to 1.2 % Mg	2 % Si 3.5 % Mg	

Source: Pumphrey a. o.

TALAT | Effects of Alloying Elements on Cracking Sensitivities | 4202.01.07

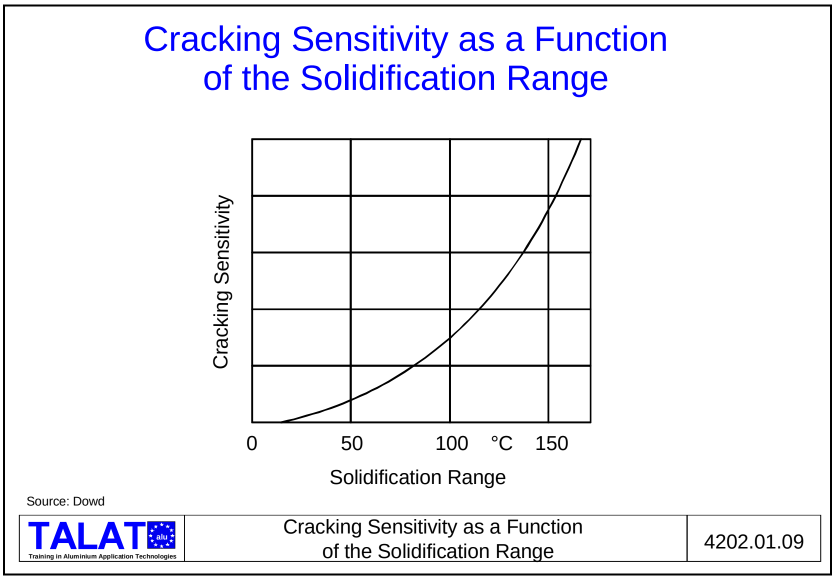
Melting and Solidification Intervals for Wrought Aluminium Alloys

The cracking susceptibility increases with increasing solidification range. Pure aluminium has no such solidification range and has, therefore, almost no crack sensitivity (**Figure 4202.01.08**).



Cracking Sensitivity as a Function of the Solidification Range

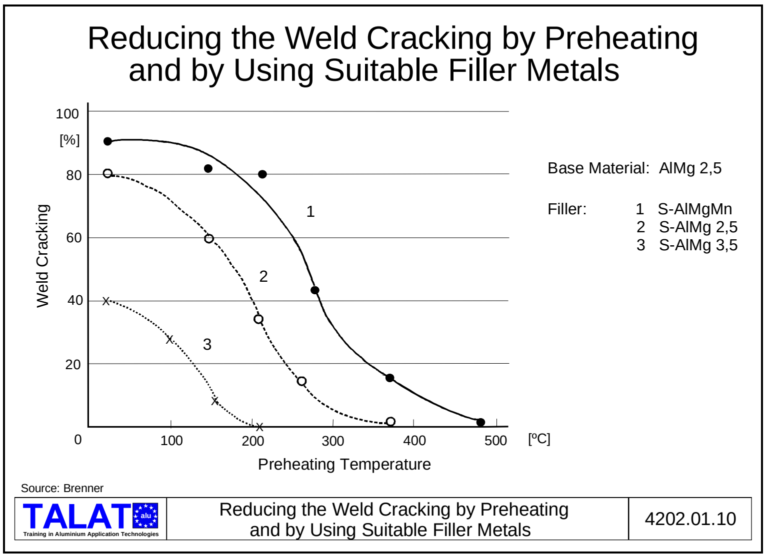
Aluminium alloys containing copper have solidification intervals of greater than 100 °C and are thus highly sensitive to cracking (**Figure 4202.01.09**).



Reducing Weld Cracking by Preheating and by Using Suitable Filler Metals

Besides the metallurgical possibilities, a number of other methods have been successfully employed to reduce the crack sensitivity (**Figure 4202.01.10**). These are:

- preheating the parts (especially recommended for thick sheets)
- an unhindered shrinkage of the parts (this reduces the dimensional and geometrical accuracy)
- low heat input (welding processes with higher welding rates and lower energy per unit length of weld)



4202.02 Filler Material

- ♦ Filler Metals for Aluminium

Filler Metals for Aluminium

Filler materials used can be divided into three groups containing silicium, copper or magnesium as the main alloying elements. Depending on the alloy, varying amounts of additives can be added, e.g. manganese, chromium, titanium as well as iron. Zirconium additions to the alloy 2319 improve the heat treatability and deliver a fine-grained structure (**Figure 4202.02.01**).

