TALAT Lecture 4500

Resistance Welding

23 pages, 25 figures

Basic Level

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Objectives:

– to describe the spot welding characteristics of aluminium and its alloys,
– the spot welding process,
– the choice of process parameters,
– strength values,
– electrode life and
– requirements for quality assurance

Prerequisites:

- general engineering background,
- metallurgy and physical properties of aluminium and
- surface characteristics (e.g. TALAT lecture 5101)

Date of Issue: 1994

4500 Resistance Welding

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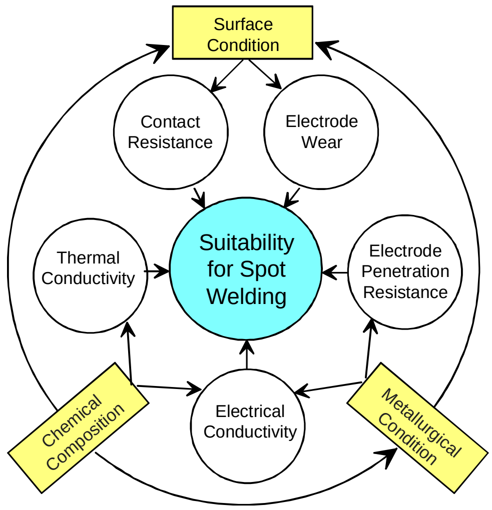
Suitability of Aluminium and its Alloys for Spot Welding

The suitability of aluminium and its alloys for spot welding depends mainly on 3 factors:

- surface condition
- chemical composition
- metallurgical condition.

Because of its high affinity to oxygen, the free surface of aluminium is covered by a dense, tightly adhering oxide film. This film is a non-conductor of electricity and must, therefore, be removed prior to welding. This is generally accomplished mechanically by brushing or chemically by etching. The oxide film, if it comes in direct contact with the contacting electrode, would lead to a local accumulation of heat at the contacting region and metal pick-up on electrode, i.e., the electrode life would be very limited.

Both electrical and thermal conductivity depend strongly on the chemical composition. The very good electrical conductivity of pure aluminium makes it necessary to use large currents. Consequently, both thermal stressing and electrode wear are high. The state of a metal, whether hard or soft, depends on its metallurgical condition. Cold worked aluminium can generally be better spot-welded than aluminium in a soft condition (**Figure 4500.01.01**).



Source: Leuschen

TALAT Training in Aluminium Application Technologies | Suitability of Aluminium and its Alloys for Spot Welding | 4500.01.01

Comparison of Physical Properties of Aluminium and Unalloyed Steel

The physical properties of the parts to be welded have a very strong effect on the quality of the joint. Thus, the electrical conductivity X of pure aluminium at 20 °C is 35 m/Ω mm² and can, depending on the purity and the content of alloying elements, fall down to 15 m/Ω mm² for other aluminium alloys. In contrast to this, the electrical conductivity of low alloyed steels is less than 9.3 m/Ω mm². Similarly, the thermal conductivity of aluminium alloys lies between 100 to 240 W/m K, i.e., about thrice as large as the corresponding value for steel (**Figure 4500.01.02**).

Comparision of Physical Properties of Aluminium and Unalloyed Steel (0.15%C) at RT

Material Designation	Density (g/cm³)	Melting Range (°C)	Electrical Conductivity (m/Ωmm²)	Thermal Conductivity (W/mK)	Coeff. of Thermal Expansion (10^{-6} K^{-1})
Al 99.5	2.70	646-657	34-36	210-220	23.5
AlMn	2.73	645-655	22-28	160-200	23.5
AlMg1	2.69	630-650	23-31	160-200	23.6
AlMgSi0.5	2.70	585-650	28-34	200-240	23.4
AlMgSi	2.70	585-650	24-32	170-220	23.4
AlMg0.4Si1.2	2.70	590-650	26-30	160-190	23.4
AlCuMg1	2.80	512-650	18-28	130-200	23.0
AlMg3	2.70	580-650	16-24	110-170	23.0
AlMg5	2.60	560-630	15-22	100-160	23.0
AlMg4.5Mn	2.66	574-638	16-19	110-140	24.2
C-Steel	7.85	1510	9.3	50	11.0

TALAT Training in Aluminium Application Technologies | Comparision of Physical Properties of Aluminium and Unalloyed Steel (0.15%C) at RT | 4500.01.02

Due to the high thermal conductivity of aluminium, a large portion of the heat created is absorbed by the cooled electrode and the surrounding material. Consequently, a stationary state of equilibrium between the heat input and output is reached within a short welding time. For this reason, it is essential that the welding energy for aluminium be delivered within as short a time as possible. Thus, the current required for welding aluminium is about twice that for welding steel sheets of the same thickness, and this although the aluminium alloys have a much lower melting point.

Resistances during Spot Welding of Steel and Aluminium

The formation of the weld nugget depends mainly on the current strength, the resistance and the welding time. The heat generated can be calculated using Joule's law:

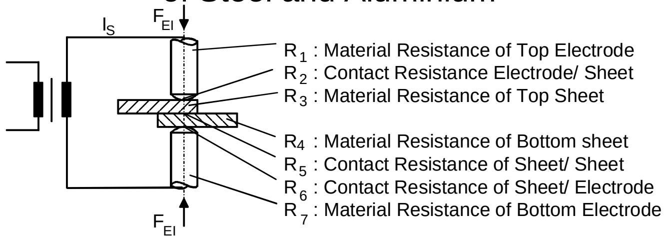
$$Q = 0.23 \cdot I^2 \cdot R \cdot t$$

where

Q = amount of heat
I = current
R = electrical resistance
t = time

The total resistance is made up of the contact resistances and the material resistances. The material resistances of the sheets and the contact resistances between the sheets themselves and between sheet and electrode have very different orders of magnitude for aluminium and steel. The welding parameters (current, time, force) have thus to be adapted for the higher electrical and thermal conductivities of aluminium.