Filler Metals for Aluminium

Alloy	Si	Cu	Mn	Mg	Cr	Ti	V	Zr	Others
1050 A	0.30	0.05	-	-	-	0.05	-	-	0.40 Fe; 0.07 Zn
1080 A	0.15	0.02	-	-	-	0.03	-	-	0.15 Fe; 0.06 Zn
1100	-	0.12	-	-	-	-	-	-	min 99.00 Al
1188	-	-	-	-	-	-	-	-	min 99.00 Al
2319	-	6.30	0.30	-	-	0.15	0.10	0.17	-
3103	0.50	0.10	1.20	0.15	0.03	0.10	-	-	0.6 Fe; 0.2 Zn
4043 A	5.20	0.30	0.15	0.20	-	0.15	-	-	-
4047 A	12.20	0.05	0.25	0.05	-	0.15	-	-	-
4145	10.00	4.00	-	-	-	-	-	-	-
5183	-	-	0.75	4.70	0.15	-	-	-	-
5356	-	-	0.12	5.00	0.12	0.13	-	-	-
5554	-	-	0.75	2.75	0.12	0.12	-	-	-
5556 A	0.25	0.10	0.75	5.20	0.12	0.12	-	-	-
5654	-	-	-	3.50	0.25	0.10	-	-	-
5754	0.25	0.05	0.30	3.00	0.15	0.20	-	-	0.4 Fe; 0.2 Zn

TALAT — Filler Metals for Aluminium — 4202.02.01

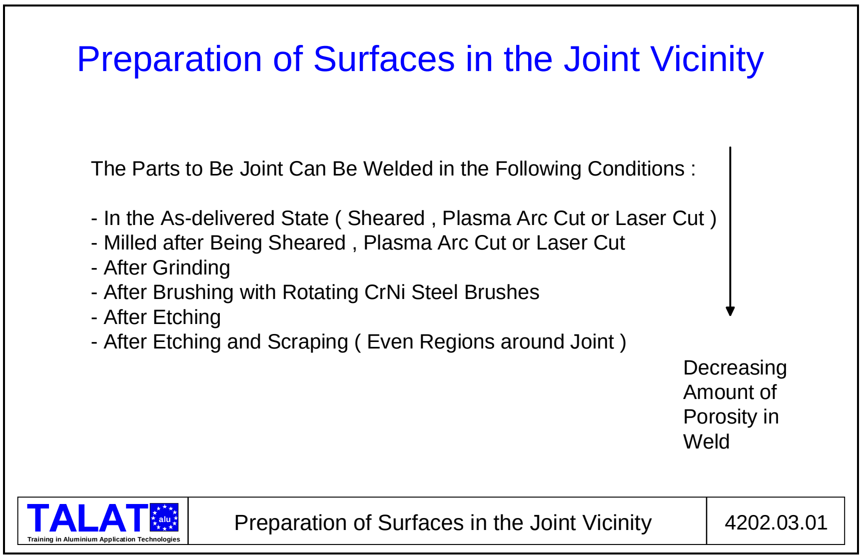
4202.03 Joint and Edge Preparation

- ♦ Preparation of Surfaces in the Joint Vicinity
- ♦ Joint Preparation for TIG Welding
- ♦ Joint Preparation for MIG Welding

Preparation of Surfaces in the Joint Vicinity

The cleanliness of the parts to be welded in the vicinity of the joint has a very pronounced effect on the welding results, this effect being greater than for steel welding.

Cleaning immediately before welding is very important. This reduces, in particular, the porosity.



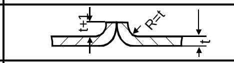
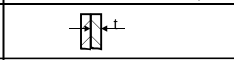
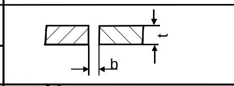
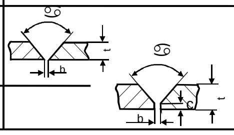
Mechanical or chemical methods are essential for high quality, reproducible welds (**Figure 4202.03.01**).

Joint Preparation for TIG Welding

Only flanged joint welds and edge joint welds can be produced in thin parts without the use of filler metals. If the alloys used have a high crack sensitivity, then it becomes necessary, even in these cases, to use an appropriate filler metal.

As in the case of steels, butt and fillet welds can be welded with filler metals after an appropriate edge preparation. Square butt joints can be one-sided welded up to 4 mm and double-sided welded up to 16 mm. The joint gap depends on the welding position as well as on the type of gas and current used. The Vee-angles used should be preferably 70°.

Joint Preparation For TIG Welding

Workpiece Thickness [t]	Welding Method	Joint from Cross - Section	Dimensions α, ß Degrees	Gap b	Web Height c
up to 2	One - Sided		-	-	-
up to 4	One - Sided		-	-	-
up to 4	One - Sided		-	0 to 1	-
4 to 16	Double - Sided		-	0 to 8	-
4 to 10	One - Sided or Double - Sided		90 to 100	0 to 1	up to 2
> 10	Double - Sided		60 to 70	0 to 4	ca. 3

TALAT | Joint Preparation For TIG Welding | 4202.03.02

During one-sided welding, the root edges should be slightly chamfered to prevent oxides from rising up and to hinder the formation of a concave (sucked-up) root surface.

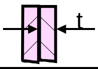
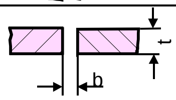
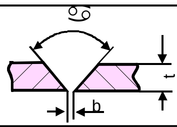
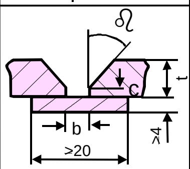
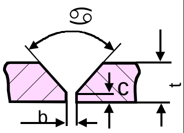
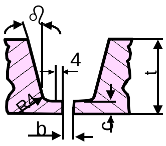
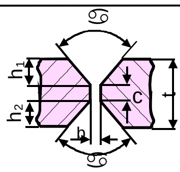
Extruded profiles can be designed with weld pool supporting webs, making it possible to use the one-sided welding method even for thicker parts. The edge is prepared either mechanically (cutting, turning, milling) or thermally (plasma, laser) (**Figure 4202.03.02**). European Standard (EN) for Joint Preparation is in preparation.

Joint Preparation for MIG Welding

Because of the higher melting power, MIG welding is more economical than TIG welding for welding thicker parts. The lower limit of sheet thicknesses which can be MIG welded is 2 mm. Weld pool supports (CrNi sections, ceramics) are necessary for thicknesses of up to ca. 6 mm because of the deeper penetration. Extruded profiles can be designed to incorporate such supports. Material thicker than ca. 4 mm should be welded using the double-sided welding method.

Edges are prepared either thermally (plasma arc or laser cutting) or mechanically (**Figure 4202.03.03**).

Edge Preparation For MIG Welding

Work-piece Thickness [t]	Welding Method	Joint from Cross - Section	Dimen- sions a ; ß Degrees	Gap b	Web Height c	Edge Height h
up to 4	One - Sided		-	-	-	-
2 to 4	One - Sided		-	0 to 2	-	-
4 to 16	Double - Sided		-	0 to 3	-	-
6 to 20	One - Sided or Double - Sided		50 to 70	0 to 2	up to 2	-
> 6	One - Sided		15 to 30	3 to 7	2 to 4	-
> 10	Double - Sided		50 to 70	-	2 to 6	-
> 10	One - Sided		up to 10	0 to 1	2 to 4	-
> 10	Double - Sided		50 to 70	0 to 2	3 to 4	$\frac{t - c}{2}$

TALAT alu Training in Aluminium Application Technologies	Edge Preparation for MIG Welding	4202.03.03

4202.04 Literature/References

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

Evrard, M.: Apprécation du risque de fissuration dans le soudage de alliages légers., Soud. et Tech. Conn. (1962), H. 4/5, p 85/98

-DIN 8552 T. 1 „Fugenformen und Maße für das WIG- und MIG-Schweißen von Aluminium (EN in preparation)

4202.05 List of Figures