Resistance During Spot Welding of Steel and Aluminium



Resistance at Start of Welding	Steel	Aluminium
R_1, R_7 .	Negligibly Small	
R_2, R_4, R_6 .	Small	Large
R_3, R_5 .	Large	Small

F_{El} : Electrode Force
I_S : Welding Current

Source: Leuschen

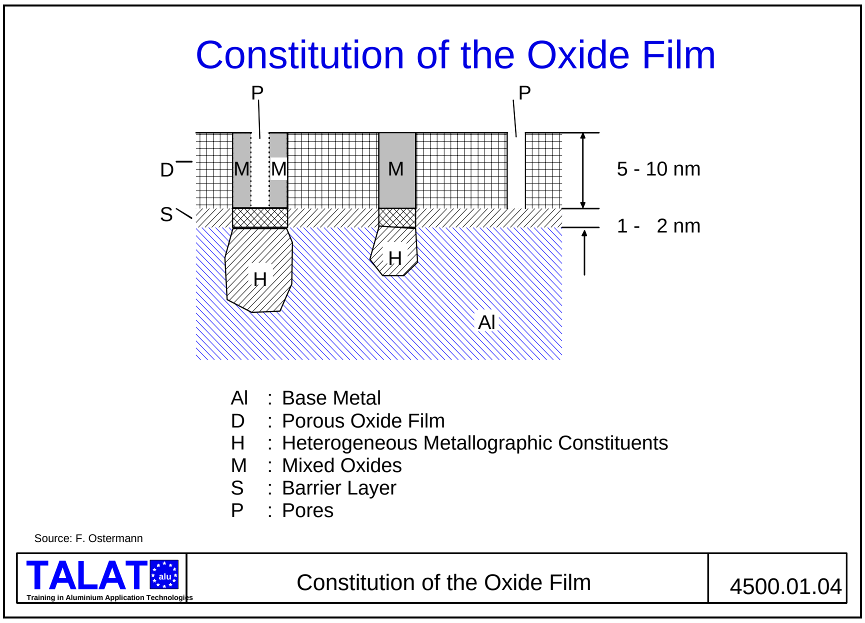
TALAT	Resistance During Spot Welding of Steel and Aluminium	4500.01.03

An intensive cooling of the electrodes is of paramount importance to avoid any electrode metal pick-up tendency.

Due to the low resistance of the material aluminium, the spot welding must be carried out with high welding currents within short welding times using a special electrode force programme (**Figure 4500.01.03**).

Constitution of the Oxide Film

The high affinity of aluminium for oxygen, which causes metallic blank aluminium to be covered at once with a thin, dense and tightly adhering oxide film, has a major effect on the suitability of aluminium for spot welding. The oxide film has a high thermal stability and a melting temperature of over 2,000°C and is a non-conductor of electricity. Diffusion processes govern the formation and growth of this oxide film; its thickness increases in proportion to the square-root of time.



The oxide film consists of an almost pore-free barrier layer and a covering porous oxide layer. The typical thicknesses lie between 0.005 and 0.01 µm (**Figure 4500.01.04**).

During welding, the high electrode contact pressure causes the sheet surfaces to be deformed locally. This causes the brittle oxide film to crack, so that the welding current can now flow through the fine contact bridges; due to the heat developed and the continuing deformation, the contact bridges are enlarged, causing the contact resistance to fall rapidly.

Surface Pretreatment

Chemical surface pretreatment is more suitable than mechanical surface pretreatment for large aluminium surfaces. It consists of the following steps:

- cleaning
- drying
- etching
- rinsing
- passivation and rinsing
- drying

Most of the etchants used also attack the metallic aluminium once the oxide skin is removed and, if the contact time is long enough, form a new coating layer which once again increases the contact resistance. Therefore, the etching parameters must be strictly adhered to and followed by a thorough rinsing by spraying with cold or warm (preferably deionised) water (**Figure 4500.01.05** and **Figure 4500.01.06**).

Chemicals	Etching Conditions					Remarks
1. Sodium Hydroxide (NaOH)	Composition Temperature Time	1.1 50g/l RT 2min	1.2 50g/l 60°C 1min	1.3 50g/l 60°C 2min	1.4 200g/l RT 1min	Not Suitable for G-AlSi and G-AlSiMg. Neutralise after etching in ca. 30% HNO_3
	Composition Temperature Time	1.5 200g/l RT 2min	1.6 200g/l 60°C 1min	1.7 200g/l 60°C 2min		
2. (Na_2CO_3) + Sodium Fluoride (NaF)	Composition Temperature Time	2.1 75g/l 20g/l 50°C 30sec	2.2 75g/l 20g/l 50°C 2min			Only for Cu and Si contents of 1%
3. Sulphuric Acid (H_2SO_4) 95% + Sodium Fluoride (NaF)	Composition Temperature Time	3.1 100g/l 15g/l RT 4min	3.2 100g/l 15g/l RT 4min			As required, dip in 50% HNO_3 to remove deposit
4. Nitric Acid (HNO_3) 66% + Hydrofluoric Acid (HF) 40%	Composition Temperature Time	4.1 1050g/l 280g/l RT 8sec	4.2 1350g/l 23g/l RT 50sec	4.3 91g/l 0.5g/l RT 5.5sec		

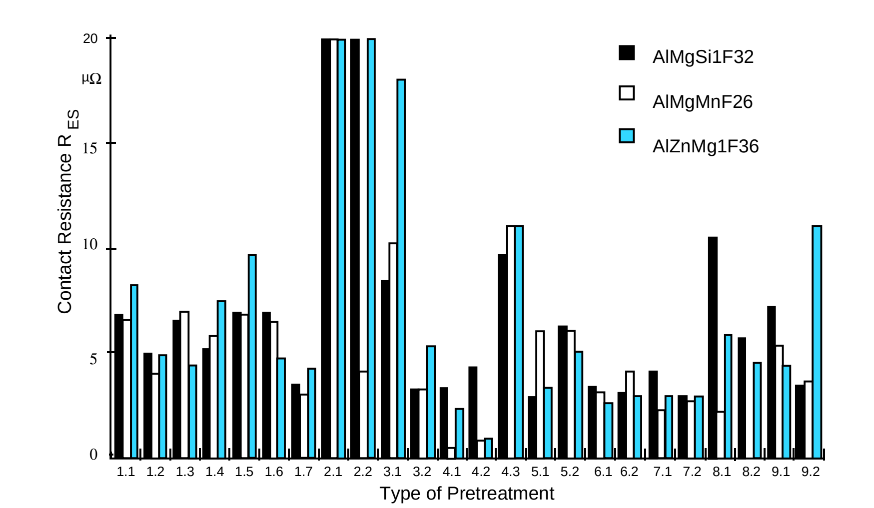
TALAT Training in Aluminium Application Technologies | Surface Pretreatment I | 4500.01.05

Chemicals	Etching Conditions					Remarks
5. Hydrofluoric Silic Acid (H_2SiF) 32.5%	Composition/ Temperature/ Time	5.1 8.7g/l RT 3min	5.2 38.7g/l RT 9min			
6. Sulphuric Acid (H_2SO_4) 95% + Chromium Trioxide (CrO_3)	Composition/ Temperature/ Time	6.1 35g/l 148g/l 55°C 20min	6.2 100g/l 5g/l 60°C 20min			
7. C-Phosphoric Acid (H_3PO_4) 85% + Butanol ($CH_3(CH_2)OH$) + Propanol ($CH_3CH(OH)CH_3$)	Composition/ Temperature/ Time	7.1 171g/l 324g/l 234g/l RT 7.5min	7.2 171g/l 324g/l 234g/l RT 20min			As Required, Dip in ca. 30% HNO_3 to Remove Deposits
8. O-Phosphoric Acid (H_3PO_4) 85% + Potassium Dichromate ($K_2Cr_2O_7$)	Composition/ Temperature/ Time	8.1 40g/l 0.4g/l 25°C 10min	8.2 40g/l 0.4g/l 25°C 35min			
9. O-Phosphoric Acid (H_3PO_4) 85% + Nitric Acid (HNO_3)	Composition/ Temperature/ Time	9.1 1360g/l 49g/l 90°C 2min	9.2 1360g/l 49g/l 90°C 5min			

TALAT — Surface Pretreatment II — 4500.01.06

Contact Resistance after Surface Pretreatment

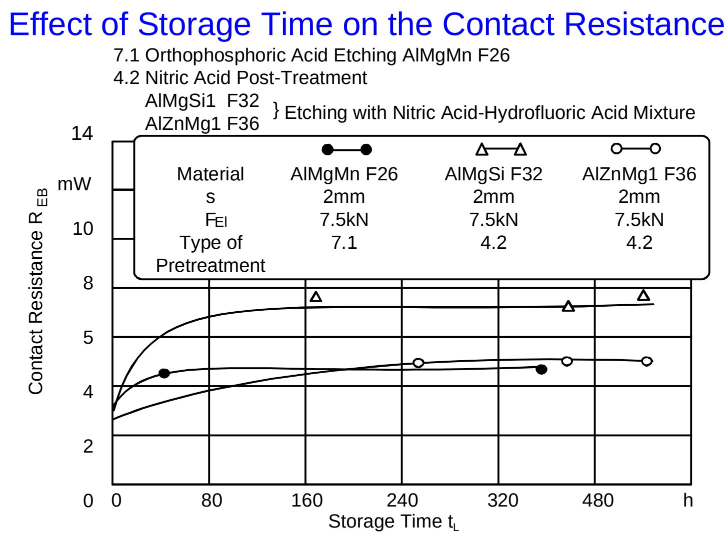
A proper surface pretreatment can reduce the contact resistance between electrode and sheet to values between 3 and 50 µΩ (**Figure 4500.01.07**). Alkaline solutions, e.g., 10 to 20 % sodium hydroxide solution and mixed acids, are the most commonly used etchants. The acids added to the solution inhibit the aggressive surface reaction of the sodium hydroxide solution, making an exact adherence to the optimum etching time less critical. Ready-for-use etching solutions save the step of preparing such solutions and can even be applied locally with a brush or sponge.



TALAT — Contact Resistance after Surface Pretreatment — 4500.01.07

Effect of Storage Time on the Contact Resistance

In some cases, the etching step is followed by a post-treatment in 20 to 50 % nitric or ortho phosphorous acid. This treatment removes any excess etchant residues from the surface which, if not removed, could lead to harmful deposits, like for example, the deposition of copper during the etching of copper-containing alloys. Another effect is to create a uniform thin oxide film (< 0.01 µm). This ensures that the contact resistance values have low scatter from the very beginning, and that this value changes little even during long storage times due to the dense surface covering layer (**Figure 4500.01.08**).



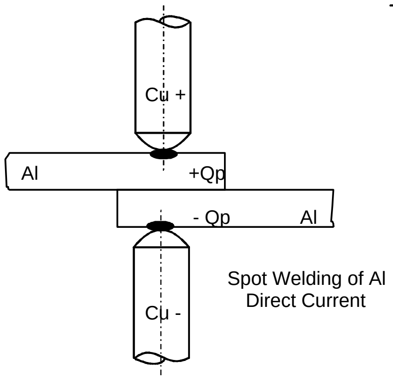
TALAT | Effect of Storage Time on the Contact Resistance | 4500.01.08

Immediately after the last rinsing step, the parts must be dried with warm air, in order to prevent the formation of flecks which could increase the contact resistance and electrode metal pick-up tendency. A sure method of preventing formation of flecks is by dipping the rinsed sheets in methanol before drying them with hot air.

Peltier Effect (Schematic)

During direct current welding, the Peltier effect occurs, causing a larger electrode wear at the anode than at the cathode. This effect is caused by the heat consumed during transfer of electricity at the contact cathode-sheet and the heat released at the contact anode-sheet. This difference in reactions is caused by the corresponding positions of aluminium and copper in the electrochemical potential series. The additional heat released at the anode leads to a higher thermal stressing and to lower electrode life (**Figure 4500.01.09**).

Peltier Effect (Schematic)



Element	Voltage (V)
K	-2.925
Na	-2.713
Mg	-2.37
Al	-1.66
Zn	-0.763
Fe	-0.440
Cd	-0.402
Ni	-0.23
Sn	-0.140
Pb	-0.126
H_2	0.000
Cu	+0.337
Ag	+0.799
Pt	+1.20
Au	+1.50
F	+2.87

Electrochemical Potential Series
Based on Hydrogen Electrode at 25°C

Source: Leuschen

TALAT Training in Aluminium Application Technologies | Peltier Effect (Schematic) | 4500.01.09

In order to minimise this effect, welding machines have been developed in which the electrode polarity is changed after each spot weld.

Characteristics of Differently Designed Spot Welding Machines

Besides the commonly used single-phase welding machines for spot welding, one also now has the three-phase welding machines which can deliver the high currents required. The latter work either according to the frequency conversion principle or with secondary rectification. Thus the following requirements can be much better fulfilled:

- reduction of power requirements
- improvement of the power factor cos φ
- reduction of the unbalanced power loading.

The construction of a single-phase alternating current machine is simple but leads to an unsymmetrical (unbalanced) power loading at high energies and possesses a low power factor. Another disadvantage is the limited sheet thickness which can be welded.

Modern high-energy spot-welding machines are constructed nowadays as three-phase machines with their typical low power requirements and high power factors. Using these machines, it is possible to weld sheets up to 6 mm in thickness (**Figure 4500.01.10**).

Characteristics of Differently Designed Spot Welding Machines

	Single Phase AC	Three Phase Frequency Changer	Three Phase Rectifier
Welding Current	Phase Cut Sinus Current (50Hz)	Pulsed Current	DC with Rest Waviness
Grid Loading	Two-Phase	Two-Phase with Cyclic Alternation	Three-Phase
Power Requirement	High	Low	Low
Power Factor	0.4-0.7	0.8-0.9	0.9
Maximum Weldable Al SheetThickness	3 + 3	6 + 6	6 + 6

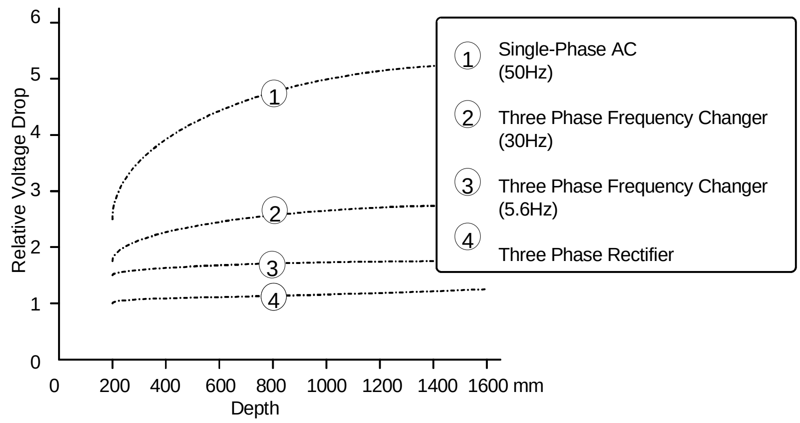
TALAT Training in Aluminium Application Technologies | Characteristics of Differently Designed Spot Welding Machines | 4500.01.10

Relative Voltage Drop of a Resistance Welding Machine

A comparison of the weld throat depths of machines of different constructions, clearly shows the disadvantage of the single-phase alternating current machine. The voltage drop here is about 3 to 6 times higher (**Figure 4500.01.11**).

This fact must be taken into account, especially when large amounts of ferro-magnetic materials, e.g., clamping and transporting arrangements, reach into the secondary window.

Relative Voltage Drop of a Resistance Welding Machine

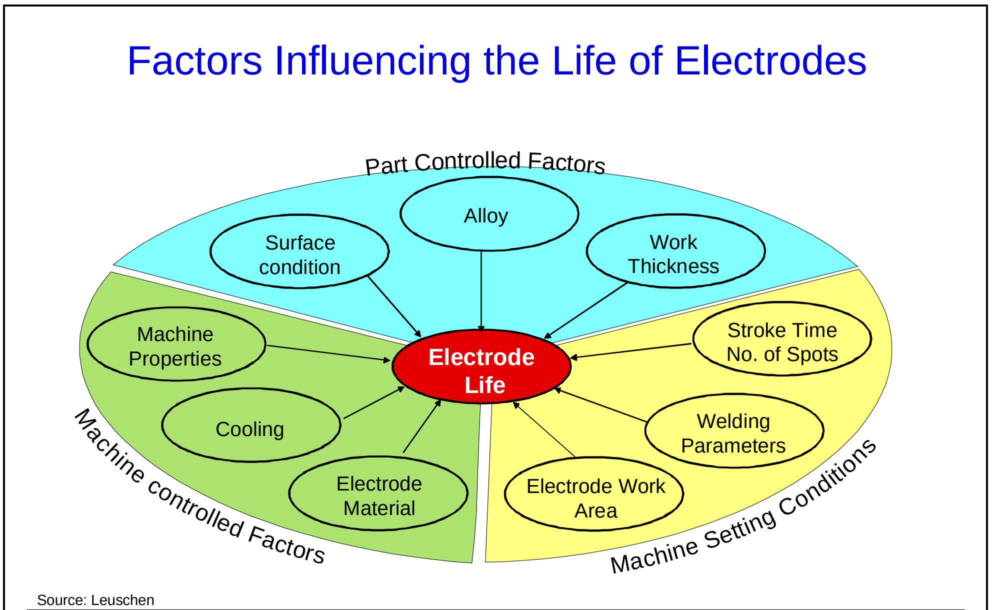


TALAT Training in Aluminium Application Technologies | Relative Voltage Drop of a Resistance Welding Machine | 4500.01.11

Factors Influencing the Life of Electrodes

The regulating and controlling possibilities, the welding machine and the parts to be welded have a strong influence on the life of the electrodes. Reducing the electrode metal pick-up is of great importance and can be influenced by having a uniform surface condition obtained through the use of mechanical and chemical pretreatments. This can be best controlled by measuring the contact resistance between electrode and sheet.

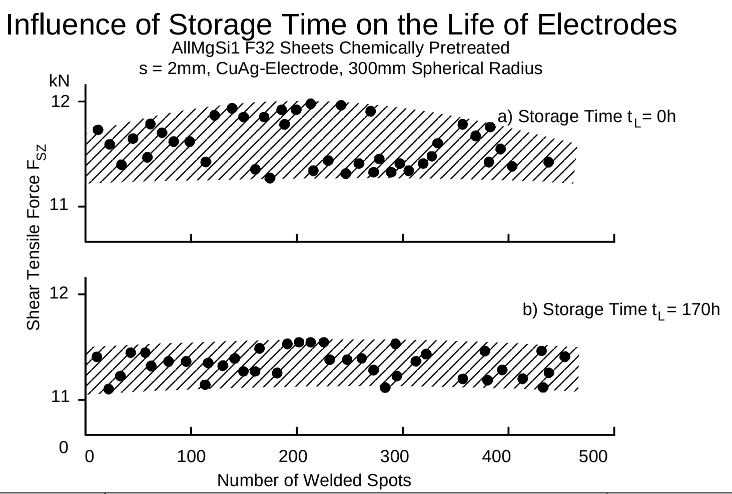
The regulating and controlling possibilities of the welding machine, e.g., chronological programming of current and force, the resetting behaviour of the electrodes as well as cooling of the electrode, affect the stroke frequency and consequently the number of possible weld spots. The higher stroke frequency of roll seam welding necessitates a direct external cooling of the electrodes (**Figure 4500.01.12**).



Factors Influencing the Life of Electrodes 4500.01.12

Influence of Storage Time on Life of Electrodes

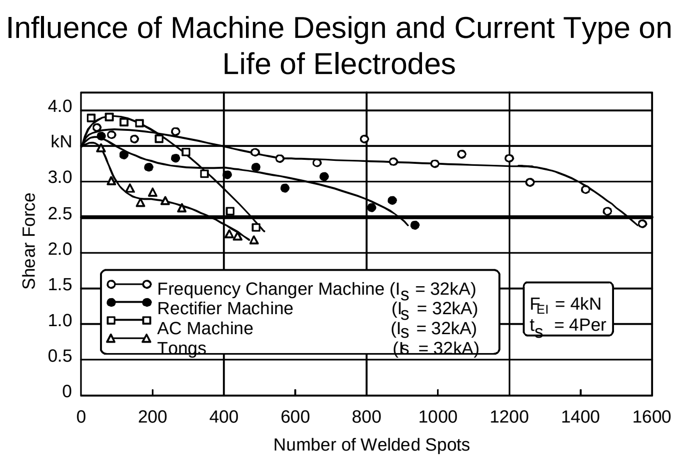
With suitable chemical surface pretreatments, the sheets retain their suitability for welding over long periods of time, i.e., the attainable life of electrodes also remains unchanged. In spite of this, efforts must be undertaken to keep the storage time as low as possible in order to avoid problems caused by dust dirtying the surface of the sheets (**Figure 4500.01.13**).



TALAT | Influence of Storage Time on the Life of Electrodes | 4500.01.13

Influence of Machine Design and Current Type on Life of Electrodes

Since the energy input of direct current machines is more uniform and occurs without current surges (peaks), higher electrode lives can be obtained than with alternating currents. The life of the electrodes can be further enhanced by changing the polarity of the electrodes after each weld spot, thereby reducing the Peltier effect and having a more uniform wear. Stationary equipment with a higher stiffness also have longer electrode lives than spot welding tongs (**Figure 4500.01.14**).



Source: Leuschen

TALAT | Influence of Machine Design and Current Type on Life of Electrodes | 4500.01.14

The distortion in the tong arms gives rise to an added frictional effect in the contact region electrode-sheet. Similar effects occur when the electrodes are arranged slantingly.

4500.02 The Process of Resistance Spot Welding

- Current-force diagram for spot welding aluminium
- Recommended values for spot welding with direct current
- Example of a field of suitable welding parameters
- Minimum values for spot welding aluminium parts
- Effect of weld spot diameter on the shear strength
- Correlations between pretreatment, weld strength and electrode life
- Repeated tensile stress fatigue strength of one spot samples
- Fatigue tests using specimens similar to engineering part
- Fatigue strength of spot welded 1.6 mm thick 2024 cl sheets

Current-Force Diagram for Spot Welding Aluminium

A current-force programme in which both parameters change with time, is used to produce welds of high quality.

An initial force is applied to ensure a good contact between sheet and electrode, thereby reducing the contact resistance. The force is then lowered, i.e., the contact resistance between the sheets increases, and the current is allowed to flow.

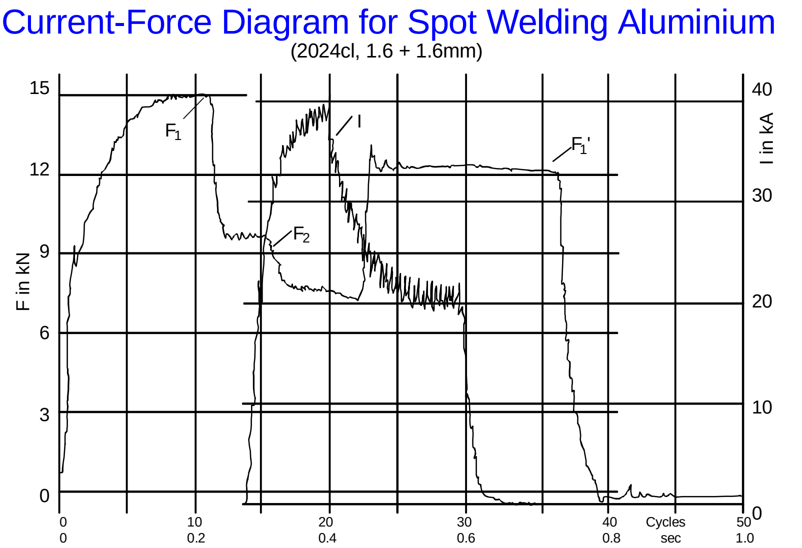
The rate of current increase (up slope), amplitude, time and current decrease rate (down slope) can be regulated to suit the alloy to be welded.

Heating of the metals during current flow causes these to soften, so that the force decreases. Shortly after the maximum current is reached, the force is increased to press the sheets against each other (forging effect). Similar programmes are mandatory for welding in the aerospace industry (**Figure 4500.02.01**).

Guidelines are available for the spot welding of a large number of aluminium alloys. The parameters stated in the guidelines depend, among others, on the surface condition and roughness, type of current, material thickness as well as form of electrodes and material.

The currents used for aluminium are much higher than those required for spot welding steel, making it necessary to utilise machines with a higher power rating for spot welding aluminium.

The type of material used for the electrodes has a significant influence on the operational life. Experience has proved that material strength and hardness are of greater importance than the electrical conductivity.



Source: SLV Berlin

TALAT | Current-Force Diagram for Spot Welding Aluminium | 4500.02.01

Recommended Values for Spot Welding with Direct Current

Because of differences in the characteristic physical and mechanical values of steel and aluminium, a different set of parameters has to be used for the spot welding of these materials. Because of the high thermal conductivity of aluminium, the welding times chosen should be as short as possible to prevent the formation of a stationary state of equilibrium in which the input heat is absorbed by the material and is thus no longer available for the formation of the weld nugget. Consequently, this means that very high welding currents have to be used (**Figure 4500.02.02**). The welding machines take this fact into account and are designed for the proper power ratings. Since aluminium has a lower hardness than steel, the electrode forces required for spot welding are lower. High forces would cause unallowable electrode indentations in the aluminium

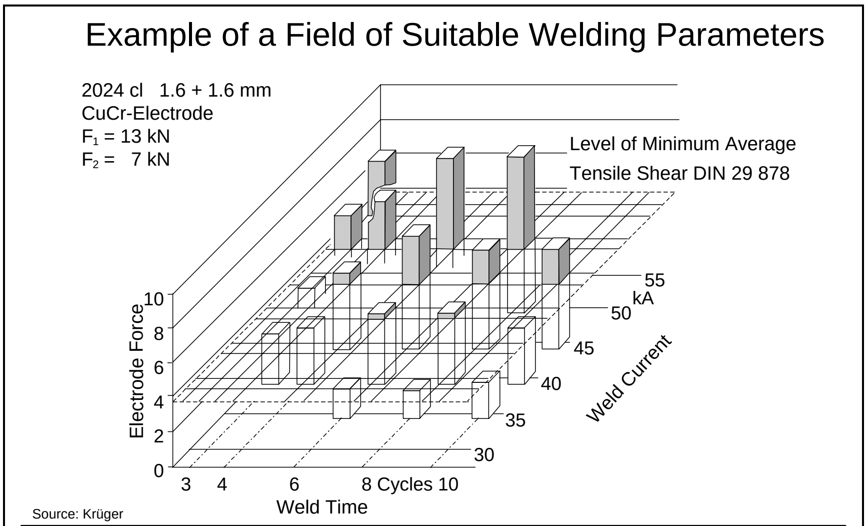
Sheet Thickness mm / Values Set	0.35	0.5	0.8	1.0	1.25	1.5	2.0	2.5	3.0	3.5
Electrode Diameter mm	16	16	16	16	16	20	20	20	25	25
Electrode Spherical Radius / mm	75	75	75	75	100	100	100	100	100	150
Electrode Force kN	1.5	1.8	2.2	3.0	3.5	4.0	5.0	6.5	8.0	10.0
Welding Current kA	18-22	19-24	24-30	25-32	26-34	27-35	30-38	34-42	38-45	44-50
Welding Time Per	2	2	3	3	4	5	6-8	7-9	8-10	9-12
Weld Nugget Diameter / mm	3.0	3.5	4.5	5.0	5.5	6.0	7.0	8.0	8.5	9.5
Weld Spot Diameter / mm	3.5	4.0	5.0	5.5	6.0	6.5	7.7	8.7	9.3	10.3

Source:DVS Pamphlet 2932 T.3

TALAT | Guide Values for Spot Welding with Direct Current | 4500.02.02

Example of a Field of Suitable Welding Parameters

The welding parameters depend on the most appropriate correlations between current, time, force and weld strength. These are determined experimentally in test series in which constant and variable parameters are chosen. The appropriate welding data which delivers the required standard weld strengths can thus be determined (**Figure 4500.02.03**).



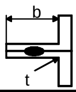
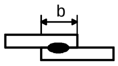
Example of a Field of Suitable Welding Parameters 4500.02.03

Minimum Values for Spot Welding Aluminium Parts

Analogous to the parameter settings, geometrical values like weld spot and nugget diameter as well as distance from edge depend on the material. The amount of overlap and the distance between the weld spots depend on the electrical conductivity of the work material, i.e., the distance chosen between the weld spots increases with increasing electrical conductivity.

The diameters of weld spot and weld nugget depend on the electrode geometry and on the number of weld spots. Therefore, the effect of increasing electrode diameter on the weld spot strength must be regularly controlled. The minimum strengths are laid out in the appropriate regulations (**Figure 4500.02.04**).

Minimum Values for Spot Welding Aluminium Parts

Material	AlMg5Mn							AlMg0.4Si1.2						
Sheet Thickness t	1.0	1.15	1.25	1.5	2.0	2.5	3.0	1.0	1.15	1.25	1.5	2.0	2.5	3.0
Min. Weld Nugget Diameter d_L	4.0	4.3	4.5	4.9	5.7	6.3	6.9	4.5	4.8	5.0	5.5	6.3	7.1	7.8
Min. Weld Spot Diameter d_p	4.4	4.7	5.0	5.4	6.3	7.0	7.6	5.0	5.3	5.5	6.0	7.0	7.8	8.6
Min. Distance from edge v	5.5	5.9	6.3	6.8	7.9	8.8	9,5	6.3	6.6	6.9	7.5	8.8	9.8	10.8
 Electrode Diameter d_E	16				20			16				20		
Min. Flange Width	17.5	18.0	19.0	19.5	23.5	25.0	26.5	18.5	19.0	19.5	20.0	24.5	26.0	27.5
 Electrode Diameter d_E	16				20			16				20		
Min. Overlap	13.0	14.0	14.5	15.5	18.0	19.5	21.0	14.5	15.5	16.0	17.0	19.5	21.5	23.5
All Values in mm	$d_L \geq 4.0*\sqrt{t}$							$d_L \geq 4.0*\sqrt{t}$						

$d_p = 1.1*d_L$ $v \geq 1.25*d_p$ $b \geq d_E / 2 + r + v + x$ $r = 1.5*t$ $ü = 2*v+y$

x = Flange Width Tolerance + Flange Misalignment + Electrode Misalignment = 2.5

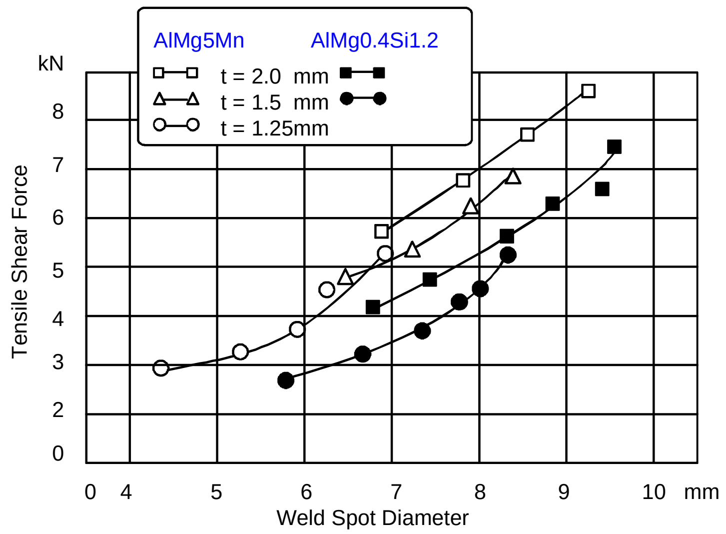
y = Sheet Misalignment + Electrode Misalignment = 2.0

Source: Leuschen

TALAT Training in Aluminium Application Technologies | Minimum Values for Spot Welding Aluminium Parts | 4500.02.04

Effect of Weld Spot Diameter on the Shear Strength

The load-carrying capacity of the joint depends on the weld spot diameter. Depending on the welded materials, weld spot diameter and shear strength increase proportionally (see **Figure 4500.02.05**). Heat-treatable alloys which have been age hardened, lose this hardening effect in the heat affected zone of the weld. A heat treatment of such components is, in principle, possible but its practical use is strongly limited by the part size and possible distortion expected. Therefore, the unavoidable loss in strength is compensated for by increasing the weld spot diameter. Larger weld spot diameters are necessary to attain the required shear strength with softer materials.



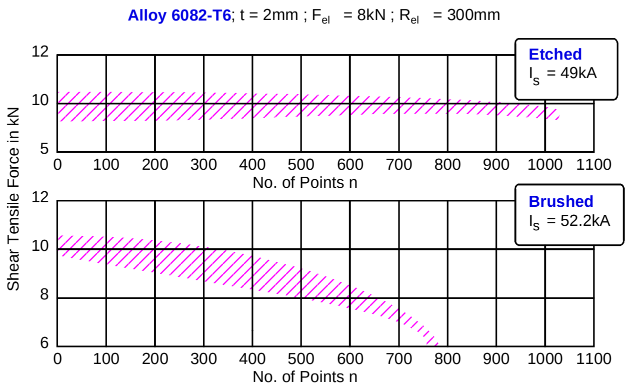
Source: Leuschen

TALAT | Effect of Weld Spot Diameter on Tensile Shear Strength | 4500.02.05

Correlations between Surface Pretreatment, Weld Strength and Electrode Life

The mechanical pretreatment can be carried out with simple equipment and does not require any special rooms. The softer alloys (pure aluminium, AlMn) tend to "smear" easily so that proper care must be taken while working with them. The same care must be taken for plated alloys, in order to prevent a mechanical removal of the thin plating. Small areas can be mechanically pretreated with hand-held or rotating (ø > 200 mm) brushes made of stainless steel or also with steel wool. Grinding is carried out using grinding wheels or grinding bands. Abrasive powder with uniform particle size is used to obtain a fine surface finish. Overheating is prevented by using moderate grinding pressures, appropriate operating speeds (30 to 40 m/min) as well as by introducing additives (fat, paraffin) to the abrasive powder.

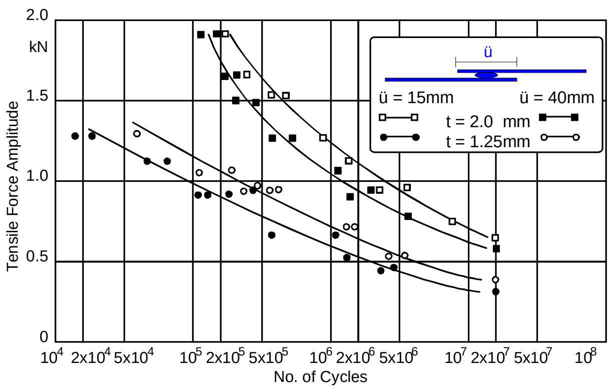
A disadvantage of mechanical surface pretreatments is the roughening of the surface. The contact resistance can only be reduced down to 50 to 100 µΩ, the associated heating at the interface electrode/sheet surface leads to electrode metal pick-up. The mechanical pretreatment produces an active surface which oxidises rapidly to form a new oxide film. Consequently, the contact resistance rises sharply within short storage times, increases of 20 µΩ occurring within about 20 min (**Figure 4500.02.06**).



Correlations between Surface Pretreatment, Weld Strength and Electrode Life | 4500.02.06

Repeated Tensile Stress Fatigue Strength of One-Spot Samples

The fatigue behaviour of materials can be ascertained at values of 2 x 10^7 cycles and more. Weld defects like pores and cavities which are not located at the weld nugget edges have hardly any influence. Cracks and reductions in cross-section due to too high electrode pressures, reduce the fatigue strength sharply. The amount of overlap also has a significant effect on the fatigue behaviour (**Figure 4500.02.07**).

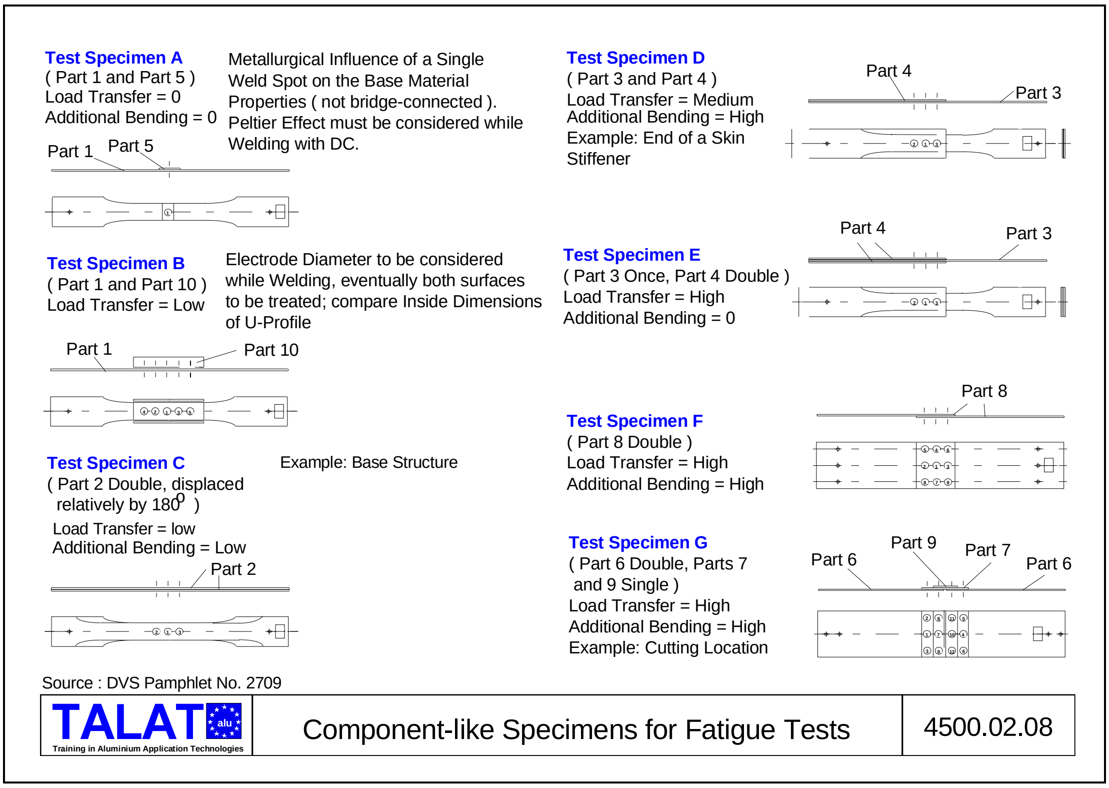


Source: Leuschen

Fatigue Strength of Single-Spot Welded Samples | 4500.02.07

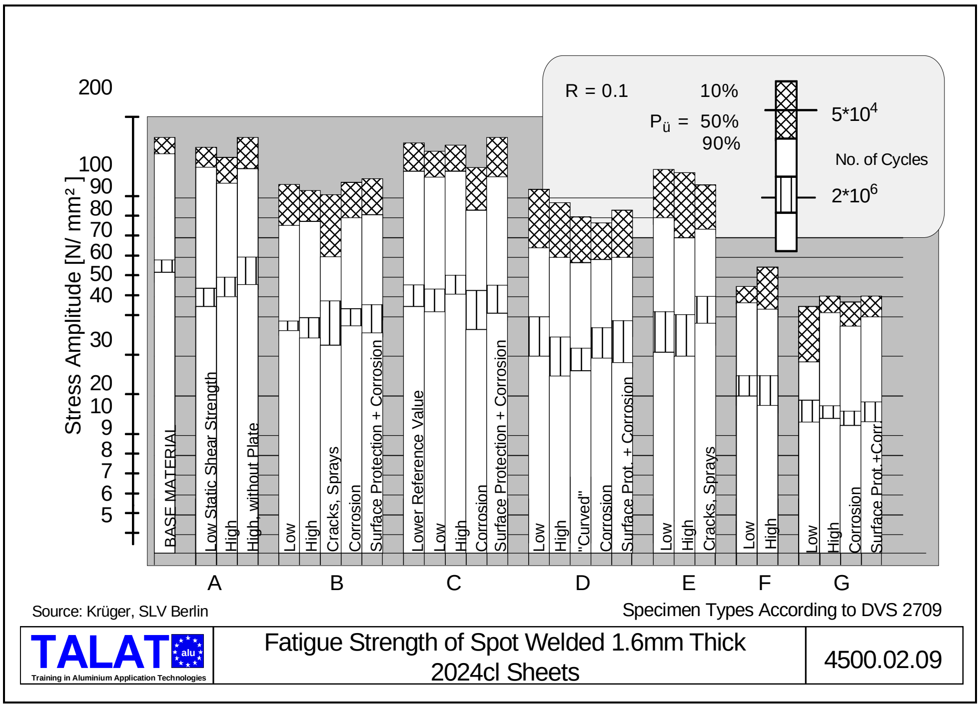
Fatigue Tests Using Specimens Similar to Engineering Parts

The results of fatigue tests can only be compared using standardised specimen forms. The load transfer and additional bending are decisive factors for single and double layered joints. The specimens have to be prepared singly, i.e., they may not be taken out of the sheet or the constructional part. The welding is carried out using special arrangements, and the welding procedure must always be recorded (**Figure 4500.02.08**).



Fatigue Strength of Spot Welded 1.6 mm Thick 2024 cl Sheets

Experiments have shown that the effect of specimen form on the fatigue strength is much greater than that of other variables like lower or higher current, cracks, corrosion etc. The effect of the added bending due to specimen form is clearly visible. Therefore, a careful evaluation of the results is essential (**Figure 4500.02.09**).



4500.03 Quality Assurance

- Allowable imperfections of spot welds in aluminium alloys (according to aeronautical standards) determined by metallography
- Allowable imperfections of spot welds in aluminium alloys (according to aeronautical standards) determined by x-ray examination.

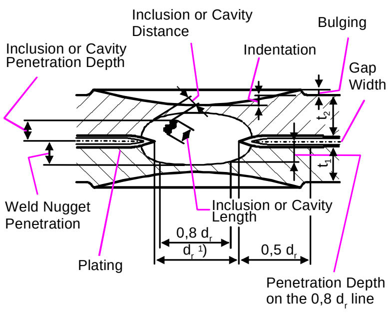
Allowable Imperfections of Spot Welds in Aluminium Alloys (According to Aeronautical Standards) Determined by Metallography

The geometrical characteristics and allowable defect dimensions for spot welds depend on the corresponding evaluation group (EG). The EG I has the strictest requirements (crack and inclusions are not allowed in this evaluation group) (**Figure 4500.03.01**).

Allowable Imperfections of Spot Welds in Aluminium Alloys Determined by Metallography

Ser. No.	Characteristics		EG	Required or allowable value	
1	Cracks		I	Not allowed	
			II	Longest single crack 10 % of weld nugget penetration, measured from nugget middle	
			III	Longest single crack 30 % of weld nugget penetration, measured from nugget middle	
2	Inclusions, cavities		I II III	Not allowed 2 (in number) 3 (in number)	
3	Length of cavity or inclusions		II III	$\leq 0.15\ d_r$ ¹) $\leq 0.25\ d_r$	
4	Distance of cavity or inclusion from edge		II, III	$\geq 0.15\ d_r$	
5	Penetration of cavity or inclusion		II III	$\leq 0,25\ d_r$ $\leq 0.50\ d_r$	
6	Penetration depth of nugget within 0.8 d_r		I, II, III	$\geq 0.2\ t_1$ and $\leq 0.9\ t_1$	
			I, II, III	$\geq 0.2\ t_1$ and $\leq 1.0\ t_1$	
			I, II III	$\geq 0.2\ t_1$ and $\leq 0.8\ t_1$ $\geq 0.2\ t_1$ and $\leq 0.9\ t_1$	
7	Nugget diameter d ²)		I, II, III	see table	
8	Gap thickness 0,5 d_r		I I II,III	$\leq 0.05\ (t_1 + t_2)$ or ≤ 0.15 mm $\leq 0.05\ (t_1 + t_2)$ or ≤ 0.12 mm $\leq 0.075\ (t_1 + t_2)$ or ≤ 0.15 mm	larger of the values allowed
9	Indentation depth or bulging	Aerodynamic	I, II, III	$\leq 0.2\ t_1$, bu ≤ 0.1 mm	
		Not aero-dynamic	I, II	For $t_1 \leq 0.2$ mm, allowed 0.3 t_1 For $t_1 > 0.2$ mm, allowed 0.1 t_1 or 0.13 mm	
			III	For $t_1 \leq 0.2$ mm, allowed 0.2 t_1 or 0.2 mm For $t_1 > 0.2$ mm, allowed 0.4 t_1	
10	Overlapped spot with roller seam weld		I, II, III	see table	

¹) d_r = the weld nugget diameter measured on the metallographic specimen
²) d_r = the required minimum weld nugget diameter



Source: DIN 29 878

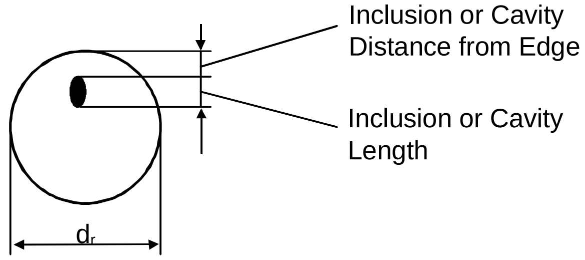
TALAT Training in Aluminium Application Technologies | Allowable Imperfections of Spot Welds in Aluminium Alloys Determined by Metallography | 4500.03.01

Characteristics which can be made visible in a metallographic section allow a much more comprehensive evaluation of the quality of the spot weld joint than radiographs. The effort of producing the former is also much higher.

Allowable Imperfections of Spot Welds in Aluminium Alloys (According to Aeronautical Standards) Determined by X-Ray Examination

Inclusions and cavities can also be determined using the radiographic testing method. An important factor here is the location distance of the defect from the edge. Defects located within the interior of the weld spot have a lower notch effect and are therefore not as dangerous as those located at the spot boundaries (**Figure 4500.03.02**).

Allowable Imperfections of Spot Welds in Aluminium Alloys Determined by X-Ray Examination



Ser. No.	Characteristics	EG	Allowable Values
1	Cracks	I II III	not allowed 10 % 30 %
2	Inclusions, cavities	I II III	not allowed 2 (in number) 4 (in number)
3	Inclusion or cavity length	II III	$\leq$ 0,15 d_r $\leq$ 0,25 d_r
4	Total area of inclusions or cavities	II, III II, III	< 10 % of nugget area < 5 % of nugget area
5	Inclusion or cavity distance from edge	I, II	$\leq$ 0,15 d_r

Source: DIN 29 878

TALAT Training in Aluminium Application Technologies	Allowable Imperfections of Spot Welds in Aluminium Alloys Determined by X-Ray Examination	4500.03.02

4500.04 Literature

B. Leuschen, Joining aluminium body materials, in F. Ostermann (ed.) „Aluminium Materials Technology for Automobile Construction“,MEP Mechanical Engineering Publications Ltd., London, 1993

4500.05 List of Figures